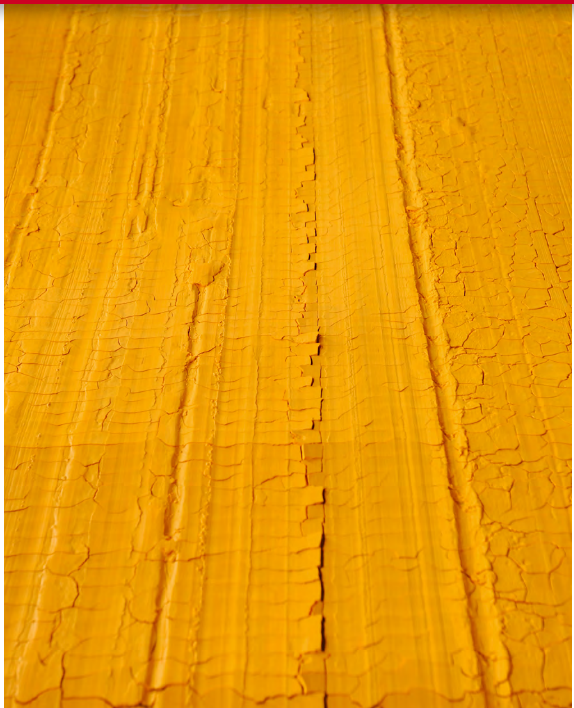
A Joint Report by the Nuclear Energy Agency
and the International Atomic Energy Agency

Uranium 2020
Resources, Production and Demand



IAEA
International Atomic Energy Agency

NEA
NUCLEAR ENERGY AGENCY

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Uranium 2020:
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NEA No. 7551

NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1 February 1958. Current NEA membership consists of 33 countries: Argentina, Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, Romania, Russia, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission and the International Atomic Energy Agency also take part in the work of the Agency.

The mission of the NEA is:

- to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally sound and economical use of nuclear energy for peaceful purposes;
- to provide authoritative assessments and to forge common understandings on key issues as input to government decisions on nuclear energy policy and to broader OECD analyses in areas such as energy and the sustainable development of low-carbon economies.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

Cover photos: The Barakah nuclear power plant, United Arab Emirates (ENEC); Husab mine in Namibia (Swakop Uranium); Yellow Cake (Areva/Jean-Marie Taillat).

Preface

Since the mid-1960s, with the co-operation of their member countries and states, the OECD Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA) have jointly prepared periodic updates (currently every two years) on world uranium resources, production and demand. Such updates have been published in what are commonly known as the "Red Books".

This 28th edition features a comprehensive assessment of uranium supply and demand and projections through the year 2040. The basis of this assessment is a comparison of uranium resource estimates (according to categories of geological certainty and production cost) and mine production capability with anticipated uranium requirements arising from projected installed nuclear capacity. Current data on resources, exploration, production and uranium stocks are also presented, along with historical summaries of exploration and production, and plans for future mine development. Available information on uranium secondary supply is provided and the potential impact of secondary sources on the market is assessed. Individual country reports offer detailed information on recent developments in uranium exploration and production, on environmental activities, regulatory requirements and on relevant national uranium policies.

This publication has been prepared on the basis of data obtained through questionnaires sent by the NEA to OECD member countries and by the IAEA to other countries. It contains official data provided by 31 countries and 14 national reports prepared by the NEA and the IAEA. This report is published under the responsibility of the OECD Secretary-General.

Acknowledgements

This joint report was prepared by the NEA and IAEA Secretariats. The contributions from across the two agencies were led by Luminita Grancea at the NEA, and Mark Mihalasky and Martin Fairclough at the IAEA. The NEA/IAEA gratefully acknowledge the attentive support provided by members of the Joint NEA/IAEA Uranium Group, as well as the co-operation of those organisations and individuals listed in Appendix 1 and 2. In compiling and preparing Chapters 1 and 3, Jean René Blaise (France), Alexander Boytsov (Russian Federation), Adrienne Hanly (Austria), Luis López (Argentina), James Marlatt (Canada), Gabi Schneider (Namibia) and Robert Vance (Canada), provided valuable help. The input and participation of all was essential for the successful completion of this report.

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Executive summary

Uranium 2020: Resources, Production and Demand presents the results of the most recent review of world uranium market fundamentals and offers a statistical profile of the world uranium industry. It contains 45 country reports on uranium exploration, resources, production and reactor-related requirements, 31 of which were derived from officially reported government data, and 14 that were prepared by the NEA and IAEA Scientific Secretaries. Projections of nuclear generating capacity and reactor-related uranium requirements through 2040 are presented, as well as a discussion of long-term uranium supply and demand issues.

Resources

Global uranium resources have once again increased, but much more modestly so than reported in recent editions, as total identified recoverable resources increased by only 1% since 2017. The most significant increases occurred in lower cost reasonably assured resources (<USD 40/kgU) and higher cost inferred resources (<USD 130/kgU and <USD 260/kgU). Though a portion of these changes relate to new discoveries (e.g. Canada), the majority result from newly identified resources at known uranium deposits and re-evaluations of previously identified uranium resources.

Uranium resources are classified by a scheme (based on geological certainty and costs of production) developed to combine resource estimates from a number of different countries into harmonised global figures. Identified resources (which include *reasonably assured resources*, or *RAR*, and *inferred resources*) refer to uranium deposits delineated by sufficient direct measurement to conduct pre-feasibility and sometimes feasibility studies. For *RAR*, high confidence in estimates of grade and tonnage are generally compatible with mining decision-making standards. *Inferred resources* are not defined with such a high degree of confidence and generally require further direct measurement prior to making a decision to mine. Undiscovered resources (*prognosticated* and *speculative*) refer to resources that are expected to exist based on geological knowledge of previously discovered deposits and regional geological mapping. *Prognosticated resources* refer to those expected to exist in known uranium provinces, generally supported by some direct evidence. *Speculative resources* refer to those expected to exist in geological provinces that may host uranium deposits. Both *prognosticated* and *speculative resources* require significant amounts of exploration before their existence can be confirmed and grades and tonnages can be defined. Unconventional resources are defined as very low-grade resources or those from which uranium is only recoverable as a minor by-product or co-product. For a more detailed description, see Appendix 3.

Globally, Australia continues to lead with 28% of the world identified resources in the category <USD 130/kgU (equivalent to USD 50/lb U_3O_8), with over 64% of Australia's national total endowment related to a single site, the world class Olympic Dam deposit. In terms of lower cost resources (<USD 80/kgU and <USD 40/kgU, equivalent to USD 30/lb U_3O_8 and USD 15/lb U_3O_8), Kazakhstan leads with 49% and 36% of the world total, respectively. Moreover, Kazakhstan reported overall increases in resources in all cost categories, owing to exploration efforts and monetary currency exchanges. Noteworthy changes in resources also occurred in other major producing countries, such as in Australia, Canada and Namibia, where ongoing assessment of resources led to adjustments in resource values.

Total identified resources recoverable (reasonably assured and inferred) as of 1 January 2019 amounted to 6 147 800 tonnes of uranium metal (tU) in the <USD 130/kgU category, a slight increase of 0.1% compared to 2017. In the highest cost category (<USD 260/kgU), total identified resources amounted to 8 070 400 tU, an increase of 1% compared to the total reported for the previous edition.

Reasonably assured resources (RAR) decreased by about 2-3% in all high cost categories. The most notable changes in RAR are reported in the <USD 80/kgU category, with a decrease of 2.8%, and in the <USD 40/kgU category, with an increase of 4.4%, compared to values reported in 2017. The overall changes in RAR can be primarily attributed to mining depletion or re-evaluation of uranium resources in countries such as Australia, China, Namibia and new resources identified as a result of exploration activities in Canada and Kazakhstan.

In comparison, inferred resources in the <USD 260/kgU cost category increased overall from 3 173 000 tU in 2017 to 3 346 400 tU (5.5%) in 2019, mainly due to the re-evaluation of resources, with Australia, Kazakhstan, Mongolia and Niger reporting the most significant increases.

A summary has been prepared of worldwide in situ identified resources. Overall, when they are reported as in situ instead of recoverable, resources increase by 17% to 31%. Compared with the previous edition, the total identified in situ resources slightly decreased from 10 652 900 tU to 10 584 500 tU. Reporting in situ resources provides a more optimistic view of the available resource base and gives some indication of how the resource base could increase with improvements in mining and processing methods, which would lead to better recovery.

Additions to the conventional resource base in the future could come from undiscovered resources (prognosticated resources and speculative resources), which as of 1 January 2019 amounted to 7 220 300 tU, a 4% decrease from the 7 530 600 tU reported in the previous edition. Unconventional resources are another source of potential future supply, and currently amount to nearly 39 million tU. It is important to note that in some cases, including those of major producing countries with large identified resource inventories, estimates of undiscovered resources and unconventional resources are either not reported or have not been updated for several years.

The uranium resource figures presented in this volume are a snapshot of the situation as of 1 January 2019. Readers should keep in mind that resource figures are dynamic and related to commodity prices.

Exploration and mining development

Continuing a downward trend over several years, worldwide domestic exploration and mine development expenditures decreased to approximately USD 0.5 billion in 2018, a large drop from USD 2 billion in 2014. Non-domestic figures, a subset of global exploration and development expenditures, declined to under USD 0.07 billion in 2018. Total expenditures continue to decrease in response to a sustained depressed uranium market since mid-2011.

From 2014 to 2015, total expenditures dropped from over USD 2 billion to USD 876.5 million, followed by a decline to USD 681.9 million in 2016, and have since continued to decline to USD 482.9 million in 2018. Reported 2018 global expenditures represent a 75% drop in exploration and mine development expenditures reported in 2012. Expenditures decreased in many countries, mainly because of persistently depressed uranium prices that slowed down several exploration and mine development projects.

Of the countries reporting exploration and mine development expenditures from 2016 through 2018, the total over this three-year period amounted to USD 1.8 billion with Canada, China, India, the United States and Kazakhstan leading the way. Expenditures in Canada alone exceeded the total spending of the remaining top five countries.

From 2016 to 2019, the global share of exploration drilling has increased from 61% to 76% of total expenditures. Canada, China and Kazakhstan accounted for just over 93% of the exploration drilling length reported in 2016 and 2017, declining slightly to 88% in 2018 and to 84% of the world total in 2019 (preliminary data).

Production

Global uranium mine production decreased by nearly 11% from 2017 to 2018, but experienced a slight increase of 1% in 2019. Major producing countries, including Canada and Kazakhstan, limited total production in recent years in response to a sustained depressed uranium market. Uranium production cuts have been unexpectedly deepened with the onset of the global COVID-19 pandemic in early 2020. New to this edition, is a uranium resource and annual production capacity of idled mines. These operations could potentially be brought back into production relatively rapidly with appropriate market signals.

As of 1 January 2019, 16 countries reported producing uranium, with the global total amounting to 53 516 tU. World production increased slightly to 54 224 tU in 2019, mainly through increases in Australia, Kazakhstan and Niger. Kazakhstan's continuous growth in production came to an end in 2017 as production cuts were instituted to reduce supply to an oversupplied market. Kazakhstan nonetheless remained by far the world's largest producer, even as production was eased back to 23 391 tU in 2017 and 21 705 tU in 2018. Kazakhstan's 2018 production alone totalled more than the combined production in that year from Canada, Australia and Namibia, respectively the second, third and fourth largest producers of uranium.

Production by in situ leaching (ISL) remained the dominant technology through the reporting period, accounting for over 55% of total global uranium production in 2018 and approximately 57% in 2019.

Overall, world uranium production decreased by 4.7% from 62 997 tU in 2016 to 60 025 tU in 2017, then by a further 10.8% to 53 516 tU in 2018 as producers instituted production cuts. These planned reductions were greatest in Canada, Kazakhstan and Niger. In Canada, for example, Rabbit Lake mine was suspended in mid-2016, then mining at the McArthur River and milling at Key Lake was suspended at the end of January 2018, all due to an unfavourable market. Production also declined dramatically in the United States. These actions are in addition to a list of 14 idled mines – those with associated identified uranium resources and mining/processing facilities that have all necessary licenses, permits and agreements for operation and have produced commercially in the past – that amount to over 27 500 tU of annual production capacity and could potentially be brought back into production relatively rapidly with appropriate market signals.

Planned uranium production cuts have been unexpectedly deepened with the onset of the global COVID-19 pandemic in early 2020. In March 2020, Canada announced that it had suspended production at the Cigar Lake mine and McClean Lake mill to slow the spread of COVID-19. In early April 2020, Kazakhstan also announced that it was reducing operational activities at all uranium mines. The pandemic also caused restrictions at other mining operations, such as in Australia, Namibia or South Africa. In August 2020, some of these restrictions began to be eased and several producers gradually resumed production. However, with these unplanned reductions, 2020 uranium production targets will be a challenge to achieve, and effects of pandemic-related restrictions on mining and milling could be felt through 2021 and beyond.

Environmental and social aspects of uranium exploration and production

With uranium production projected to expand to meet global demand in the mid-term, efforts are being made to develop safe mining practices and to continue to minimise environmental impacts. Brief overviews in the country reports provide information about the status of environmental and social aspects of uranium mining, including site remediation and decommissioning projects, which highlights the progress that the uranium industry has made on environmental stewardship.

Although the focus of this publication remains uranium resources, production and demand, the environmental and social aspects of the uranium production cycle are gaining increasing importance and, as in the last few editions, updates on activities in this area have been included in the country reports. With a need for increased uranium production to meet demand, the continued development of transparent, safe and well-regulated operations that minimise environmental impacts is crucial, particularly for those countries hosting uranium production for the first time.

For this edition, 25 countries provided information on activities related to environmental aspects of uranium production cycle, including ongoing work related to closed facilities.

Additional information on environmental aspects of uranium production may be found in *Managing Environmental and Health Impacts of Uranium Mining* (NEA, 2014[1]), which outlines significant improvements that have been undertaken in these areas since the early strategic period of uranium mining to the present day. More recently, the IAEA Bulletin, *Uranium: From Exploration to Remediation* (IAEA, 2018[2]) includes some information on this topic.

Uranium demand

Nuclear capacity is expected to rise for the foreseeable future as global energy demand is projected to increase and due to the growing need for a clean energy transition. Reactor-related uranium requirements vary considerably from region to region, reflecting projected nuclear capacity increases and possible inventory building. Annual uranium requirements are projected to be largest in the East Asia region. Recognising the security of supply, reliability and predictability that nuclear power offers and promoting incentives for all types of low-carbon technologies, are key conditions for a greater projected growth in nuclear capacity, and consequently, in uranium demand.

As of 1 January 2019, a total of 450 commercial nuclear reactors were connected to the grid globally, with a net generating capacity of 396 GWe requiring about 59 200 tU annually. Taking into account changes in policies announced in several countries and revised nuclear programmes, world nuclear capacity is projected to grow to between 354 GWe net in the low demand case and about 626 GWe net in the high demand case by 2040. The low case represents a decrease of about 11% from 2018 nuclear generating capacity, while the high case represents an increase of about 58%. Accordingly, world annual reactor-related uranium requirements (excluding mixed oxide fuel [MOX]) are projected to rise to between 56 640 tU and 100 225 tU by 2040.

Nuclear capacity projections vary considerably from region to region. The East Asia region is projected to experience the largest increase, which, by the year 2040, could result in increases of more than 24% and 138% over 2018 capacity in the low and high cases, respectively. While representing significant regional capacity increases, it is important to note that countries in this region (e.g. China) have demonstrated the ability to build multiple reactors with predictable costs and schedules. Nuclear capacity in non-EU member countries on the European continent is also projected to increase considerably, with 66 GWe of capacity projected by 2040 in the high case (increases of about 50% over 2018 capacity). Other regions projected to experience significant nuclear capacity growth include the Middle East, Central and Southern Asia, with more modest growth projected in Africa, Central and South America, and the South-eastern Asia regions.

For North America, the projections see nuclear generating capacity decreasing by 2040 in both the low and high cases, depending largely on future electricity demand, lifetime extension of existing reactors and government policies with respect to greenhouse gas emissions. The reality of financial losses in several reactors in the United States has resulted in a larger number of premature shutdowns to be assumed. In the European Union, nuclear capacity in 2040 is projected to decrease by 52% in the low case scenario and decrease by 8% in the high case, if actual policies are maintained.

As in the case of nuclear capacity, uranium requirements vary considerably from region to region, reflecting projected capacity increases and possible inventory building. Annual uranium requirements are projected to be largest in the East Asia region, where an increase in installed nuclear generating capacity drives significant growth in uranium needs.

1 NEA (2014), *Managing Environmental and Health Impacts of Uranium Mining*, OECD Publishing, Paris, www.oecd-nea.org/jcms/pl_14766/managing-environmental-and-health-impacts-of-uranium-mining.

2 IAEA (2018), "Uranium: From Exploration to Remediation", *IAEA Bulletin*, Volume 59-2, June 2018, Vienna, www.iaea.org/bulletin/59-2.

Key factors influencing future nuclear energy capacity include projected electricity demand, the economic competitiveness of nuclear power plants, as well as funding arrangements for such capital-intensive projects, proposed waste management strategies and public acceptance of nuclear energy. The extent to which nuclear energy is seen to be beneficial in climate change mitigation could contribute to even greater projected growth in nuclear capacity and, consequently, in uranium demand. The COVID-19 pandemic has highlighted the importance of electricity security in modern societies. Recognising the security of supply, reliability and predictability that nuclear power offers and promoting incentives for all types of low-carbon technologies are key conditions for a faster deployment of nuclear power. Near-term actions, including supporting lifetime extensions and expanding new builds of both large and small modular reactors (SMRs), are required.

Supply and demand relationship

The currently defined resource base is more than adequate to meet low and high case uranium demand through 2040, but doing so will depend upon timely investments to turn resources into production. Nonetheless, meeting high case demand requirements to 2040 would consume about 87% of the total 2019 identified resource base recoverable at a cost of <USD 80/kgU (equivalent *USD 30/lb* U_3O_8*). Challenges remain with depressed market prices and other concerns in mine development include geopolitical factors, technical challenges and legal and regulatory frameworks.*

As of 1 January 2019, world uranium production provided nearly 90% of world reactor requirements, whereas in 2017, global primary production provided about 95% of requirements, with the remainder supplied by so-called secondary sources. The secondary supply includes excess government and commercial inventories, spent fuel reprocessing, underfeeding and uranium produced by the re-enrichment of depleted uranium tails, as well as low-enriched uranium (LEU) produced by blending down highly enriched uranium (HEU).

Uranium producers vigorously responded to the market signal of increased prices and projections of rapidly rising demand prior to the Fukushima Daiichi accident. However, the continued decline in uranium market prices following the accident and lingering uncertainty about nuclear power development in some countries has at least temporarily reduced uranium requirements, further depressed prices and slowed the pace of mine production and development. More recently, the significant temporary rise in the spot price seen in the spring 2020 (about USD 34/lb U_3O_8 equivalent to USD 88/kgU), was precipitated largely by additional curtailments to primary production brought on by the COVID-19 pandemic. Readers should note that the reduction in uranium mining operations due to the pandemic is not expected to create performance disruptions of nuclear power reactors in the near term, as significant inventories are held by utilities and fuel cycle producers.

For the foreseeable future, projected primary uranium *production capabilities*, including existing, committed, planned and prospective production centres, would satisfy projected low case and partially high case requirements through 2040 if developments proceed as planned. Meeting high case demand requirements to 2040 would consume less than 28% of the total 2019 identified resource base recoverable at a cost of < USD 130/kgU (USD 50/lb U_3O_8). However, when considering lower cost resources, in the light of current market prices, meeting projected high case requirements to 2040 would consume about 87% of identified resources at a cost USD 80/kgU (<USD 30/lb U_3O_8). Nonetheless, significant investment and technical expertise will be required to bring these resources to the market. Producers will have to overcome a number of significant and, at times, unpredictable issues in bringing new production facilities on stream, including geopolitical and local factors, technical challenges and legal and regulatory frameworks. To do so, strong market conditions will be critical for achieving the required industry investment.

Although declining market prices have led to significant reductions in uranium production and a delay in some mine development projects, other projects have advanced through regulatory and further stages of development. An improvement of uranium market conditions should see at least some of the delayed projects or the idled mines reactivated in order to ensure supply to a growing global nuclear fleet. The current global network of uranium mine facilities is, at the same time, relatively sparse, creating the potential for supply vulnerability. Nevertheless, utilities have been building significant inventory over the last few years at reduced prices, which should help to protect them from such events in the near term.

Although information on secondary sources is incomplete, the availability of these sources is generally expected to decline somewhat after 2020. However, available information indicates that there remains a significant amount of previously mined uranium, some of which could feasibly be brought to the market in the coming years. With the enrichment capacity at least temporarily in excess of requirements, enrichment providers are well-positioned to reduce tails assays below contractual requirements and thereby create additional uranium supply. In the longer term, alternative fuel cycles, if successfully developed and implemented, could have a significant impact on the uranium market, but it is too early to say how cost-effective and widely implemented these proposed alternative fuel cycles could be.

Conclusions

Sufficient uranium resources exist to support continued use of nuclear power and significant growth in nuclear capacity for low-carbon electricity generation and other uses (e.g. heat, hydrogen production) in the long term. Identified recoverable resources, including reasonably assured resources and inferred resources (at a cost <USD 260/kgU, equivalent to USD 100/lb U_3O_8) are sufficient for over 135 years, considering uranium requirements as of 1 January 2019. However, considerable exploration, innovative techniques and timely investment will be required to turn these resources into refined uranium ready for nuclear fuel production and to facilitate the deployment of promising nuclear technologies.

In the wake of recent significant reductions in uranium production and the effects of COVID-19 pandemic, the coming challenges are likely to be those associated with constrained investment capabilities, as a result of depressed market conditions that will push the industry to optimise its activities still further.

Chapter 1. **Uranium supply**

This chapter summarises the status of worldwide uranium resources, exploration and production.

Uranium resources

Identified conventional resources

The global distribution of identified conventional resources is shown in Figure 1.1. Identified resources consist of *reasonably assured resources* (RAR) and *inferred resources* (IR) recoverable at a cost of less than USD 260/kgU (USD 100/lbU_3O_8; see Appendix 3). Unless otherwise noted, resource figures in this report refer exclusively to recoverable resources; that is, the potential amount of uranium recovered after losses in mining and processing are deducted. In situ resource figures are also presented at times in this report, referring to the estimated amount of uranium in the ground, and are clearly indicated as such.

Relative changes in different resource and cost categories of global identified resources between this edition and the 2018 edition of the Red Book are summarised in Table 1.1 (note that resources of a given cost category also include resources from lower cost categories; see Appendix 3 about how to read and interpret cost category resource figures). Although the overall picture remains one of increasing global resources, as in previous editions, the changes from 2017 to 2019 are minor compared to past editions, with high cost identified resources increasing by only 1.0% compared to 2017. Overall RAR declined slightly (1.9%) but increased by 4.4% in the lowest cost category (<USD 40/kgU). IR increased by 5.5% overall, notably in the higher cost categories (<USD 130 and <USD 260/kgU), while lower cost IR (<USD 80/kgU and <USD 40/kgU) declined by 4.5% and 2.5%, respectively. Identified resources recoverable at costs of <USD 40/kgU, the most economically attractive category, increased by 2.2% from 1 057 700 tU in 2017 to 1 080 500 tU in 2019.

Table 1.1. **Changes in identified recoverable resources 2017-2019**

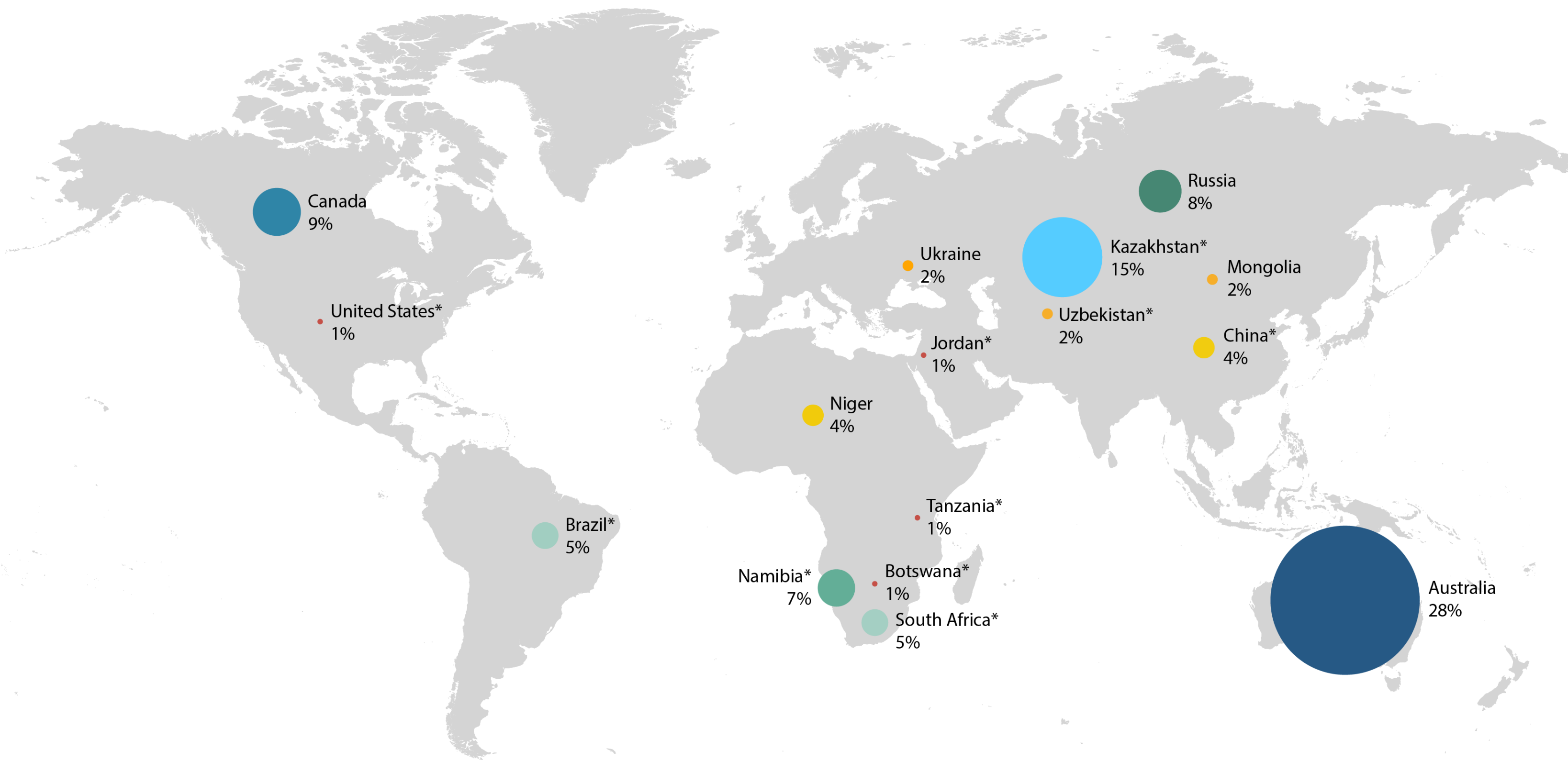
(1 000 tU)

Resource category	2017	2019	Change (1 000 tU)[(a)]	% change
Identified (total)				
<USD 260/kgU	7 988.6	8 070.4	81.8	1.0
<USD 130/kgU	6 142.2	6 148.3	6.1	0.1
<USD 80/kgU	2 079.5	2 007.6	-71.9	-3.5
<USD 40/kgU[(b)]	1 057.7	1 080.5	22.8	2.2
RAR				
<USD 260/kgU	4 815.0	4 723.7	-91.3	-1.9
<USD 130/kgU	3 865.0	3 791.7	-73.3	-1.9
<USD 80/kgU	1 279.9	1 243.9	-36.0	-2.8
<USD 40/kgU[(b)]	713.4	744.5	31.1	4.4
Inferred resources				
<USD 260/kgU	3 173.0	3 346.4	173.4	5.5
<USD 130/kgU	2 277.0	2 355.7	78.7	3.5
<USD 80/kgU	799.9	763.6	-36.3	-4.5
<USD 40/kgU[(b)]	344.4	335.9	-8.5	-2.5

(a) Changes might not equal differences between 2017 and 2019 because of independent rounding. (b) Resources in the cost category of <USD 40/kgU and <USD 80/kgU should be regarded with some caution since some countries do not report low-cost resource estimates, mainly for confidentiality concerns, whereas other countries that have never, or not recently hosted uranium mining may be underestimating mining costs.

Figure 1.1. **Global distribution of identified resources**

(<USD 130/kgU as of 1 January 2019)



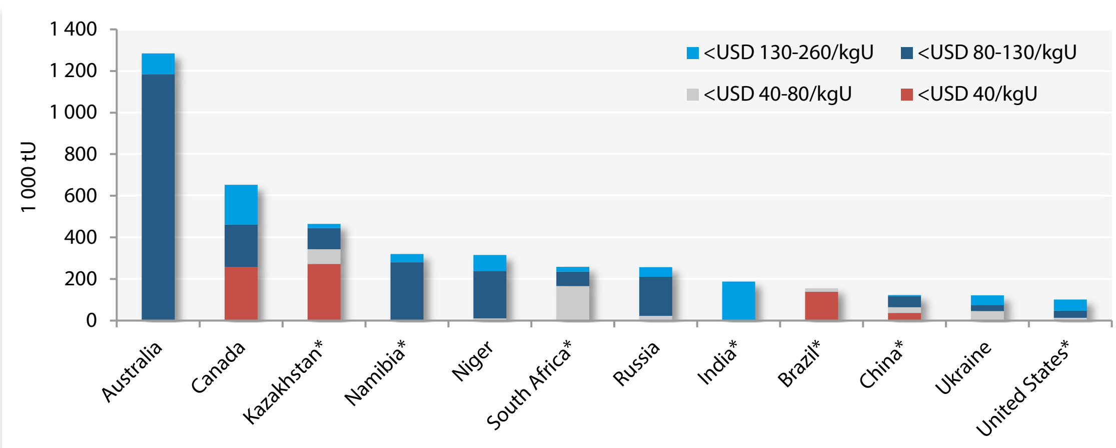
* Secretariat estimate or partial estimate.

The global distribution of identified resources among 16 countries that are either major uranium producers or have significant plans for growth of nuclear generating capacity illustrates the widespread distribution of these resources. Together, these 16 countries are endowed with 95% of the identified global resource base in this cost category (the remaining 5% are distributed among another 21 countries). The widespread distribution of uranium resources is an important geographic aspect of nuclear energy in light of security of energy supply.

The overall increase in the <USD 40/kgU category of identified resources is largely the result of increased low-cost RAR in Kazakhstan and a minor increase in Canada overcoming declines in China, Spain and Uzbekistan. The increase in higher cost (<USD 130 and <USD 260/kgU) IR is principally the result of the new and reassessed mining and processing recoverability information in Australia, as well as increases in Botswana, Jordan, Kazakhstan, Mongolia, Namibia, Russia, Turkey and Zambia that overcome declines in Canada, China, Iran and Mauritania. Amid these changes is a notable increase of resources in all cost categories of RAR and IR in Kazakhstan, owing to exploration activities and local currency changes, as well as an overall decline of RAR and IR in all cost categories in China, owing to re-evaluation of existing deposits.

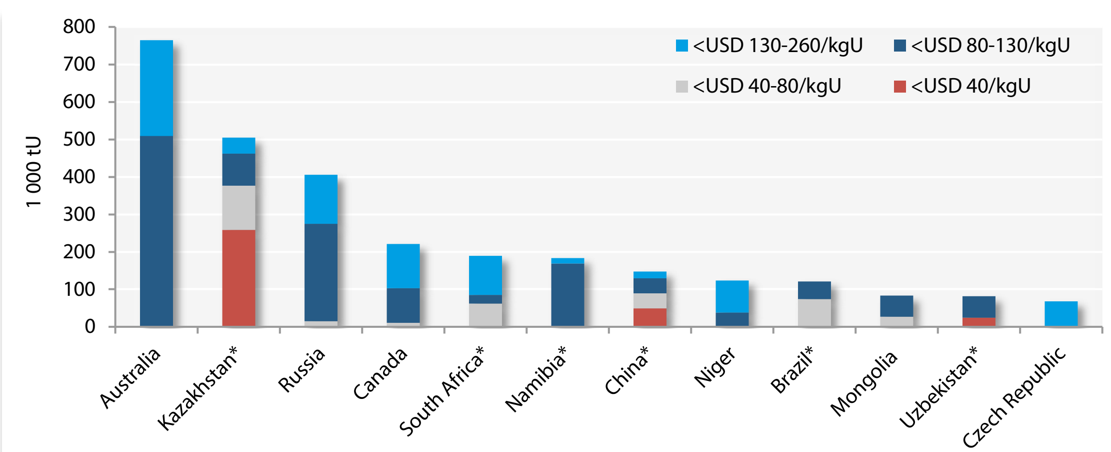
Current estimates of identified resources, RAR and IR, on a country-by-country basis, are presented in Tables 1.2, 1.3 and 1.4, respectively, and graphically summarised in Figures 1.2 and 1.3. Table 1.5 summarises major changes in resources between 2017 and 2019 in selected countries.

Figure 1.2. **Distribution of reasonably assured resources (RAR) among countries with a significant share of resources**



* Secretariat estimate or partial estimate.

Figure 1.3. **Distribution of inferred resources among countries with a significant share of resources**



* Secretariat estimate or partial estimate.

Table 1.2a. **Identified recoverable resources**

(as of 1 January 2019, tonnes U, rounded to nearest 100 tonnes)

Country	Cost ranges			
	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Algeria[c,d]	0	0	0	19 500
Argentina	2 400	17 900	38 700	39 800
Australia	NA	NA	1 692 700	2 049 400
Botswana*	0	0	87 200	87 200
Brazil[d]	138 100	229 400	276 800	276 800
Canada	260 500	269 500	564 900	873 000
Central African Republic*[a,c]	0	0	32 000	32 000
Chad*[a,c,d,e]	0	0	0	2 400
Chile	0	0	0	1 400
China[d]	86 000	154 200	248 900	269 700
Congo, Dem. Rep. of*[a,c,d]	0	0	0	2 700
Czech Republic	0	0	900	119 200
Egypt[d]	0	0	400	1 900
Finland[c,d]	0	0	1 200	1 200
Gabon[a,c]	0	0	4 800	5 800
Germany[c]	0	0	0	7 000
Greece[a,c]	0	0	0	7 000
Greenland[d]	0	0	0	114 000
Hungary[c,d]	0	0	0	13 500
India[d,e]	NA	NA	NA	195 900
Indonesia[b,d]	0	1 500	8 400	8 400
Iran, Islamic Republic of[b,d]	0	0	7 500	7 500
Italy[a,c]	0	6 100	6 100	6 100
Japan[a,c]	0	0	6 600	6 600
Jordan[d]	0	0	52 500	52 500
Kazakhstan[d]	530 600	720 200	906 800	969 200
Malawi*	0	0	6 200	14 300
Mali*[d]	0	0	8 900	8 900
Mauritania*	0	0	17 100	24 500
Mexico[d]	0	0	3 700	5 000
Mongolia	0	60 000	143 500	143 500
Namibia*	0	0	448 300	504 200
Niger	0	9 900	276 400	439 400
Paraguay*	0	0	0	3 600
Peru[a,d]	0	33 400	33 400	33 400
Portugal[c]	0	4 500	7 000	7 000
Romania*[a,c]	0	0	6 600	6 600
Russia[b]	0	38 000	486 000	661 900
Senegal[d]	0	0	0	1 100
Slovak Republic[a,b,d]	0	12 700	15 500	15 500
Slovenia[c,d]	0	5 400	9 200	9 200
Somalia*[a,c,d]	0	0	0	7 600
South Africa*	0	228 000	320 900	447 700
Spain[d,f]	8 100	28 500	28 500	28 500
Sweden*[c,d]	0	0	9 600	9 600
Tanzania*[b]	0	46 800	58 200	58 200
Turkey[b,d]	0	0	12 500	13 600
Ukraine	0	72 900	108 700	186 900
United States[d]	0	13 900	47 900	101 900
Uzbekistan*	54 800	54 800	132 300	132 300
Viet Nam[d]	0	0	0	3 900
Zambia*	0	0	31 000	31 000
Zimbabwe[a,c,d]	0	0	0	1 400
Total[g]	1 080 500	2 007 600	6 147 800	8 070 400

* Secretariat estimate. (a) Not reported in 2019 responses, data from previous Red Book. (b) Assessment partially made within the last five years. (c) Assessment not made within the last five years. (d) In situ resources were adjusted by the Secretariat to estimate recoverable resources using recovery factors provided by countries or estimated by the Secretariat. (e) Cost data not provided, therefore resources are reported in the <USD 260/kgU category. (f) Updated to report recoverable resources. (g) Totals related to cost ranges <USD 40/kgU and <USD 80/kgU should be regarded with some caution since certain countries do not report low-cost resource estimates, mainly for confidentiality concerns, whereas other countries that have never, or not recently hosted uranium mining, may be underestimating mining costs.

Table 1.2b. **Identified in situ resources**

(as of 1 January 2019, tonnes U, rounded to nearest 100 tonnes)

Country	Cost ranges			
	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Algeria(c)	0	0	0	26 000
Argentina(d)	3 400	24 800	54 000	54 600
Australia(f)	NA	NA	2 540 500	2 934 200
Botswana*(d)	0	0	140 600	140 600
Brazil	184 300	314 600	382 300	382 300
Canada(d,f)	298 400	308 700	647 100	1 000 000
Central African Republic*	0	0	42 700	42 700
Chad*(a,e)	0	0	0	3 200
Chile(d)	0	0	0	1 900
China	107 900	192 600	316 300	344 000
Congo, Dem. Rep. of*(a,c)	0	0	0	3 600
Czech Republic(d)	0	0	1 400	197 400
Egypt	0	0	500	2 500
Finland(c)	0	0	1 500	1 500
Gabon(a,c,d)	0	0	6 400	7 700
Germany(c,d)	0	0	0	9 300
Greece(a,c,d)	0	0	0	9 300
Greenland	0	0	0	228 000
Hungary(c)	0	0	0	17 900
India(e)	NA	NA	NA	259 500
Indonesia(b)	0	2 000	11 200	11 200
Iran, Islamic Republic of(b)	0	0	9 900	9 900
Italy(a,c,d)	0	8 100	8 100	8 100
Japan(a,c,d,f)	0	0	7 800	7 800
Jordan	0	0	70 000	70 000
Kazakhstan	596 100	809 800	1 027 600	1 102 700
Malawi*(d)	0	0	7 800	19 000
Mali*	0	0	11 800	11 800
Mauritania*(d)	0	0	19 900	29 700
Mexico	0	0	4 900	6 700
Mongolia(d)	0	79 200	190 500	190 500
Namibia*(d)	0	0	560 400	630 300
Niger(d)	0	12 200	340 700	547 400
Paraguay*	0	0	0	4 300
Peru(a)	0	47 700	47 700	47 700
Portugal(c,d)	0	6 000	9 300	9 300
Romania*(a,c,d)	0	0	8 800	8 800
Russia(b,d, f)	0	50 600	596 800	847 500
Senegal	0	0	0	1 500
Slovak Republic(a,b)	0	15 800	19 300	19 300
Slovenia(c)	0	7 200	12 200	12 200
Somalia*(a,c,d)	0	0	0	10 200
South Africa*(d,f)	0	313 900	440 800	614 500
Spain(f)	9 800	34 300	34 300	34 300
Sweden*(c)	0	0	12 800	12 800
Tanzania*(b,d)	0	58 500	72 800	72 800
Turkey(b)	0	0	15 300	16 700
Ukraine(d)	0	83 200	123 600	212 800
United States	0	18 600	67 100	135 900
Uzbekistan*(d)	68 500	68 500	171 300	171 300
Viet Nam	0	0	0	5 200
Zambia*(d)	0	0	34 300	34 300
Zimbabwe(a,c)	0	0	0	1 800
Total(g)	1 268 400	2 456 300	8 070 300	10 584 500

* Secretariat estimate. (a) Not reported in 2019 responses, data from previous Red Book. (b) Assessment partially made within the last five years. (c) Assessment not made within the last five years. (d) Recoverable resources were adjusted by the Secretariat to estimate in situ resources using recovery factors provided by countries or estimated by the Secretariat according to the expected production method (Appendix 3). (e) Cost data not provided, therefore resources are reported in the <USD 260/kgU category. (f) Recovery factor change from previous report. (g) Totals related to cost ranges <USD 40/kgU and <USD 80/kgU should be regarded with some caution since certain countries do not report low-cost resource estimates, mainly for reasons of confidentiality, whereas other countries that have never, or not recently hosted uranium mining, may be underestimating mining costs.

Table 1.2c. **Comparison of identified resources reported as in situ versus recoverable**
(as of 1 January 2019)

Identified resources (tU)	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Total in situ	1 268 400	2 456 300	8 070 300	10 584 500
Total recoverable	1 080 500	2 007 600	6 147 800	8 070 900
Difference	187 900	448 700	1 922 500	2 513 600
Difference %	17.4	22.4	31.3	31.1
Recovery %	82.6	77.6	68.7	68.9

Table 1.3a. **Reasonably assured recoverable resources**
(as of 1 January 2019, tonnes U, rounded to nearest 100 tonnes)

Country	Cost ranges			
	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Algeria(c,d)	0	0	0	19 500
Argentina	0	5 100	11 000	11 000
Australia	NA	NA	1 183 900	1 284 800
Botswana*	0	0	20 400	20 400
Brazil(d)	138 100	155 900	155 900	155 900
Canada	258 500	258 500	461 600	652 200
Central African Republic*(a,c)	0	0	32 000	32 000
Chile	0	0	0	600
China(d)	37 100	64 500	119 000	122 600
Congo, Dem. Rep. of*(a,c,d)	0	0	0	1 400
Czech Republic	0	0	900	50 900
Finland(c,d)	0	0	1 200	1 200
Gabon(a,c)	0	0	4 800	4 800
Germany(c)	0	0	0	3 000
Greece(a,c)	0	0	0	1 000
Greenland(d)	0	0	0	51 400
India(d,e)	NA	NA	NA	188 000
Indonesia(b,d)	0	1 500	5 300	5 300
Iran, Islamic Republic of(b,d)	0	0	3 200	3 200
Italy(a,c)	0	4 800	4 800	4 800
Japan(a,c)	0	0	6 600	6 600
Jordan(d)	0	0	6 000	6 000
Kazakhstan(d)	272 200	343 800	445 100	464 700
Malawi*	0	0	4 400	9 700
Mali*(d)	0	0	5 000	5 000
Mauritania*	0	0	5 700	5 900
Mexico(d)	0	0	1 800	1 800
Mongolia	0	33 300	60 500	60 500
Namibia*	0	0	279 400	320 700
Niger	0	9 900	238 700	315 500
Paraguay*	0	0	0	2 900
Peru(a,d)	0	14 000	14 000	14 000
Portugal(c)	0	4 500	6 000	6 000
Romania*(a,c)	0	0	3 000	3 000
Russia(b)	0	23 300	211 200	256 600
Slovak Republic(a,b,d)	0	8 800	8 800	8 800
Slovenia(c,d)	0	1 700	1 700	1 700
Somalia*(a,c,d)	0	0	0	5 000
South Africa*	0	166 300	236 000	258 000
Spain(d,f)	8 100	19 100	19 100	19 100
Sweden*(c,d)	0	0	4 900	4 900
Tanzania*(b)	0	38 300	39 700	39 700
Turkey(b,d)	0	0	3 700	3 700
Ukraine	0	46 200	74 900	122 100
United States(d)	0	13 900	47 900	101 900
Uzbekistan*	30 500	30 500	50 800	50 800
Viet Nam(d)	0	0	0	900
Zambia*	0	0	12 800	12 800
Zimbabwe(a,c,d)	0	0	0	1 400
Total(g)	744 500	1 243 900	3 791 700	4 723 700

See notes on page 21.

Table 1.3b. **Reasonably assured in situ resources**

(as of 1 January 2019, tonnes U, rounded to nearest 100 tonnes)

Country	Cost ranges			
	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Algeria[c]	0	0	0	26 000
Argentina[d]	0	7 100	15 400	15 400
Australia[f]	NA	NA	1 748 100	1 849 100
Botswana*[d]	0	0	32 900	32 900
Brazil	184 300	209 700	209 700	209 700
Canada[d,f]	296 200	296 200	528 800	747 000
Central African Republic*	0	0	42 700	42 700
Chile[d]	0	0	0	700
China	48 700	83 600	154 300	159 000
Congo, Dem. Rep. of*[a,c]	0	0	0	1 900
Czech Republic[d]	0	0	1 400	83 900
Finland[c]	0	0	1 500	1 500
Gabon[a,c,d]	0	0	6 400	6 400
Germany[c,d]	0	0	0	4 000
Greece[a,c,d]	0	0	0	1 300
Greenland[f]	0	0	0	102 800
India[e]	NA	NA	NA	249 100
Indonesia[b]	0	2 000	7 100	7 100
Iran, Islamic Republic of[b]	0	0	4 300	4 300
Italy[a,c,d]	0	6 400	6 400	6 400
Japan[a,c,d,f]	0	0	7 800	7 800
Jordan	0	0	8 000	8 000
Kazakhstan	305 800	386 600	504 100	527 700
Malawi*[d]	0	0	5 500	13 000
Mali*	0	0	6 700	6 700
Mauritania*[d]	0	0	6 600	7 000
Mexico	0	0	2 500	2 500
Mongolia[d]	0	44 200	80 500	80 500
Namibia*[d]	0	0	349 300	400 900
Niger[d]	0	12 200	294 700	389 500
Paraguay*	0	0	0	3 400
Peru[a]	0	20 000	20 000	20 000
Portugal [c,d]	0	6 000	8 000	8 000
Romania*[a,c,d]	0	0	4 000	4 000
Russia[b,d,f]	0	31 000	263 500	333 300
Slovak Republic[a,b]	0	10 900	10 900	10 900
Slovenia[c]	0	2 200	2 200	2 200
Somalia*[a,c,d]	0	0	0	6 700
South Africa* [d,f]	0	229 400	324 600	354 600
Spain [f]	9 800	23 000	23 000	23 000
Sweden*[c]	0	0	6 500	6 500
Tanzania*[b,d]	0	47 900	49 600	49 600
Turkey[b]	0	0	4 300	4 300
Ukraine[d]	0	53 000	85 400	138 900
United States	0	18 600	67 100	135 900
Uzbekistan*[d]	38 100	38 100	63 500	63 500
Viet Nam	0	0	0	1 200
Zambia*[d]	0	0	14 100	14 100
Zimbabwe[a,c]	0	0	0	1 800
Total[g]	882 900	1 528 100	4 971 400	6 176 700

* Secretariat estimate. (a) Not reported in 2019 responses, data from previous Red Book. (b) Assessment partially made within the last five years. (c) Assessment not made within the last five years. (d) Recoverable resources were adjusted by the Secretariat to estimate in situ resources using recovery factors provided by countries or estimated by the Secretariat according to the expected production method (Appendix 3). (e) Cost data not provided, therefore resources are reported in the <USD 260/kgU category. (f) Recovery factor change from previous report. (g) Totals related to cost ranges <USD 40/kgU and <USD 80/kgU should be regarded with some caution since certain countries do not report low-cost resource estimates, mainly for reasons of confidentiality, whereas other countries that have never, or not recently hosted uranium mining, may be underestimating mining costs.

Table 1.4a. **Inferred recoverable resources**

(as of 1 January 2019, tonnes U, rounded to nearest 100 tonnes)

Country	Cost ranges			
	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Argentina	2 400	12 700	27 700	28 800
Australia	NA	NA	508 800	764 600
Botswana*	0	0	66 800	66 800
Brazil(d)	0	73 500	120 900	120 900
Canada	1 900	10 900	103 300	220 800
Chad*(a,c,d,e)	0	0	0	2 400
Chile	0	0	0	900
China(d)	48 900	89 700	129 900	147 100
Congo, Dem. Rep. of*(a,c,d)	0	0	0	1 300
Czech Republic	0	0	0	68 300
Egypt(d)	0	0	400	1 900
Gabon(a,c)	0	0	0	1 000
Germany(c)	0	0	0	4 000
Greece(a,c)	0	0	0	6 000
Greenland(d)	0	0	0	62 600
Hungary(c,d)	0	0	0	13 500
India(d,e)	NA	NA	NA	8 000
Indonesia(b,d)	0	0	3 000	3 000
Iran, Islamic Republic of(b,d)	0	0	4 200	4 200
Italy(a,c)	0	1 300	1 300	1 300
Jordan(d)	0	0	46 500	46 500
Kazakhstan(d)	258 400	376 400	461 700	504 400
Malawi*	0	0	1 800	4 600
Mali*(d)	0	0	3 900	3 900
Mauritania*	0	0	11 500	18 500
Mexico(d)	0	0	1 800	3 200
Mongolia	0	26 700	82 900	82 900
Namibia*	0	0	168 900	183 500
Niger	0	0	37 700	123 900
Paraguay*	0	0	0	700
Peru(a,d)	0	19 400	19 400	19 400
Portugal(c)	0	0	1 000	1 000
Romania*(a,c)	0	0	3 600	3 600
Russia(b)	0	14 700	274 800	405 300
Senegal(d)	0	0	0	1 100
Slovak Republic(a,b,d)	0	3 900	6 700	6 700
Slovenia(c,d)	0	3 800	7 500	7 500
Somalia*(a,c,d)	0	0	0	2 600
South Africa*	0	61 700	84 800	189 700
Spain(d,f)	0	9 400	9 400	9 400
Sweden*(c,d)	0	0	4 700	4 700
Tanzania*(b)	0	8 500	18 500	18 500
Turkey(b,d)	0	0	8 800	9 900
Ukraine	0	26 700	33 800	64 800
Uzbekistan*	24 300	24 300	81 500	81 500
Viet Nam(d)	0	0	0	3 000
Zambia*	0	0	18 200	18 200
Total(g)	335 900	763 600	2 355 700	3 346 400

* Secretariat estimate. (a) Not reported in 2019 responses, data from previous Red Book. (b) Assessment partially made within the last five years. (c) Assessment not made within the last five years. (d) In situ resources were adjusted by the Secretariat to estimate recoverable resources using recovery factors provided by countries or estimated by the Secretariat according to the expected production method (Appendix 3). (e) Cost data not provided, therefore resources are reported in the <USD 260/kgU category. (f) Updated to report recoverable resources. (g) Totals related to cost ranges <USD 40/kgU and <USD 80/kgU should be regarded with some caution since certain countries do not report low-cost resource estimates, mainly for confidentiality concerns, whereas other countries that have never, or not recently hosted uranium mining, may be underestimating mining costs.

Table 1.4b. **Inferred in situ resources**

(as of 1 January 2019, tonnes U, rounded to nearest 100 tonnes)

Country	Cost ranges			
	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Argentina(d)	3 400	17 700	38 600	39 200
Australia(f)	NA	NA	792 300	1 085 100
Botswana*(d)	0	0	107 700	107 700
Brazil	0	104 900	172 600	172 600
Canada(d,f)	2 200	12 500	118 300	253 000
Chad*(a e)	0	0	0	3 200
Chile(d)	0	0	0	1 200
China	59 200	109 000	162 000	185 000
Congo, Dem. Rep. of*(a,c)	0	0	0	1 700
Czech Republic(d)	0	0	0	113 500
Egypt	0	0	500	2 500
Gabon(a,c,d)	0	0	0	1 300
Germany(c,d)	0	0	0	5 300
Greece(a,c,d)	0	0	0	8 000
Greenland	0	0	0	125 100
Hungary(c)	0	0	0	17 900
India(e)	NA	NA	NA	10 500
Indonesia(b)	0	0	4 100	4 100
Iran, Islamic Republic of(b)	0	0	5 500	5 500
Italy(a,c,d)	0	1 700	1 700	1 700
Jordan	0	0	62 000	62 000
Kazakhstan	290 300	423 200	523 500	575 000
Malawi*(d)	0	0	2 300	6 000
Mali*	0	0	5 200	5 200
Mauritania*(d)	0	0	13 300	22 700
Mexico	0	0	2 500	4 300
Mongolia(d)	0	35 100	110 000	110 000
Namibia*(d)	0	0	211 200	229 400
Niger(d)	0	0	46 000	157 900
Paraguay*	0	0	0	900
Peru(a)	0	27 700	27 700	27 700
Portugal(c,d)	0	1 300	1 300	1 300
Romania*(a,c,d)	0	0	4 800	4 800
Russia(b,d,f)	0	19 600	333 400	514 200
Senegal	0	0	0	1 500
Slovak Republic(a,b)	0	4 900	8 400	8 400
Slovenia(c)	0	5 000	10 000	10 000
Somalia*(a,c,d)	0	0	0	3 500
South Africa* (d,f)	0	84 500	116 200	259 900
Spain(f)	0	11 300	11 300	11 300
Sweden*(c)	0	0	6 300	6 300
Tanzania*(b,d)	0	10 600	23 200	23 200
Turkey(b)	0	0	10 900	12 400
Ukraine(d)	0	30 200	38 200	73 900
Uzbekistan*(d)	30 400	30 400	107 800	107 800
Viet Nam	0	0	0	4 000
Zambia*(d)	0	0	20 100	20 100
Total(g)	385 500	929 600	3 098 900	4 407 800

* Secretariat estimate. (a) Not reported in 2019 responses, data from previous Red Book. (b) Assessment partially made within the last five years. (c) Assessment not made within the last five years. (d) Recoverable resources were adjusted by the Secretariat to estimate in situ resources using recovery factors provided by countries or estimated by the Secretariat according to the expected production method (Appendix 3). (e) Cost data not provided, therefore resources are reported in the <USD 260/kgU category. (f) Recovery factor change from previous report. (g) Totals related to cost ranges <USD 40/kgU and <USD 80/kgU should be regarded with some caution since certain countries do not report low-cost resource estimates, mainly for confidentiality concerns, whereas other countries that have never, or not recently hosted uranium mining, may be underestimating mining costs.

Table 1.5. **Major identified recoverable resource changes by country**

(in 1 000 tonnes U)

Country	Resource category	2017	2019	Changes	Reasons
Argentina	IR				Ongoing exploration by private companies results in increased IR.
	<USD 40/kgU	0.0	2.4	2.4	
	<USD 80/kgU	9.1	12.7	3.6	
	<USD 130/kgU	30.0	27.7	-2.3	
	<USD 260/kgU	31.0	28.8	-2.2	
Australia	RAR				RAR decline and high-cost IR increase owing to: i) new, and reassessed uranium recoverability information ii) the shifting of some resources to higher cost categories, and iii) the depletion of the Ranger stockpile.
	<USD 130/kgU	1 269.8	1 183.9	-85.9	
	<USD 260/kgU	1 400.6	1 284.8	-115.8	
	IR				
	<USD 130/kgU	548.5	508.8	-39.7	
	<USD 260/kgU	654.2	764.6	110.4	
Botswana	RAR				Re-evaluation of known resources increases overall resource totals.
	<USD130/kgU	13.7	20.4	6.7	
	<USD 260/kgU	13.7	20.4	6.7	
	IR				
	<USD 130/kgU	59.8	66.8	7.0	
	<USD 260/kgU	59.8	66.8	7.0	
Canada	RAR				Overall decrease in identified resources in the low-cost categories due to mining depletion. Increased RAR in the higher cost categories due to new resources identified as the result of exploration activities (i.e. Arrow, Phoenix/Griffon, Triple R and Fox Lake deposits).
	<USD 40/kgU	255.9	258.5	2.6	
	<USD 80/kgU	275.2	258.5	-16.7	
	<USD 130/kgU	409.7	461.6	51.9	
	<USD 260/kgU	592.9	652.2	59.3	
	IR				
	<USD 40/kgU	7.6	1.9	-5.7	
	<USD 80/kgU	35.2	10.9	-24.3	
	<USD 130/kgU	104.7	103.3	-1.4	
	<USD 260/kgU	253.5	220.8	-32.7	
China	RAR				Overall decline due to mining and re-evaluation of uranium resources.
	<USD 40/kgU	44.3	37.1	-7.2	
	<USD 80/kgU	102.2	64.5	-37.7	
	<USD 130/kgU	136.7	119.0	-17.7	
	<USD 260/kgU	136.7	122.6	-14.1	
	IR				
	<USD 40/kgU	56.9	48.9	-8.0	
	<USD 80/kgU	120.3	89.7	-30.6	
	<USD 130/kgU	153.7	129.9	-23.8	
	<USD 260/kgU	153.7	147.1	-6.6	
Denmark/ Greenland	RAR				Change in recovery factor from 65% to 50% reduces recoverable resources.
	<USD 260/kgU	66.8	51.4	-15.4	
	IR				
	<USD 260/kgU	81.3	62.6	-18.7	
India	RAR				Additional exploration defines additional resources in the Cuddapah Basin and extensions to known deposits.
	<USD 260/kgU	149.0	188.0	39.0	
Iran, Islamic Republic of	RAR				Ongoing exploration within previously surveyed areas identifies additional resources and results in the conversion of IR to RAR.
	<USD130/kgU	1.1	3.2	2.1	
	<USD 260/kgU	1.1	3.2	2.1	
	IR				
	<USD 130/kgU	5.1	4.2	-0.9	
	<USD 260/kgU	5.1	4.2	-0.9	
Jordan	RAR				Increased resources after re-evaluation of known resources and development of JORC compliant resource estimates.
	<USD130/kgU	4.8	6.0	1.2	
	<USD 260/kgU	4.8	6.0	1.2	
	IR				
	<USD 130/kgU	38.6	46.5	7.9	
	<USD 260/kgU	38.6	46.5	7.9	
Kazakhstan	RAR				Overall increases in identified resources as a result of exploration activities, notably at Budenovskoye (sites 6 and 7), Inkai (sites 1 and 4), the Tortkuduk block at Moinkun and at Northern Karasan (Karasan 1 site).
	<USD 40/kgU	227.9	272.2	44.3	
	<USD 80/kgU	304.4	343.8	39.4	
	<USD 130/kgU	415.2	445.1	29.9	
	<USD 260/kgU	434.8	464.7	29.9	
	IR				
	<USD 40/kgU	253.2	258.4	5.2	
	<USD 80/kgU	335.1	376.4	41.3	
	<USD 130/kgU	427.0	461.7	34.7	
	<USD 260/kgU	469.7	504.4	34.7	

Table 1.5. **Major identified recoverable resource changes by country** *(cont'd)*
(in 1 000 tonnes U)

Country	Resource category	2017	2019	Changes	Reasons
Mauritania	RAR				Drilling and analyses done to complete feasibility study results in conversion of IR to RAR.
	<USD 130/kgU	0.7	5.7	5.0	
	<USD 260/kgU	1.0	5.9	4.9	
	IR				
	<USD 130/kgU	15.7	11.5	-4.2	
	<USD 260/kgU	22.8	18.5	-4.3	
Mongolia	RAR				Ongoing exploration focussing on sandstone deposits amenable to ISL in southern basins leads to a decrease in lower cost resources but increases in higher cost RAR and IR.
	<USD 80/kgU	49.8	33.3	-16.5	
	<USD 130/kgU	49.8	60.5	10.7	
	<USD 260/kgU	49.8	60.5	10.7	
	IR				
	<USD 80/kgU	63.8	26.7	-37.1	
	<USD 130/kgU	63.8	82.9	19.1	
	<USD 260/kgU	63.8	82.9	19.1	
Namibia	RAR				Decreased RAR and increased IR due to mining depletion and the reclassification and removal of "non-minable" Rössing mine resources.
	<USD 130/kgU	335.3	279.4	-55.9	
	<USD 260/kgU	368.5	320.7	-47.8	
	IR				
	<USD 130/kgU	106.8	168.9	62.1	
	<USD 260/kgU	172.9	183.5	10.6	
Niger	RAR				Ongoing exploration defines additional resources at exisiting mines and deposits under development (e.g. Madaouela and Dasa).
	<USD 80/kgU	0.0	9.9	9.9	
	<USD 130/kgU	237.4	238.7	1.3	
	<USD 260/kgU	336.4	315.5	-20.9	
	IR				
	<USD 130/kgU	42.6	37.7	-4.9	
	<USD 260/kgU	89.2	123.9	34.7	
Russia	RAR				Ongoing exploration and technical-economic evaluation of resources (e.g. sandstone type Khokhlovskoye and Shargadykskoye deposits), combined with mining depletion results in an RAR decline but an overall increase in identified resources due to additional IR.
	<USD 80/kgU	24.5	23.3	-1.2	
	<USD 130/kgU	214.5	211.2	-3.3	
	<USD 260/kgU	260.0	256.6	-3.4	
	IR				
	<USD 80/kgU	15.3	14.7	-0.6	
	<USD 130/kgU	271.0	274.8	3.8	
	<USD 260/kgU	396.9	405.3	8.4	
Turkey	RAR				Exploration and re-evaluation of resources reduces RAR in all cost categories and low-cost IR, but increases IR in the higher cost categories.
	<USD 80/kgU	6.5	0.0	-6.5	
	<USD 130/kgU	6.5	3.7	-2.8	
	<USD 260/kgU	6.5	3.7	-2.8	
	IR				
	<USD 80/kgU	0.5	0.0	-0.5	
	<USD 130/kgU	0.5	8.8	8.3	
	<USD 260/kgU	0.5	9.9	9.4	
Ukraine	RAR				Re-assessment of existing deposits results in increases in lower cost resources and declines in higher cost resources.
	<USD 80/kgU	41.3	46.2	4.9	
	<USD 130/kgU	81.2	74.9	-6.3	
	<USD 260/kgU	137.7	122.1	-15.6	
	IR				
	<USD 80/kgU	16.9	26.7	9.8	
	<USD 130/kgU	32.9	33.8	0.9	
	<USD 260/kgU	81.3	64.8	-16.5	
United States	RAR				Ongoing deposit appraisal results in increased resources.
	<USD 80/kgU	13.1	13.9	0.8	
	<USD 130/kgU	47.2	47.9	0.7	
	<USD 260/kgU	100.8	101.9	1.1	
Zambia	RAR				Overall increase as development of existing deposits continues.
	<USD 130/kgU	11.1	12.8	1.7	
	<USD 260/kgU	11.1	12.8	1.7	
	IR				
	<USD 130/kgU	16.1	18.2	2.1	
	<USD 260/kgU	16.1	18.2	2.1	

The most significant changes during this reporting period are observed in low-cost (<USD 40/kgU) RAR increasing by 4.4%, as well as increases in the higher cost categories (<USD 260/kgU, <USD 130/kgU) of IR by 5.5% and 3.5%, respectively. Reasonably assured resources comprise 59% of the identified resource total, a less than 1% decrease compared to the last reporting period.

Jordan and Kazakhstan reported increases in both RAR and IR. Kazakhstan reported substantial increases in tonnage in all RAR and IR cost categories, whereas Jordan recorded much more modest increases in tonnage that nonetheless represented a 25% increase in the higher cost categories (<USD 130/kgU and <USD 260/kgU) of RAR compared to 2017. Canada reported substantial increases in higher cost RAR and decreased IR in all cost categories, including notable declines of 75% and 69% from 2017 in the lower cost IR categories (<USD 40/kgU, <USD 80/kgU), respectively. Iran and Mauritania reported modest tonnage increases in higher cost RAR, nonetheless nearly doubling RAR in the case of Iran and increasing it multiple times in Mauritania. Both countries reported declining IR as exploration efforts produced higher confidence resource estimates. Niger recorded RAR tonnage increases in both the <USD 80/kgU and <USD 130/kgU cost categories and a substantial increase (39%) in high cost IR.

Mongolia, the United States and Zambia reported minor increases in higher cost RAR (<USD 130/kgU and <USD 260/kgU), with Mongolia reporting the greatest increase of 21% over 2017. Lower cost (<USD 80/kgU) IR was reduced by 58% in Mongolia, whereas higher cost IR increased by 30% in Mongolia and 13% in Zambia (the United States does not report IR). Ukraine reported a 12% increase in lower cost (<USD 80/kgU) RAR and a 58% increase in IR in the same cost category. India reported a 26% increase in RAR compared to 2017, all in the highest cost category as India does not report uranium resources by costs of production.

Namibia reported a 17% and 13% decrease respectively in higher cost (<USD 130/kgU, <USD 260/kgU) RAR and a substantial 58% increase in IR in the <USD 130/kgU cost category. Australia reported decreases of 7% and 8% respectively in higher cost RAR (<USD 130/kgU and <USD 260/kgU, as well as a decrease of 7% in IR in the <USD 130/kgU cost category and a substantial 17% increase in high cost IR. While RAR in Argentina remained unchanged, IR was increased from 2017 in the lower cost categories reported (<USD 40/kgU, <USD 80/kgU) due to non-government exploration efforts. Turkey reported substantial decreases in all RAR cost categories reported (<USD 80/kgU, <USD 130/kgU, <USD 260/kgU) and substantial increases in higher cost (<USD 130/kgU, <USD 260/kgU) IR. Greenland and Spain reported decreases in RAR and IR across all cost categories owing to recovery factor reductions in Greenland and the reassessment of recoverable versus in situ resources in Spain.

Australia still dominates the world's uranium resources with 28% of the total identified resources at <USD 130/kgU and 25% of identified resources in the highest cost category (<USD 260/kgU). However, 64% of Australia's uranium resources (and 16% of global identified resources) are attributed to the world-class polymetallic Fe-oxide breccia complex, the Olympic Dam deposit, where uranium is mined as a co-product. Kazakhstan remains a distant second with approximately 15% available at <USD 130/kgU and 12% in the <USD 260/kgU cost category. Canada's share has been reduced slightly since the last reporting period to about 11% in the <USD 260/kgU category and 9% in the <USD 130/kgU category. All remaining countries have less than a 10% share in these higher cost categories. Only 16 countries represent approximately 95% of the total resources in the <USD 130/kgU cost category (see Figure 1.1).

With respect to the lower cost categories, Australia does not report any resources at these costs and thus Kazakhstan leads with 36%, followed by Canada with 13%, Brazil and South Africa each with 11% and China with 8% of the total resources in the <USD 80/kgU category. Only seven countries reported resources in the <USD 40/kgU category, with Kazakhstan having the largest share at 49%, followed by Canada at 24%, Brazil at 13%, China at 8% and Uzbekistan with 5%. Spain and Argentina both have less than 1% each of the total in this cost category. Readers are cautioned concerning these lower cost (<USD 40/kgU, <USD 80/kgU) resource estimates, since Australia does not report resources in these cost categories, the United States does not report IR and some countries that have never, or have not recently hosted uranium mining, may be underestimating mining costs.

Starting in the 2016 edition, a summary has been prepared of worldwide in situ identified resources (see Tables 1.2b, 1.3b and 1.4b). Table 1.2c is a summary comparison of in situ identified resources and recoverable identified resources by cost category. Overall, there is a 17% to 31% increase in the resources when they are reported as in situ. This corresponds to average recoveries ranging from approximately 69% to 83%. Total identified in situ resources decreased marginally (<1%) from 10 652 900 tU reported in the last edition to 10 584 500 tU for this edition as more countries provided in situ figures rather than figures produced by the application of generic recovery factors as NEA/IAEA estimates.

Reporting in situ resources provides a more optimistic view of the available resource base and provides an indication of how the resource base could be increased with improvements in mining and processing methods that would lead to better recovery. Nonetheless, recoverable resources still provide the best and more realistic estimate of uranium supply.

Distribution of resources by production method

For this edition of the Red Book, countries once again were asked to report identified resources by cost categories and by the expected production method: open-pit or underground mining, in situ leaching (ISL, sometimes referred to as in situ recovery, or ISR), heap leaching or in-place leaching, co-product/by-product or unspecified.

In the cost category <USD 40/kgU, although underground mining remains an important production method for RAR (Table 1.6), mainly from Canada, Brazil, Russia and Ukraine, ISL has slightly surpassed underground mining in this, the lowest-cost category of high confidence resources. ISL resources, mainly from Kazakhstan, and to a lesser extent, Russia and Uzbekistan, make the most significant contributions. Co-product/by-product production, mainly from Brazil and South Africa, make up most of the remainder, followed by alkaline ISL and open-pit mining. The total is likely underestimated owing to the difficulty in assigning mining costs accurately in the co-product/by-product category.

Table 1.6. **Reasonably assured resources (recoverable) by production method**

(as of 1 January 2019, tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Open-pit mining	16 423	100 054	924 249	1 106 268
Underground mining	317 319	402 877	1 020 976	1 417 934
In situ leaching acid	319 864	439 840	532 735	591 761
In situ leaching alkaline	19 950	27 342	64 504	30 142
Co-product/by-product	71 050	255 167	1 207 544	1 394 998
Unspecified	-	18 723	41 546	182 546
Total	744 606	1 244 003	3 791 554	4 723 649

In the <USD 80/kgU category, resources expected to be produced by ISL and underground mining methods make the most significant contributions with by-product/co-product category and open-pit mining rising in importance. The <USD 130/kgU category is led by resources in the by-product/co-product category, predominately a result of the world-class Olympic Dam deposit in Australia, with underground and open-pit mining making the most significant contributions of the remainder, followed by ISL acid. The underground and co-product/by-product categories continue to lead in the <USD 260/kgU category (Table 1.6), followed by open-pit mining. Canada holds the largest resource total for underground mining while Namibia and Niger make the largest contributions to open-pit production. Olympic Dam is responsible for most of the by-product category, with Brazil, Greenland and South Africa making up the majority of the remaining total. ISL makes an important contribution in all cost categories with Kazakhstan being the dominant player.

The pattern of production method for IR (Table 1.7) is slightly different from that of RAR. In the lowest cost categories (<USD 40/kgU and <USD 80/kgU), ISL dominates. In the <USD 130/kgU category, ISL continues to lead, but is followed closely by co-product/by-product, underground and open-pit mining. In the highest cost category (<USD 260/kgU), underground mining leads with co-product/by-product, with ISL and open-pit mining making significant contributions. Since the United States does not report IR, the ISL alkaline category is under-represented in Table 1.7.

Table 1.7. **Inferred resources (recoverable) by production method**

(as of 1 January 2019, tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Open-pit mining	2 430	59 045	526 256	688 332
Underground mining	1 925	65 124	546 794	901 061
In situ leaching acid	324 791	495 203	614 750	729 251
In situ leaching alkaline	6 790	8 470	9 233	9 233
Co-product/by-product	0	94 580	583 181	815 616
Unspecified	0	41 130	75 890	203 185
Total	335 936	763 552	2 356 104	3 346 678

Distribution of resources by processing method

In 2019, countries were once again requested to report identified resources by cost categories and by the expected processing method: conventional from open-pit or conventional from underground mining, ISL, in-place leaching, heap leaching from open pit or heap leaching from underground, or unspecified. It should be noted that not all countries reported their resources according to processing method.

The overall distribution has changed little since the last reporting period. In all but the lowest cost category for RAR where ISL resources are greatest (see Table 1.8), conventional processing from underground mining is the major contributor, owing principally to Australia's Olympic Dam deposit. In the higher cost categories, conventional processing from open pit and ISL make increasing contributions, but even when combined do not surpass the underground resources. In the IR category (see Table 1.9), ISL dominates in the two lower cost categories, but in the two higher cost categories is surpassed by underground conventional methods. The amount that is reported as unspecified is important because the exploration of many deposits is insufficiently advanced for any mine planning to have been carried out. Note that the United States does not report IR by processing method, leading to under-representation in the ISL alkaline category in Table 1.9.

Table 1.8. **Reasonably assured resources (recoverable) by processing method**

(as of 1 January 2019, tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Conventional from OP	14 965	79 811	651 897	797 583
Conventional from UG	317 319	569 214	2 107 904	2 605 877
In situ leaching acid	319 864	439 840	532 735	591 761
In situ leaching alkaline	19 950	27 342	30 142	30 142
In-place leaching*	-	-	516	8 863
Heap leaching** from OP	1 134	20 243	269 932	356 275
Heap leaching** from UG	-	-	17 770	18 670
Unspecified	71 374	107 553	180 658	314 478
Total	744 606	1 244 003	3 791 554	4 723 649

* Also known as stope leaching or block leaching.

** A subset of open-pit and underground mining, since it is used in conjunction with them.

Table 1.9. **Inferred resources (recoverable) by processing method**
(as of 1 January 2019, tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Conventional from OP	2 430	41 332	338 867	559 066
Conventional from UG	1 925	126 780	1 040 918	1 512 741
In situ leaching acid	324 791	495 203	614 751	729 252
In situ leaching alkaline	6 790	8 470	9 233	9 233
In-place leaching*	-	-	2 068	13 594
Heap leaching** from OP	-	19 417	134 667	139 116
Heap leaching** from UG	-	-	6 675	11 714
Unspecified	-	72 350	208 925	371 962
Total	335 936	763 552	2 356 104	3 346 678

* Also known as stope leaching or block leaching.

** A subset of open-pit and underground mining, since it is used in conjunction with them.

Distribution of resources by deposit type

In 2019, countries also reported identified resources by cost categories and by geological types of deposits using the deposit classification scheme introduced in the 2014 edition (Appendix 3).

Sandstone RAR (mainly in China, Kazakhstan, Niger, Russia and Uzbekistan) tops all cost categories. In the higher cost categories (<USD 130/kgU and <USD 260/kgU), polymetallic iron-oxide breccia complex deposits in Australia become increasingly more important, along with Proterozoic unconformity-related resources, metasomatite, intrusive and paleo-quartz-pebble conglomerate resources (Table 1.10).

Table 1.10. **Reasonably assured resources (recoverable) by deposit type**
(as of 1 January 2019, tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Proterozoic Unconformity	258 540	258 540	570 900	740 255
Sandstone	339 814	544 767	990 219	1 201 080
Polymetallic Fe-Oxide Breccia Complex	-	-	898 546	967 737
Paleo-quartz-pebble conglomerate[(a)]	-	166 337	228 784	256 702
Granite-related	27 184	59 150	66 262	90 205
Metamorphite	-	1 522	5 778	49 582
Intrusive	-	-	250 523	362 206
Volcanic-related	-	42 118	141 597	144 531
Metasomatite	66 663	112 644	332 492	436 132
Surficial deposits	-	-	124 094	165 316
Carbonate	-	-	-	107 308
Collapse breccia	405	405	405	405
Phosphate	52 000	53 270	120 888	128 583
Lignite – coal	-	-	15 848	15 848
Black shale	-	-	-	-
Unspecifed	-	5 250	45 218	57 759
Total	744 606	1 244 003	3 791 554	4 723 649

(a) In South Africa, Paleo-quartz-pebble conglomerate resources include tailings resource.

Similar patterns are apparent in the IR category (see Table 1.11). Sandstone-hosted resources dominate all cost categories. In the lowest cost category (<USD 40/kgU), the Proterozoic unconformity-type is a distant second to sandstone, but in the <USD 80/kgU), paleo-quartz-pebble conglomerate, volcanic-related, metasomatite and phosphate-based resources rise in importance. In the higher cost categories (<USD 260/kgU and <USD 130/kgU), polymetallic iron-oxide breccia complex and metasomatite resources are the second and third most important deposit types, but these types of deposits still do not rival sandstone-based resources in abundance.

Table 1.11. **Inferred resources (recoverable) by deposit type**

(as of 1 January 2019, tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Proterozoic unconformity	1 925	10 945	138 626	230 349
Sandstone	333 531	533 157	792 213	1 093 036
Polymetallic Fe-Oxide Breccia Complex	-	-	428 506	532 127
Paleo-quartz-pebble conglomerate[(a)]	-	72 456	85 161	130 091
Granite-related	-	9 421	61 308	77 695
Metamorphite	-	720	2 988	9 294
Intrusive	-	-	122 368	245 605
Volcanic-related	480	45 411	138 489	153 300
Metasomatite	-	33 949	376 764	506 197
Surficial deposits	-	-	67 288	115 975
Carbonate	-	-	3 863	3 862
Collapse breccia	-	19 008	19 008	19 008
Phosphate	-	30 010	37 137	47 137
Lignite coal	-	-	2 010	72 785
Black shale	-	-	32 900	32 900
Unspecified	-	8 475	47 475	77 317
Total	335 936	763 552	2 356 104	3 346 678

(a) In South Africa, Paleo-quartz-pebble conglomerate resources include tailings resources.

Proximity of resources to production centres

A total of nine countries provided estimates on the availability of resources for near-term production by reporting the percentage of identified resources (RAR and IR) recoverable at costs of <USD 80/kgU and <USD 130/kgU that are proximal to existing and committed production centres (see Table 1.12). Resources proximal to existing and committed production centres in six of the countries listed a total of 1 200 385 tU at <USD 80/kgU (about 80% of the total resources reported in this cost category). This is 7.4% lower than the 2017 value of 1 296 035 tU. This change over the two-year reporting period is attributed to decreased resources in this cost category in Canada, Niger and Russia, offset by an increase in Kazakhstan. Resources proximal to existing and committed production centres in the nine countries listed a total of 3 160 532 tU at <USD 130/kgU (about 63% of the total resources reported in this cost category). This is 5.4% lower than the 3 341 873 tU reported for 2017 and is the result of decreases of resources in this cost category in Australia and Niger, offset by increases in Canada, Kazakhstan and Namibia. The decline in the percentage of proximal resources in Brazil from the previous edition is the result of delay in development of the Caetite production centre and the subsequent change in its status from existing to planned.

Table 1.12. **Identified resources (recoverable) proximate to existing or committed production centres***

Country	RAR + inferred recoverable at <USD 80/kgU cost category			RAR + inferred recoverable at <USD 130/kgU cost category		
	Total resources (tU)	Proximate resources (tU)	Proximate resources %	Total resources (tU)	Proximate resources (tU)	Proximate resources %
Australia	NA	NA	NA	1 692 667	1 354 134	80
Brazil	229 396	7 205	8	276 786	16 607	6
Canada	269 485	269 485	100	564 945	344 616	61
Iran, Islamic Rep of	-	-	-	7 484	7 484	100
Kazakhstan	720 172	676 962	94	906 844	643 859	71
Namibia	-	-	-	448 346	250 177	56
Niger	9 920	9 920	100	276 404	237 707	86
Russia	37 959	37 579	99	485 966	116 632	24
South Africa	227 993	189 234	83	320 873	189 315	59
Total	1 494 925	1 200 385	80	4 980 315	3 160 532	63

* Identified resources only in countries that reported proximity to production centres, not world total.

Undiscovered resources

Undiscovered resources (prognosticated and speculative; see Appendix 3) refer to resources that are expected to occur based on geological knowledge of previously discovered deposits and regional geological mapping. Prognosticated resources (PR) refer to those expected to occur in known uranium provinces, generally supported by some direct evidence. Speculative resources (SR) refer to those expected to occur in geological provinces that may host uranium deposits. Both prognosticated and speculative resources require significant amounts of exploration before their existence can be confirmed and grades and tonnages can be more accurately determined. All PR and SR are reported as in situ resources (see Table 1.13).

Worldwide, reporting of PR and SR is incomplete; a total of 25 countries (including 3 NEA/IAEA estimates) reported undiscovered resources for this edition, compared to the 35 reporting RAR (including nine NEA/IAEA estimates). Only seven countries of those reporting, updated undiscovered resource figures for this edition. Twenty countries reported both prognosticated and speculative resources. Bolivia, Germany, Italy, Jordan, Mauritania, Poland, Venezuela and Zimbabwe reported only speculative resources, whereas Bulgaria, Egypt, Greece, Hungary, Indonesia, Portugal, the Slovak Republic, Slovenia and Uzbekistan reported only prognosticated resources.

In addition to few recently updated assessments, some countries with significant resource potential, such as Argentina, Australia and the United States, do not report undiscovered resources. A number of different quantitative mineral resource assessment approaches and integrated quantitative and mineral prospectivity mapping methods have been investigated and applied at local, regional and national scales, including in Argentina (for a variety of uranium deposits types, using the Deposit-Size-Frequency quantitative method), Australia (for surficial-type deposits, using a variety of integrated methodologies), and the United States (for sandstone-hosted and surficial-type uranium deposits, using the 3-Part method). For additional details on such methods and applications, see IAEA (2018).

The United States, for example, is now re-estimating undiscovered resources using the USGS "3-Part" form of quantitative mineral resource assessment (Singer et al., 2010). Two assessments have been completed, estimating about 84 500 tU recoverable in the Texas Coastal Plain and 15 000 tU in situ in the Southern High Plains region (Mihalasky et al., 2015; Hall et al., 2017). However, this recent work is yet to be classified into either speculative or prognosticated resource categories and, as a result, is not reported in Table 1.13. Only about 10% of the undiscovered uranium resources in the US have been recently reassessed.

China, as well, reports significant resource potential not included in Table 1.13. A systematic nationwide uranium resource prediction and evaluation estimated that prognosticated resources amounted to 2 million tU. Since a cost range is not assigned to these resources, they are not included in Table 1.13.

Table 1.13. **Reported undiscovered resources**
(in 1 000 tU as of 1 January 2019)

Country	Prognosticated resources			Speculative resources			Total SR
	Cost ranges			Cost ranges			
	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	<USD 130/kgU	<USD 260/kgU	Cost range unassigned	
Argentina	NA	13.8	13.8	NA	79.5	NA	79.5
Brazil[(a)]	300.0	300.0	300.0	NA	NA	500.0	500.0
Bolivia[(b)]	0.0	0.0	0.0	0.0	0.0	1.7	1.7
Bulgaria[(b)]	NA	NA	25.0	NA	NA	NA	NA
Canada[(a)]	50.0	150.0	150.0	700.0	700.0	0.0	700.0
Chile[(a)]	0.0	0.0	2.3	0.0	0.0	2.4	2.4
China[(b,c)]	3.6	3.6	3.6	4.1	4.1	NA	4.1
Colombia[(b)]	NA	11.0	11.0	217.0	217.0	NA	217.0
Czech Republic	0.0	0.0	222.9	0.0	0.0	17.0	17.0
Egypt	0.0	1.5	1.5	NA	NA	NA	NA
Germany[(a)]	NA	NA	NA	NA	NA	74.0	74.0
Greece[(b)]	6.0	6.0	6.0	NA	NA	NA	NA
Hungary[(a)]	0.0	0.0	13.4	0.0	0.0	0.0	0.0
India	NA	NA	127.2	NA	NA	55.1	55.1
Indonesia	0.0	0.0	30.2	0.0	0.0	0.0	0.0
Iran, Islamic Republic of[(d)]	0.0	9.8	9.8	0.0	0.0	48.0	48.0
Italy[(b)]	0.0	0.0	0.0	10.0	10.0	NA	10.0
Jordan[(a)]	0.0	0.0	0.0	0.0	50.0	NA	50.0
Kazakhstan	81.8	109.8	109.8	186.3	186.3	NA	186.3
Mauritania*	0.0	0.0	0.0	NA	NA	19.0	19.0
Mexico[(b)]	NA	3.0	3.0	NA	NA	10.0	10.0
Mongolia[(a)]	13.3	13.3	13.3	1 319.0	1 319.0	NA	1 319.0
Namibia*	0.0	0.0	57.0	0.0	0.0	110.7	110.7
Niger	0.0	13.6	13.6	0.0	51.3	0.0	51.3
Peru[(b)]	6.6	20.0	20.0	19.7	19.7	0.0	19.7
Poland[(b)]	0.0	0.0	0.0	0.0	0.0	20.0	20.0
Portugal	1.0	1.5	1.5	NA	NA	NA	NA
Romania[(b)]	NA	3.0	3.0	3.0	3.0	NA	3.0
Russia	0.0	110.7	169.3	148.2	540.2	0.0	540.2
Slovak Republic[(b)]	0.0	3.7	10.9	0.0	0.0	0.0	0.0
Slovenia[(a)]	0.0	1.1	1.1	0.0	0.0	0.0	0.0
South Africa[(b)]	0.0	74.0	159.0	243.0	411.0	280.0	691.0
Ukraine[(a)]	0.0	8.4	22.5	0.0	120.0	255.0	375.0
United States	NA	NA	NA	NA	NA	NA	NA
Uzbekistan*	24.8	24.8	24.8	NA	NA	NA	NA
Venezuela[(b)]	NA	NA	NA	0.0	0.0	163.0	163.0
Viet Nam[(a)]	NA	NA	81.2	NA	NA	321.6	321.6
Zimbabwe[(b)]	0.0	0.0	0.0	25.0	25.0	NA	25.0
Total	487.1	882.5	1 606.7	2 875.3	3 736.1	1 877.5	5 613.6

NA = Data not available. (a) Reported in 2019 responses, but values have not been updated within last five years. (b) Not reported in 2019 response, data from previous Red Book. (c) China has conducted a systematic nationwide uranium resource prediction and evaluation with prognosticated resources estimated to be around 2 million tU. Since a cost range is not assigned to these resources, they are not included in this table. (d) Reported in 2019 responses, but only partially assessed within last five years. (*) Secretariat estimate; no changes since last edition.

Total PR in the highest cost category (<USD 260/kgU) amounted to 1.607 million tU, a 5.4% decrease compared to 2017. In the lower cost categories (i.e. <USD 80/kgU and <USD 130/kgU), the PR totals decreased by 33% and 13% respectively, compared to the last reporting period. Increases were reported for India and Russia in the <USD 260/kgU cost category only, and Egypt reported small tonnages for the first time. Decreases were reported for the Czech Republic, Iran, Kazakhstan, Mongolia and Russia as exploration increased confidence of estimates to transfer the resources into IR or RAR, or through deposit re-assessment (for the Czech Republic and Iran in the higher cost categories (USD 130/kgU and <USD 260/kgU) and for Russia in the lower cost categories (<USD 80/kgU and USD 130/kgU). Kazakhstan and Mongolia reported decreased PR in all cost categories. No changes are reported for the remaining countries since the last reporting period.

SR in the <USD 260/kgU cost category decreased by 5.9% compared to 2017 due to declining figures reported by Kazakhstan, Mongolia and Russia. In the unassigned cost category, there was an overall increase of 1%, owing to increases reported by India and Iran. The total SR in the <USD 130/kgU cost category decreased by 12% since the last report, with decreases reported by Kazakhstan, Mongolia and Russia. No other countries reported changes in this cost category.

High-cost (<USD 260/kgU) PR and total SR amount to a combined total of 7 220 300 tU, a decrease of 4% from the 7 530 600 tU reported for 2017.

Other resources and materials

Conventional resources are defined as resources from which uranium is recoverable as a primary product, a co-product or an important by-product, while unconventional resources are resources from which uranium is only recoverable as a minor by-product, such as uranium associated with phosphate rocks, non-ferrous ores, carbonatite, black shale and lignite (see Appendix 3 for descriptions). Most of the unconventional uranium resources reported to date are associated with uranium in black shales and phosphate rocks, but other potential sources exist (e.g. seawater).

It is important to note that unconventional resources are not always classified to the same degree of certainty as conventional resources (i.e. they are not identified resources) as many of them are currently not being mined or have only been mined in the past. This has significant implications for their availability to be a part of the uranium supply chain in the short-term. Furthermore, many are not economically feasible in prevailing market conditions.

A comprehensive compilation of unconventional uranium resources and other potential nuclear fuel materials is challenging as many countries do not provide updated information. Unconventional uranium resources were reported occasionally by countries in Red Books beginning in 1965, and until 2003 estimates have been provided by 18 countries. Table 1.14 summarises unconventional resource estimates reported in Red Books between 1965 and 2003 (NEA, 2006) and incorporates unconventional resource assessments included in the national reports of this 2020 edition, as well as information from publicly available sources, to illustrate the evolution of these resource estimates.

Additional resources are reported for this edition by expanding data sources to include publicly available information, such as the IAEA UDEPO database (see below). This increases the number of countries reporting unconventional resources to 38 with only 7 countries, Brazil, Egypt, Finland, Jordan, Russia, Sweden and Thailand, reporting updated information in their national reports. Based on this information a total of nearly 39 million tU is assigned to the unconventional resource base.

The IAEA maintains a database, World Distribution of Uranium Deposits – UDEPO (https://infcis.iaea.org), which provides additional information about the potential unconventional resource base. As of 1 August 2020 (IAEA UDEPO, 2020), UDEPO reports 43.5 million tU as original historical resources from 38 countries for deposits classified as lignite-coal, black shale, phosphate and carbonate deposits, which are typically considered unconventional resources. A note of caution is warranted: deposit types do not necessarily correspond to the definition of unconventional resources. For example, the phosphate deposits of Brazil and carbonate deposits of India are considered conventional. Despite this, because of their deposit type they are often included as a part of unconventional resource totals. For several editions of the Red Book they have also been included in the totals for Table 1.14, but for this edition this has been corrected and the amounts reported for Kazakhstan and Brazil are only the historical values (i.e. reported between 1965 to 2003; NEA, 2006).

Table 1.14. **Unconventional uranium resources (1 000 tU) reported in 1965-2003 Red Books, with updated data* from 2011-2019 in parentheses**

Country	Phosphate rocks	Non-ferrous ores	Monazite	Carbonatite	Black schist/ shales, lignite	Other#
Algeria	(28[a])					
Australia					(0.15[a])	
Brazil	28-70	2		13		
Canada					(47.6[a])	
Central African Republic	(36.4[a])					
Chile	0.6-2.8 (0.4[b])	4.5-5.2 (0.8[b])				
China				(13[a])	(30[a])	
Columbia	20-60					
Czech Republic					(0.11[a])	
Egypt**	35-100 (210[a])					
Finland[(c)]				2.5 (2.5[b])	3.0-9.0 (24)	
France					(0.36[a])	
Germany					(204[a])	
Greece	0.5				(4[a])	
India	1.7-2.5	6.6-22.9			4	
Indonesia			(27)			
Iraq	(546[a])					
Iran, Islamic Republic of						(53)
Israel	(33[a])					
Jordan	100-123.4 (165.5)					
Kazakhstan	58***				(61[a])	
Korea					(36.2[a])	
Kyrgyzstan				(0.47[a])	(0.32[a])	
Mexico	100-151 (240)	1		(0.14[a])		
Morocco	6 526				(8 500[a])	
New Zealand	(12.2[a])					
Peru	20 (41.6)	0.14-1.41				
Poland					(151.6[a])	
Russia					(42.9[a])	
Saudi Arabia	(187.1[a])					
South Africa	(180[b])				(81.2[a])	
Sweden	(42.3[b])				300 (1 054)	
Syria	60-80					
Tanzania	(0.35[a])					
Thailand	0.5-1.5					(132)
Tunisia	(50[a])					
Turkmenistan					(50[a])	
Ukraine					(0.59[a])	
United States	14-33 (576.5[a])	1.8		(0.26[a])	(19 014[a])	
Venezuela	42					
Viet Nam	(3[a])				0.5	

(*) Updated data from publicly available sources and information provided by countries in the Red Book questionnaire. (**) Includes an unknown quantity of uranium contained in monazite. (***) Production of estimated 6 000 tU between 1959 and 1992 has been deducted from reported total. (#) Reported as unconventional resources with no indication of deposit type. (a) Secretariat estimate based on UDEPO which may include mined resources, see main text for additional information. (b) Not reported in 2019 questionnaire response; data from previous Red Books. (c) Including all measured, indicated and inferred resources at the Talvivaara black schist-hosted Ni-Zn-Cu-Co deposit.

For this report, the NEA/IAEA has provided an estimate for unconventional resources for 20 countries based on the values reported in UDEPO. Twenty-seven countries report resources associated with phosphates for a total of 9.2 million tU, which is approximately 24% of the total unconventional resource base. Morocco has the highest reported phosphate resources in the world with over 6.5 million tU, and this comprises about 17% of the unconventional resources total. Egypt, Iraq, Jordan, Saudi Arabia and South Africa also report significant resources associated with phosphates. Black schists/shales and lignite deposits represent the largest part of the unconventional resources base with just over 29.3 million tU or 75% of the total reported by 21 countries. The United States has the most significant resources in this category with deposits associated with lignite coal and black shale comprising about 576 500 tU and 19 million tU, respectively. Morocco, Poland and Sweden also have significant resources reported associated with black shales. The remaining deposit types listed in Table 1.14 (carbonate, monazite, non-ferrous ores and other) comprise less than 1% of the world total unconventional resources. Note that UDEPO includes most of the data from Table 1.14 and the higher total for unconventional resources in UDEPO (estimated at 43.4 million tU) is due to more complete information for some countries that do not report to the Red Book and the fact that some of the reported total includes already mined resources (IAEA UDEPO, 2020). Clearly, additional data is required to fully understand the unconventional resources picture. Nonetheless, the potential to expand the unconventional uranium resource base is readily apparent but will likely not be fully realised until market conditions strengthen considerably.

The potential to expand the unconventional uranium resource base is strongly tied to the ability to bring these resources into production. This will depend on i) market conditions, notably for the commercial recovery of phosphate reserves, since these determine the underlying economics of by-product uranium recovery; ii) changing business models and perceptions in the mineral industry consequent to recent market downturns resulting in expansion of portfolios to include multiple value-added products and especially materials for renewables technologies (e.g. electric storage batteries); iii) changing policies, notably to require uranium and other critical resources, such as rare earth elements, to be extracted for strategic and sustainability reasons rather than entirely on a commercial basis; and iv) a drive towards better environmental management and waste minimisation. Examples of possible policy drivers include the need to enhance the security of uranium supply to the national nuclear fuel cycle or to reap the environmental benefits of extracting uranium from phosphoric acid rather than through conventional mining, along with minimising the already very low amounts of uranium contained in fertiliser products.

Sri Lanka reports in this edition that a current focus of its early work on national fissile material development is to identify radioactive mineralisation in the country with an emphasis on the extraction of uranium from unconventional sources. Through IAEA technical co-operation projects, a substantial amount of technical assistance was provided to Sri Lanka for the discovery of economic uranium and thorium mineralisation. China reports in this edition that there are unconventional uranium resources associated with phosphate rocks, mainly distributed in the Hunan, Guizhou, and Sichuan Provinces. However, the grade is relatively low and a systematic appraisal of unconventional uranium resources has not yet been conducted.

Uranium as a co-product/by-product

A pre-feasibility report was released in 2011 for the Kvanefjeld rare earth element project of the Ilimausaq intrusion, a large alkalic layered intrusion located on the south-west coast of Greenland. In 2013, Greenland's parliament voted in favour of lifting the country's long-standing ban on the extraction of radioactive materials, including uranium, a move that could enable the Kvanefjeld project to proceed. It is the subject of a definitive feasibility study to evaluate a mining operation to produce uranium, rare earth elements and zinc.

In 2016, Denmark and Greenland signed an agreement concerning the special foreign, defence and security policy issues related to the possible future mining and export of uranium from Greenland. The agreement also served as a basis for the new Danish legislation for Greenland on safeguards and export controls, including the export of nuclear material from Greenland, being subject to nuclear co-operation agreements to provide assurances that exports are properly protected and used for peaceful purposes. In 2019, territorial restrictions regarding five nuclear conventions for Greenland were lifted. If the deposit is mined, about 425 tU/yr could be recovered as a by-product while thorium would be precipitated with other impurities such as iron, aluminium and silica and stored in a residue storage facility with the possibility of recovering the thorium in the future. Although uranium is a by-product, the resources are reported as conventional in the national report (i.e. similar to Australia, which reports by-product uranium production from Olympic Dam), with total recoverable identified resources of 148 200 tU.

Nolans Bore, Northern Territory, Australia, is a rare earth-phosphate-uranium deposit discovered in 1995. There is a conceptual plan to mine, concentrate and chemically process rare earth elements at the Nolans site, then transport a rare earth-rich intermediate product to an offshore refinery for final processing into high-value rare earth products. An estimated 4 050 tU of RAR have been delineated in the deposit. A feasibility study with a comprehensive technical and commercial work stream was undertaken. In January 2018, it was announced that the project had received state-level approval from the Environmental Protection Authority (EPA). However, an environmental approval from the Australian government and a final approval from the state government remain pending. In the most recent Definitive Feasibility Study (DFS) for the project in February 2019, only neodymium-praseodymium (Nd-Pr) oxide and phosphoric acids are mentioned in the annual production plans. The project is projected to start in the coming years and could produce 14 000 t of rare earth oxides and phosphoric acid (110 000 t/yr) as by-products.

The Pitinga deposit in Amazonas, Brazil, is one of the largest tin deposits in the world. Thick rhyolitic ashflow and tuffs are intruded by a 1 800 Ma granite. After a period of deposition of locally derived sandstone and shales, a series of rapakivi, porphyritic and sub-alkaline biotite granites were emplaced, and contain ore minerals such as zircon, pyrochlore, columbite, tantalite, xenotime and cassiterite. Beside tin, minor tantalum is currently also produced. However, the columbite mineral also contains 3.16% U_3O_8 and 4.90% ThO_2, which along with Nb, Ta, Zr and rare earth elements are not currently being recovered. A pre-feasibility study was begun to evaluate the possibility of by-product recovery of Ta, Nb, Y, rare earth elements, U and Th, with production forecasted to start in the coming years.

In past editions of the Red Book, the potential for very large, low-grade resources of uranium in the aluminium shale/schists was noted. Resources associated with black shales/schists amount to 1 054 300 tU (this includes the Häggån deposit, 307 692 tU; MMS Viken, 447 308 tU; Tasjo, 42 300 tU; and Narke uranium oil, 257 000 tU). These are significant unconventional uranium resources that potentially could be available to the market in future years if, for example, the costs of production of the bio-heap leaching technology under evaluation could justify economic production. Some of the deposits also contain high values of V, Mo, Ni and Zn. However, Sweden instituted in 2018 a ban on uranium exploration and mining in the country. In response, Australian Häggån project owner, Aura Energy, lodged a claim in 2019 against the Swedish government for compensation for its financial losses related to exploration and development of this project.

Unconventional resources of uranium in the Terrafame mine (Talvivaara Sotkamo) black schist-hosted Ni-Zn-Cu-Co deposit contain approximately 16 000 tU RAR, and about 24 000 tU total identified resources, as reported by Terrafame Oy in 2016. Although mining and production of other metals in the mine started in 2008, uranium present at 0.0017% in the ore started appearing as a contaminant in the downstream products. A licence for uranium extraction (350 t/yr) was granted in 2012. However, waste-water leaks in 2012 and 2013 stopped the operation completely, and the operator filed for bankruptcy protection in 2014. In August 2015, the state-owned company Terrafame Oy acquired the operations and assets of Talvivaara Sotkamo Oy from its bankruptcy estate and is carrying on the mining operations in Sotkamo. In October 2017, Terrafame Oy applied to the Finnish government for a licence to recover uranium as a by-product at Terrafame's mine. The mine site currently includes an almost fully completed uranium solvent extraction plant and Terrafame expects to start uranium production at Sotkamo in 2022 after licensing processes are complete.

The Elliot Lake district of Ontario, Canada, has a previous history of uranium and rare earth element production. Between 1955 and 1996, the paleo-quartz-pebble conglomerate deposit produced about 115 000 tU, as well as a small quantity of rare earth oxides. Additional exploration in the area resulted in a proposal (the Eco Ridge project) to produce rare earth oxides and uranium as co-products. An NI 43-101 resource estimate, updated in 2013, reported 23 147 tU and 93 180 t of rare earth oxides. A 2013 economic review indicated that approximately 1 173 tU/yr could be produced over 14 years of mine life. There is no update in this reporting period for this project.

South Africa has reported a significant resource base in paleo-quartz-pebble conglomerates and derived tailings and coal-hosted deposits, all of which could be sources of by-product uranium. Uranium is hosted primarily by coal (with minor amounts in the mudstones) in the Springbok Flats. A pre-feasibility study has been completed in Springbok Flats and a bankable feasibility study is in progress. In the 2016 edition of the Red Book, 70 775 tU in lignite and coal deposits were reported as inferred conventional resources. This is a good example of a reclassification of resources from "unconventional" to "conventional" resources. This reclassification is subjective since there are some parts of the definition of these resource classes that are open to different interpretations. In addition, uranium production and resources from tailings is reported as conventional and in association with the paleo-quartz-pebble conglomerate deposit type.

Uranium from phosphates

In the market scenario, phosphate deposits will only be processed commercially when it is economically viable to do so. Hence, the phosphate market acts as the determining factor of how much uranium can even theoretically be extracted from phosphate resources.

In the policy-driven scenario, the value of other recoverable elements will be added by various means – such as long-term government contracts – to the overall economic evaluation. Governments could also place a premium on securing the supply of nuclear fuel, especially where this can come from national resources, thereby eliminating dependency on third parties. In some countries, uranium extraction from phosphates could perhaps be mandated.

A hybrid situation (market and policy-driven scenario) may, however, be the most sustainable scenario over the long term. The need to combine fuel security for the utility company with commercial viability to the phosphate company and to align these requirements with the equally significant role of phosphates in providing food security could drive new business models. One benchmark in Brazil has already been set for this scenario, the Santa Quitéria greenfield joint venture between the government company, Industrias Núcleares do Brasil S.A (INB), and Galvani phosphates, with the prime customer being Eletrobras, the country's state owned nuclear power enterprise. This project is expected to produce both yellow cake and phosphate compounds in a single integrated process, thus spreading business risk across both phosphates and uranium. An alternative model is when the government steps in as the customer, as in the case of India, on the premise that the wider challenge of sustaining energy production as the fundamental driver of economic development justifies an offset of risk from the commercial producer to the tax payer. Under the hybrid option, both phosphate and uranium are managed as utility products and not as market-dependent commodities.

The prevailing market driven scenario with low uranium prices in an oversupplied market has not incentivised development of projects producing uranium as a by-product of phosphate. Brazil reports in this edition that an initial licence application for a construction was denied in 2018 and the partners are working on a new project model for Santa Quitéria. Production is not expected to begin until 2026. Argentina reports that prospective studies have been conducted on the extraction of uranium from phosphates and, in the framework of an IAEA Coordinated Research Project, preliminary studies are underway for the assessment of the uranium potential of phosphate rocks and testing uranium extraction from low-grade phosphate ores. Egypt and Jordan report in this edition that extraction of uranium from phosphates is now a principal focus of national uranium production. Mexico reports that the San Juan de la Costa phosphorite deposit, not currently a part of uranium resource inventories, is estimated to contain significant uranium resources.

Phos Energy Ltd and Cameco Corporation have developed the "PhosEnergy" process to extract uranium from the processing stream at operating phosphate mines. A demonstration plant was tested at a phosphate fertiliser production site in Florida in 2015 with good results, and a pre-feasibility study was completed for a relatively small facility (<150 tU/yr) that reported operating costs in the lower quartile of USD 50/kgU. The construction of a commercial model awaits favourable economic conditions.

Uranium from seawater

Seawater has long been regarded as a possible source of uranium because of the large amount of contained uranium (over 4 billion tU) and its almost inexhaustible nature. However, because seawater contains such a low concentration of uranium (3-4 parts per billion), developing a cost-effective method of extraction remains a challenge and elusive.

Research on uranium recovery from seawater was carried out initially from the 1950s to the 1980s in Germany, Italy, the United Kingdom and the United States. In Japan from 1981 to 1988, the Agency for Natural Resources and Energy, the Ministry of International Trade and Industry, and the Metal Mining Agency of Japan teamed up to operate an experimental marine uranium adsorption plant based on TiO_2 adsorbents.

More recently, a special issue devoted to several papers on recovery of uranium from seawater was published in the journal of Industrial and Engineering Chemical Research (ACS, 2016). One of the more recently studied methods considered for extracting uranium from seawater includes infusing fibres made of polyethylene, a common plastic, with amidoxime, a substance that attracts uranium dioxide and binds it to the fibre (Kuo et al., 2016; Abney et al., 2017). Researchers at Pacific Northwest National Laboratory and LCW Supercritical Technologies subsequently announced that they were able to produce five grams of yellowcake using this method (PNNL, 2018). Over the past five years, studies have indicated that the cost of uranium extraction from the sea has been reduced by a factor of three to four based on laboratory experience (CNA, 2016; PNNL, 2016). The importance of sea water temperature in the efficient recovery of uranium from seawater has also been documented (Kuo et al., 2018). Yi Cui and colleagues at Stanford University in the United States reported on an electrochemical method to capture uranium from seawater, demonstrating a nine-fold increase in uranium capacity, a four-fold faster rate of uranium accumulation, and favourable reusability behaviour compared to the best adsorbent materials developed for the same purpose, when using uranium spiked seawater (Cui et al., 2017). The application of carbon nanotube technology to extraction of uranium from seawater has also been actively investigated (e.g. Ahmad et al., 2020; Zhao et al., 2019). Costs are still significantly above current market prices and furthermore the technologies to extract uranium from seawater are yet to be proven cost-effective outside the laboratory setting. Nonetheless, interest remains and, for example, Thailand reports in this edition that a study on uranium extraction from seawater to improve the extraction technique has been ongoing since the end of 2011. Furthermore, if uranium extraction from seawater becomes economically competitive, the Electricity Generating Authority of Thailand may consider investment in a production centre.

Uranium exploration

Non-domestic

Only four countries (China, France, Japan and Russia) have reported non-domestic exploration and development expenditures since 2008 and this was reduced to three countries in this edition since Japan did not report (Table 1.15). Non-domestic expenditures are a subset of domestic (i.e. within country) expenditures as the totals reported on a country-by-country basis are a total of expenditures from domestic and foreign sources within each country. The recent trend in non-domestic exploration and development expenditures is depicted in Figure 1.4. During this reporting period, non-domestic exploration expenditures declined from USD 420 million in 2016 to USD 143 million in 2017, USD 73 million in 2018 and USD 54 million in 2019 (preliminary data). With development of the Husab mine in Namibia completed in early 2016 (majority owned by state-owned enterprise China General Nuclear Power Corporation), China's non-domestic expenditures (majority development) declined from USD 378 million in

2016 to USD 108 million in 2017 and USD 41 million in 2018, with USD 24 million expected in 2019 (China reported the development portion of total expenditures as 98% and 97% of total expenditures in 2015 and 2016 respectively, as the Husab mine was brought into production). In this edition, non-domestic exploration and development expenditures reported by France (all exploration) remained relatively steady through the reporting period but those by Russia (majority exploration) declined dramatically in 2017 and 2018, before increasing to USD 3.9 million in 2019. Even with this increase, Russia's non-domestic expenditures do not rival expenditures made from 2012 through 2015.

Table 1.15. **Non-domestic uranium exploration and development expenditures**

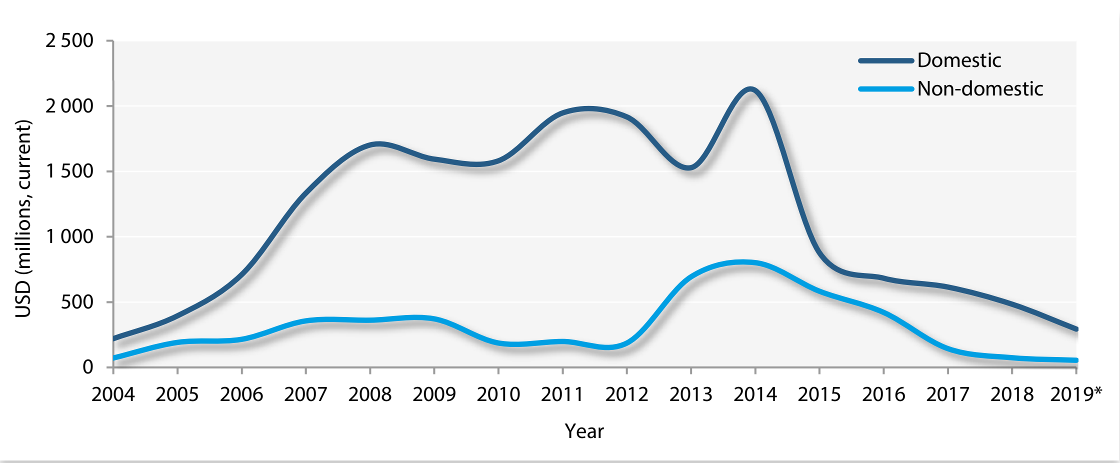
(USD thousands in year of expenditures)

Country	Pre-2012	2012	2013	2014	2015	2016	2017	2018	2019 (preliminary)
Australia	NA	NA	NA	NA	NA	NA	NA	NA	NA
Belgium	4 500	0	0	0	0	0	0	0	0
Canada	355 644	NA	NA	NA	NA	NA	NA	NA	NA
China	762 710	81 690	599 100	762 980[1]	526 310[1]	378 010[1]	108 110[1]	41 480[1]	23 580[1]
France	1 374 650	68 320	71 710	27 600	34 866	30 736	30 765	30 240	26 280
Germany	403 158	0	0	0	0	0	0	0	0
Japan	434 540	5 371[2]	3 512[2]	5 465[2]	3 922 [2]	5 089[2]	2 245[2,3]	NA	NA
Korea	NA	NA	NA	NA	NA	NA	NA	NA	NA
Russia	NA	30 100	18 200	4 900	17 100	6 100	1 800	1 500	3 900
Spain	20 400	0	0	0	0	0	0	0	0
Switzerland	29 679	0	0	0	0	0	0	0	0
United Kingdom	61 263	0	0	0	0	0	0	0	0
United States	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total	3 446 544	185 481	692 522	800 945	582 198	419 935	142 920	73 220	53 760

Note: Domestic exploration and development expenditures represent the total expenditure from domestic and foreign sources within each country. Expenditures abroad are thus a subset of domestic expenditures.

NA = Data not available. (1) Industry expenditures only. (2) Government expenditures only. (3) Expected amount from Red Book 2018. A country report for Red Book 2020 was not provided.

Figure 1.4. **Trends in exploration and development expenditures**



* Preliminary.

Several countries do not report non-domestic expenditures or have not reported these expenditures recently, and thus the data are incomplete. Canada reported expenditures of USD 139 million in 2007, and it is likely that Canada continues to be a leading investor in foreign exploration and development, but no information was reported for this edition. Australia is also known to make non-domestic investments, but figures have not been reported since 2006.

Domestic

Twenty-five countries reported domestic exploration and mine development expenditures for this edition (Table 1.16). The totals reported are on a country-by-country basis and represent the total expenditures from domestic and foreign sources within each country. The recent trend in domestic exploration and development expenditures is depicted in Figure 1.4. There is a notable decline in total expenditures compared to the last report, consistent with the trend of generally declining expenditures since 2012, with the exception of 2014 where increased expenditures were mainly due to development by China of the Husab mine in Namibia. From 2014 to 2015, total expenditures dropped from over USD 2 billion to USD 876.5 million and continued to decline to USD 681.9 million in 2016, USD 614.2 million in 2017 and USD 482.9 million in 2018, with only 292.4 million expected in 2019 (preliminary data and incomplete as some key countries missing). From 2016 to 2018, expenditures decreased in many countries, mainly because of persistently low uranium prices that slowed down many exploration and mine development projects. Reported 2018 global expenditures represent a 75% drop from exploration and mine development expenditures reported in 2012.

Table 1.16. **Domestic (industry and government) uranium exploration and development expenditures**

(USD thousands in year of expenditures)

Country	Pre-2012	2012	2013	2014	2015	2016	2017	2018	2019 (preliminary)
Algeria	NA	0	0	0	0	0	0	0	0
Argentina	95 194	10 647	9 812	4 244	5 880	4 142	5 092	2 376	1 420
Australia	1 482 849	98 695	48 787	37 124	33 665	17 295	15 115	9 044	NA
Bangladesh	453	NA	NA	NA	NA	NA	NA	NA	NA
Belgium	2 487	0	0	0	0	0	0	0	0
Bolivia	9 343	NA	NA	NA	NA	NA	NA	NA	NA
Botswana*	11 568	1 061	NA	NA	NA	NA	NA	NA	NA
Brazil	186 926	1 198	1 608	0	224	1 348	574	0	0
Cameroon	1 282	NA	NA	NA	NA	NA	NA	NA	NA
Canada	5 072 542	847 721	845 124	525 677	397 249	319 785	253 435	198 496	NA
Central African Rep.	21 800	NA	NA	NA	NA	NA	NA	NA	NA
Chile	9 618	NA	NA	NA	NA	NA	NA	NA	NA
China	420 000	131 000	189 000	197 000	152 000	128 000	125 000	120 000	154 000
Colombia	25 946	NA	NA	NA	NA	NA	NA	NA	NA
Costa Rica	364	NA	NA	NA	NA	NA	NA	NA	NA
Cuba	972	NA	NA	NA	NA	NA	NA	NA	NA
Czech Republic[(a)]	314 821	203	176	1 327	633	514	17	9	18
Ecuador	1 945	NA	NA	NA	NA	NA	NA	NA	NA
Egypt	117 271	NA	NA	NA	NA	28	28	84	84
Ethiopia	22	NA	NA	NA	NA	NA	NA	NA	NA
Finland	43 285	58 894	22 295	1 753	0	0	NA	NA	NA
France	907 240	0	0	0	0	0	0	0	0
Gabon	102 443	NA	NA	NA	NA	NA	NA	NA	NA
Germany[(c)]	2 002 789	0	0	0	0	0	0	0	0
Ghana	90	NA	NA	NA	NA	NA	NA	NA	NA
Greece	17 547	NA	NA	NA	NA	NA	NA	NA	NA
Greenland (Denmark)	4 140	NA	70	2 195	NA	NA	NA	NA	NA
Guatemala	610	NA	NA	NA	NA	NA	NA	NA	NA
Hungary	4 051	NA	NA	NA	NA	NA	NA	NA	NA
India	559 367	49 771	38 510	43 983	49 858	52 156	63 732	60 845	65 001
Indonesia	17 273	275	490	100	464	233	121	81	224

See notes on page 41.

Table 1.16. **Domestic (industry and government) uranium exploration and development expenditures** *(cont'd)*

(USD thousands in year of expenditures)

Country	Pre-2012	2012	2013	2014	2015	2016	2017	2018	2019 (preliminary)
Iran, Islamic Rep. of	142 413	82 070	43 197	50 179	6 276	17 320	39 221	13 567	9 333
Ireland	6 200	NA	NA	NA	NA	NA	NA	NA	NA
Italy	75 060	0	0	0	0	0	0	0	0
Jamaica	30	NA	NA	NA	NA	NA	NA	NA	NA
Japan	16 697	0	0	0	0	0	0	0	0
Jordan	29 845	1 839	3 175	3 820	3 697	2 886	3 531	4 831	3 531
Kazakhstan	358 392	94 303	76 420	34 676	60 934	23 935	36 620	37 252	28 645
Korea	17 866	NA	NA	NA	NA	NA	NA	NA	NA
Lesotho	21	NA	NA	NA	NA	NA	NA	NA	NA
Madagascar	5 239	NA	NA	NA	NA	13	24	NA	23
Malawi	NA	NA	NA	NA	NA	NA	NA	NA	NA
Malaysia	10 478	NA	NA	NA	NA	NA	NA	NA	NA
Mali	56 693	NA	NA	1 516	774	387	390	354	NA
Mexico[(b)]	30 606	62	93	106	93	66	886	1 204	NA
Mongolia	135 641	26 040	15 856	15 436	7 816	6 600	7 172	4 857	1 739
Morocco	2 752	NA	NA	NA	NA	NA	NA	NA	NA
Namibia	248 570	76 533	19 079	1 041 434	9 962	8 253	3 310	3 718	1 636
Niger	931 637	117 290	NA	NA	NA	4 504	322	6 937	NA
Nigeria	6 950	NA	NA	NA	NA	NA	NA	NA	NA
Norway	3 180	0	0	0	0	0	0	0	0
Paraguay	26 360	NA	NA	690	0	0	NA	NA	0
Peru	4 776	NA	NA	NA	NA	NA	NA	NA	NA
Philippines	3 492	NA	NA	NA	NA	NA	NA	NA	NA
Poland	NA	1 452	724	229	0	NA	NA	NA	NA
Portugal	17 637	NA	NA	NA	NA	NA	NA	NA	NA
Romania	10 060	NA	NA	NA	NA	NA	NA	NA	NA
Russia	865 528	64 731	46 746	39 917	17 581	18 907	9 980	13 957	9 427
Rwanda	1 505	0	0	0	0	NA	NA	NA	NA
Slovak Republic	NA	2 484	1 956	408	NA	NA	NA	NA	NA
Slovenia[(d)]	1 581	0	0	0	0	0	0	0	0
Somalia	10 000	NA	NA	NA	NA	NA	NA	NA	NA
South Africa[(e)]	262 839	32 788	1 890	1 655	5 164	NA	NA	NA	NA
Spain	177 684	12 106	13 000	5 400	9 106	1 160	1 180	908	390
Sri Lanka	43	NA	NA	NA	NA	NA	NA	NA	NA
Sudan	200	NA	NA	NA	NA	NA	NA	NA	NA
Sweden	47 900	NA	NA	NA	NA	NA	NA	NA	NA
Switzerland	3 359	0	0	0	0	0	0	0	0
Syria	1 151	NA	NA	NA	NA	NA	NA	NA	NA
Tanzania	NA	28 871	NA	NA	NA	NA	NA	NA	NA
Thailand	11 299	0	0	NA	NA	NA	NA	NA	NA
Turkey	24 578	2 815	3 048	4 875	6 842	223	768	2 987	15 538
Ukraine	53 551	2 633	1 324	1 337	689	484	1 111	800	1 390
United Kingdom	3 815	0	0	0	0	0	0	0	0
United States[(f)]	3 756 313	166 000	140 500	102 100	105 000	71 900	44 300	NA	NA
Uruguay	231	NA	NA	NA	NA	NA	NA	NA	NA
USSR	3 692 350	0	0	0	0	0	0	0	0
Uzbekistan	269 715	NA	NA	NA	NA	NA	NA	NA	NA
Viet Nam	12 249	1 697	1 427	1 875	2 610	1 794	1 540	NA	NA
Zambia[(g)]	2 463	3 518	3 751	NA	NA	NA	710	607	NA
Zimbabwe	6 902	NA	NA	NA	NA	NA	NA	NA	NA
Total**	22 780 089	1 916 697	1 528 058	2 119 056	876 517	681 933	614 177	482 913	292 400

Note: Domestic exploration and development expenditures represent the total expenditure from both domestic and foreign sources in each country for the year. NA = Data not available. (*) Secretariat estimate. (**) Updated totals from 2012 with corrected expenditures: Mexico (2012-2016) and Australia (2016). (a) Includes USD 312 560 expended in Czechoslovakia (pre-1996). (b) Government exploration expenditures only. (c) Includes USD 1 905 920, spent in GDR between 1946 and 1990. (d) Includes expenditures in other parts of the former Yugoslavia. (e) Includes expenditures for both uranium and gold in the Witwatersrand Basin until 2012. (f) Includes reclamation and restoration expenditures from 2004 to 2012. Reclamation expenditures amounted to USD 49.1 million, 62.4 million, 41.7 million, 46.3 million in 2008, 2009, 2010, 2011, 2012, respectively. (g) Non-government industry expenditures between 2011 and 2013, 2017 and 2018.

Of the countries reporting exploration and mine development expenditures from 2016 through 2018, the total over this three-year period amounted to USD 1.8 billion. Canada (44% of the total) led the way, followed by China (21%), India (10%), the United States (6.5%, despite not reporting 2018 expenditures) and Kazakhstan (5.5%). Expenditures in Canada alone exceeded the total spending of the remaining top five countries, demonstrating that Canada (mainly the Athabasca Basin) is the prime destination for uranium exploration and mine development.

Declining expenditures were reported from 2016 to 2018 in Australia, Brazil, Canada, China, and the United States (although data are incomplete) and, to a lesser extent, Argentina, the Czech Republic, and Spain. Generally increasing expenditures over this same period were reported by India, Jordan, Kazakhstan, Mexico and Turkey. Exploration and mine development expenditures were relatively steady from 2016 to 2018 in Egypt, Iran, Mongolia, Namibia, Niger, Russia and Ukraine. Kazakhstan, the world's largest uranium producer, reported increased expenditures from USD 23.9 million to USD 37.3 million from 2016 to 2018, with USD 28.6 million expected in 2019. Finland reported exploration expenditures for 2014; however, from 2015 onwards, there is no data for Finland as it is not possible to separate uranium exploration expenditures from the total reported for gold exploration, in which uranium is a potential co- or by-product. Due to confidentiality concerns, no expenditures were reported for the United States in 2018 and 2019, but expenditures have been in decline since 2012 when exploration and mine development expenditures amounted to USD 166 million, compared to USD 44.3 million in 2017, a decline of 73%.

Global expenditures are expected to continue to decrease in 2019 although it should be noted that key countries such as Australia, Canada and Niger did not report 2019 expected expenditures, so the 2019 global expenditure estimated is incomplete and is unlikely to decrease such a large amount, if at all. Declining 2019 expenditures are expected in other major uranium-producing countries, such as Kazakhstan, Namibia and Russia. For the 2016 to 2018 period, of the countries that reported exploration and development expenditures separately, Canada, China, Kazakhstan and the United States (2016 and 2017 only) reported greater exploration than mine development expenditures.

In contrast, Ukraine reported between 57% and 82% of its expenditures as mine development from 2016 to 2018 and Iran's development expenditures accounted for 40% to 64% of total expenditures over these same years. Development expenditures in Namibia accounted for 68% of total expenditures in 2016 before declining to 10% and 24% of total mine development and exploration expenditures in 2017 and 2018 following completion of the Husab mine. Egypt reported that close to 30% of its expenditures in 2018 and 2019 were used for mine development activities.

Seventeen countries reported drilling activities for this edition. Total drilling in 2016 amounted to 2 194 300 m (72% exploration; 17% development), 2 015 100 m in 2017 (74% exploration; 22% development) and 2 268 100 m in 2018 (78% exploration; 22% development), with 2 187 000 m (80% exploration and 20% development) expected in 2019. Note that the separate totals for exploration and development do not always add up to the total metres drilled as the United States does not report this information separately and drilling data for Niger was not separated into exploration and development. Also noteworthy is that Canada did not report 2019 drilling data and the United States did not provide data for 2018 and 2019, owing to confidentiality concerns. Despite these gaps, reported global drilling effort has not only declined since the last reporting period, it has been in decline since 2012 when 17 countries reported drilling that totalled 5 368 268 m in the 2016 edition of the Red Book. From 2016 to 2019, the global share of exploration drilling has increased from 61% to 76% of total expenditures.

In terms of exploration drilling distance from 2016 to 2018, most countries reported irregular but generally downward trends. Egypt, Kazakhstan, and Turkey were the only countries reporting upward trends in exploration drilling, although drilling in Kazakhstan was significantly greater than that reported for either Turkey or Egypt. China, Kazakhstan and Canada accounted for just over 93% of the exploration drilling length reported in 2016 and 2017, declining slightly to 88% in 2018 and 84% of the world total in 2019 (even though Canada did not report exploration drilling distance in 2019). In 2016 and 2017, China alone accounted for about 40% of global exploration drilling, Kazakhstan just for over 30% and Canada a little more than 20% in each year. However, in 2018 Kazakhstan led with a 40% share, followed by China (33%) and Canada (15%). Namibia reported that exploration drilling peaked in 2017 and 2018, then dropped by 87% according to preliminary data for 2019. Canada also reported a 30% decline in exploration drilling distance from 2016 to 2018. Argentina, Iran, Niger, Mongolia, Spain and Ukraine reported exploration drilling over much of the entire reporting period from 2016 to 2019, with variable drilling distance from year to year.

Only six countries reported development drilling in this edition: Canada, Iran, Kazakhstan, Namibia, Russia and Ukraine. Canada reported relatively steady development drilling effort from 2016 to 2018, yet this made up only 14% of the total drilling data reported by the country. In Iran, development drilling increased from 2016 to 2018, then decreased by 48% in 2019. In total, development drilling accounted for 50% of the total reported drilling length in Iran over this reporting period. After declining by 85% from 2016 to 2017, development drilling length in Namibia increased over 2018 and 2019, in total accounting for over 60% of all drilling in the country from 2016 to 2019. Kazakhstan reported increasing development drilling distance over the reporting period, in total accounting for half of the total global development drilling reported. Development drilling in Russia was reported only in 2016, accounting for 20% of the total global development drilling reported in that year. Reported development drilling in Ukraine increased until dropping off in 2019, accounting for 97% of the total drilling conducted in the country from 2016 to 2019. Although the United States does not report separate development and exploration drilling meterage and was not able to report combined totals in 2018 in 2019 due to confidentiality concerns, reported drilling effort declined by 74% from 2016 to 2017. It can be surmised that most of the drilling during 2016 and 2017 is related to mine development, since 92-97% of the total exploration and development expenditures for the United States are reported as development expenditures.

Trenching data, reported only by Egypt, Iran, Jordan, Mauritania and Madagascar totalled 6 790 m (1 240 trenches) in 2016, 5 250 m (902 trenches) in 2017 and 9 860 m (1 826 trenches) in 2018, with 2 010 m (91 trenches) expected in 2019. From 2016 to 2019, Iran and Jordan accounted for 100%, 97%, 98% and 75% of the global total trenching length, respectively. Iran excavated between 1 500 m and 2 700 m in each year of the reporting period, whereas Jordan dug between 780 m and 1 750 m from 2016 to 2018 and no trenching was undertaken in 2019.

Current activities and recent developments

North America

Canada, despite the global trend of declining exploration and development expenditures, has maintained higher than average expenditures and in 2018 this accounted for 43% of the world total for countries reporting this data. Overall uranium exploration and development expenditures in 2017 amounted to USD 253.4 million (CAD 332 million), a 21% decrease from 2016. Expenditures, in decline since the 2013 total of USD 845.1 million, continued in 2018 as total exploration and mine development expenditures amounted to USD 198.5 million, a 22% slide from 2017. Uranium development expenditures alone declined even more dramatically, from CAD 253 million in 2016 to CAD 195 million in 2017 and CAD 94 million in 2018, comprising about 20% to 25% of total expenditures. This decrease can be partially attributed to development activities slowing down as production began at the Cigar Lake mine. In contrast, exploration expenditures increased from CAD 164 million in 2016 to 196 million in 2019, as appraisal of recently discovered deposits continues.

Despite poor market conditions, Canada's high-grade uranium deposits remain the prime target for uranium exploration. Recently discovered large high-grade uranium deposits include Phoenix/Gryphon (Denison Mines Inc.), Triple R (Fission Uranium Corp.) and Arrow (Next-Gen Energy Corp.). During this reporting period, new mineralised intersections were discovered at several projects in the Athabasca Basin including Arrow, Rook 1/Harpoon, Triple R, Hurricane zone, Maverick zone and West McArthur. New technical reports and resource estimates have been filed for Phoenix/Gryphon, Christie Lake, Patterson Lake South and Arrow deposits. Denison continues technological testing and is conducting an environmental assessment of a proposal to use ISR to mine the Phoenix deposit, the first proposed use of this method for unconformity-type uranium deposits.

Box 1.1. **In situ leaching of unconformity-type uranium deposits?**

The Athabasca Basin, situated in the Canadian Shield of northern Saskatchewan and Alberta, Canada, hosts some of the highest-grade unconformity-related uranium deposits in the world (>10% U_3O_8). Open-pit and underground mining methods have historically been the only methods successfully used to extract these deposits. Both methods are capital intensive, requiring considerable up-front capital to fund shaft sinking or open-pit stripping. Most deposits in the Athabasca Basin are considered hard rock mines, which generally require explosives or mechanical means to extract the uranium.

Denison Mines is in the process of developing a modified, commercial-scale in situ leach (ISL) mining method at the company's Phoenix uranium deposit (27 000 tU; 19.1% U_3O_8) in the south-eastern part of the Athabasca Basin. Existing and proven mining technologies are used to create and test a novel application of the ISL mining method, which is typically used for low-grade sandstone-hosted uranium deposits. The method creates conditions necessary for ISL mining in a geologic environment where ISL was previously not considered applicable, and includes i) the application of ground freezing technology to establish a physical form of containment (via a "freeze wall") around the deposit, ii) the construction of an ISL wellfield within the freeze wall (approximately 300 recovery, injection and monitoring wells, which will intersect the deposit at approximately 400 metres depth), and iii) the augmentation of natural hydrogeological flow paths in the ore body using permeability enhancement techniques, which facilitates increased contact between the lixiviant and orebody, yielding greater uranium recovery, as well as potentially normalising the variations in mineralisation (grade) and geologic structure throughout the deposit. Injection pressure and pumping rates direct the lixiviant through the wellfield, simulating (to some degree) the natural "sweep" of traditional ISL mining. Owing to the high-grade at Phoenix, ISL wellfield operations can further be paired with a simple (direct precipitation) on-site processing facility, which has the potential to minimise discharge of treated effluent to the environment by creating a closed-loop circuit from wellfield to processing plant.

In 2019, in-ground permeability tests, conducted via a series of test wells and commercial scale wells, were carried out to evaluate the physical flows and hydraulic connections through the groundwater systems within the orebody, demonstrating the amenability of ISL mining at the Phoenix deposit. Subsequent independent hydrogeologic modelling, incorporating the results of the in-ground permeability tests, confirmed proof-of-concept for the application of ISL mining at the Phoenix deposit with respect to potential operational extraction and injection rates.

In the United States, the total expenditures for land, exploration, drilling, production, and reclamation decreased to USD 108.8 million in 2018, down 11% from USD 122.6 million in 2017 and notably lower than the 2016 total of USD 169.9 million. The trend of decreased drilling that began in 2013 continued, with the number of holes drilled for uranium decreasing by 64% from 2016 to 2017, respectively (this data is withheld in 2018 to avoid disclosure of individual company data). The total metres drilled decreased 74% from 230 733 m in 2016 to 59 741 m in 2017, a 97% decrease from the 2012 peak of 2 181 149 m (data withheld in 2018). Expenditures for 2018 and 2019 (expected) are also withheld due to commercial confidentiality concerns. Publicly available information, however, even if not officially reported, indicates that investment in the exploration sector has decreased significantly during this period. The overall decrease in reported expenditures (except exploration expenditures in 2017) is primarily the result of the current depressed uranium market and the global oversupply of uranium. Many uranium mining and exploration companies are hopeful that supportive recommendations emerging from the Nuclear Fuel Working Group established in July 2019, in response to a Section 232 Petition from two US uranium miners, will stimulate future investments and support of uranium exploration and development in the United States.

In Mexico, after several years of modest expenditures, total exploration and development expenditures increased from USD 0.66 million in 2016 to USD 1.2 million in 2018, as the government invested in the re-evaluation of previously identified resources, drilling 5 164 m in 47 holes through 2017 and 2018. Results showed that previous work did not meet international standards of evaluation and the main exploration effort is now focused on Santiago Papasquiaro, where anomalies and evidence of surface and underground uranium minerals have been defined. No exploration and development expenditures were officially reported by Mexico for 2019, but according to publicly available information from the Mexican Geological Survey, 2019 expenditures were approximately USD 871 000.

Central and South America

In Argentina, the continued investment in uranium exploration aligns with the 2006 government policy of reactivating the national nuclear energy programme. Reported domestic exploration expenditures in 2016 amounted to 62.8 million Argentine pesos (ARS), increasing to ARS 83.2 million in 2017, then declining to ARS 65.9 million in 2018, with 54.8 million expected in 2019 (expenditures in local currency are used due to the extreme currency fluctuations in Argentina in recent years). Expenditures by private exploration companies contributed 2.6 million ARS, 36.2 million ARS, 39 million ARS and 24.5 million ARS in 2016, 2017, 2018 and 2019, respectively. Because there is no requirement for private industry to report exploration expenditures, the amounts reported likely do not reflect all expenditures in the sector.

The slow-down in government exploration activities since 2017 meant that no drilling was carried out as efforts shifted to field work for geological and radiometric review, as well as sample collection for geochemical analysis and environmental studies at different sites of interest. Previously in 2016, the government had drilled 6 exploration holes totalling 114 m.

The most significant uranium ore deposit in the exploration/assessment stage in Argentina is Cerro Solo, located in Chubut Province. Here the government is focusing on feasibility studies for proposed mining and laboratory-scale tests to determine the most economically competitive milling process.

During the 2017 to 2019 period, exploration-related activities were reported for private sector companies Sophia Energy S.A., Blue Sky Uranium Corp and UrAmerica Ltd. Sophia Energy continued exploration at the Laguna Sirven deposit in Santa Cruz province, contracting the National Atomic Energy Commission to conduct an airborne radiometric survey of the entire project area. Blue Sky Uranium Corp. announced its first preliminary economic assessment for the Ivana deposit of the Amarillo Grande Project and continued efforts to expand mineralisation proximal to the deposit through pit and auger sampling, an induced polarisation geophysical survey and up to 4 500 m of drilling.

No exploration drilling by private companies was reported in 2016 but drilling of 7 159 m (467 holes) was reported in 2017, 2 378 m (236 holes) in 2018 and 610 m (81 holes) in 2019.

In early 2018, the Uranium One Group (Russia), UrAmerica Argentina and the government of Argentina signed a memorandum of understanding to promote co-operation and joint development of uranium exploration and production focused in ISL, planning to invest USD 250 million.

The IAEA has provided support to many uranium production cycle activities in Argentina over the last several years. A recently completed IAEA Coordinated Research Projects involved an assessment of the uranium potential of phosphate rocks and testing uranium extraction from low-grade phosphate ores.

In Brazil, exploration and mine development expenditures increased from USD 224 000 in 2015 to USD 1.3 million in 2016, then declined to USD 574 million in 2017 and no expenditures were made in 2018 and 2019. Exploration drilling in 2016 and 2017 spanned 14 500 m (117 holes) and 5 600 m (45 holes), respectively. In 2017, exploration efforts focused on favourable albititic areas of the northern part of Lagoa Real province, but since then efforts were devoted to making the transition from open-pit to underground mining of the Cachoeira deposit and developing open-pit mining of the Engenho deposit to expand the Lagoa Real production centre.

Chile did not report exploration and development expenditures for this edition and, given the lack of updates on projects in northern Chile's iron-oxide copper-gold belt, with potential for copper, gold, silver and uranium, activity has likely wound down since 2016.

The government of Paraguay did not respond to the Red Book questionnaire for this edition and there have been no uranium exploration activities from 2014 to 2018. After being granted regulatory approval to advance its Yuty ISL project from the exploration to exploitation phase, Transandes Paraguay S.A. (subsidiary of Uranium Energy Corporation – UEC) requested a two-year suspension of its mining project due to low uranium prices in 2015. A 2016 case study conducted to test the United Nations Framework Classification (UNFC) scheme provides additional information on the deposits, as well as the regulatory and social environment for uranium mining in Paraguay (Yancy et al., 2016). In 2019, after licensing by the Under Ministry of Mines and Energy (UMME), Transandes carried out a radon emmanometry survey and drilled one hole in the Coronel Oviedo ISL area obtaining positive results.

Peru does not report exploration and development expenditures, and the industry is not required to report expenditures to the government. Both Plateau Energy Metals Inc. (formerly Plateau Uranium Inc.) and Fission 3.0 Corp. had been advancing uranium and lithium prospects in the Macusani district projects. During the 2017 to 2018 period, Plateau Energy Metals carried out some exploration drilling activities in new areas of the Macusani district.

European Union

In the Czech Republic, exploration and development expenditures dropped from USD 514 000 in 2016 to USD 17 000 in 2017 and USD 9 000 in 2018, as efforts shifted from exploration of the Rozná deposit at depth to conserving and processing all historic data on uranium deposits in the Czech Republic, once the decision was taken to close the Rozná mine in 2017. Database building and advanced processing of the previously collected exploration data are expected to be the focus of work in the coming years, with expenditures amounting to USD 18 000 anticipated in 2019. No drilling data was reported for the 2016 to 2019 reporting period.

Denmark/Greenland reported total expenditures of between USD 1.5 million and 3 million for all commodities from 2016 to 2019, but the portion spent on uranium is not possible to separate. No drilling data was reported for this three-year period. Since 2007, Greenland Minerals Limited (prior to 2018, Greenland Minerals and Energy Ltd.) has conducted rare earth element (U-Zn) exploration activities in the Kvanefjeld area, South Greenland, including drilling of 57 710 m of core. A mining/exploitation licence application was submitted in July 2019, including updated environmental and social impact assessments (EIA and SIA) together with a navigational safety investigation study (NSS).

In Finland, no exploration exclusively for uranium was reported. However, uranium is included in some active gold exploration permits. Finland last reported expenditures in 2014 of USD 1.7 million on uranium exploration and no expenditures or drilling data have been reported since.

The government of Hungary did not report any exploration or mine development expenditures. However, reported industry exploration drilling amounted to 1 867 m (two holes) in 2016 and 950 m (one hole) in 2017 as the Mecsek deposit is being evaluated by the Australian company Wildhorse Energy for possible future production. In 2017, a summary report of all exploration activities since 2007 was submitted to and approved by the Hungarian Mining Authority. Environmental licensing, however, is on hold pending late submission of additional documents.

Spain reported USD 1.2 million in 2016 and 2017 in exploration and mine development expenditures by industry, declining to USD 908 000 in 2018 with USD 390 000 expected in 2019. Industry exploration drilling amounted to 8 993 m (108 holes) in 2016, 595 m (28 holes) in 2017 and 3 350 m (13 holes) in 2019 (no drilling was reported in 2018). This reflects a shift by Berkeley Minera España S.L.U. from exploration to licensing of its proposal to mine uranium by open pit in Salamanca province. Through 2018, 2019 and as December 2020 the documentation for the construction licence is under evaluation by the competent authorities. Should this licence be granted, an exploitation licence would still be pending. However, a draft climate change and energy transition bill, presented to the Spanish Parliament in May of 2020 and later amended in October of 2020 to include radioactive minerals, would prohibit the exploration and exploitation of uranium in Spain.

In Portugal there has been no exploration or exploitation of uranium since 2001, although there are unexploited uranium deposits located in the southern part of the country.

On 16 May 2018, the Swedish parliament passed an amendment to the Environmental Code banning uranium exploration and mining in the country. Prior to this, most exploration activity was related to the potential of alum (black) shale, where uranium could be recovered as a by-product along with other co-products such as molybdenum, vanadium, nickel, zinc and petroleum products. Aura Energy Ltd., an Australian company that had worked for several years to develop the Häggån Project for uranium and vanadium mining, lodged a claim against the Swedish government in November 2019 for compensation of financial losses resulting from this recently legislated ban on uranium exploration and mining.

Although no domestic uranium exploration and mine development activities have been carried out in France since 1999, majority government owned Orano (formerly Areva) and its subsidiaries remain active abroad. During 2016-2018, Orano and its subsidiaries focused on targets aimed at the discovery of exploitable resources in Canada, Gabon, Kazakhstan, Mongolia, Namibia and Niger. Total non-domestic exploration expenditures remained relatively steady since 2016 at about USD 30 million in each year, with a slight decline to USD 26 million expected in 2019. No development expenditures were reported.

In previous reports, countries such as Poland and the Slovak Republic were either interested in or issuing permits to explore for and develop domestic uranium deposits for mining. Neither Poland or the Slovak Republic, or any other country in the European Union, reported uranium exploration and mine development expenses for this edition, except for those outlined above. In February 2018, it was reported that the Supreme Court of the Slovak Republic supported the Environment Ministry in not extending an exploration licence for uranium held by Ludovika Energy.

Europe (non-EU)

In Russia, in 2018, the Dalur company, owned by JSC Atomredmetzoloto (ARMZ), completed exploration of the Khokhlovskoye deposit in the Kurgan Region. It also began intensive exploration of the Dobrovolnoye deposit, which is planned to be brought into production within the next five years to maintain regional uranium production capacity by ISL at a level of 600 tU/year. Both deposits are being developed for sulphuric acid ISL mining.

Domestic exploration and mine development expenditures in Russia varied between USD 9 and 19 million from 2016 to 2018, with development expenditures accounting for just over half of total expenditures over these years. Exploration and mine development expenditures are expected to decline in 2019 to USD 9.4 million.

Overseas expenditures, made by subsidiaries of the State Corporation ROSATOM (the Uranium One Group and its Canadian-based branch Uranium One Inc.), involved exploration and pilot test work at five joint ventures in Kazakhstan, and pilot test work in Tanzania to prepare for development of the Mkuju River uranium project.

In Turkey, government exploration expenditures increased from USD 223 000 in 2016 to USD 3.0 million in 2018, with USD 15.5 million expected in 2019. No development expenditures were reported. Efforts were mainly focused on exploration of granite, acidic igneous and sedimentary rocks in Edirne, Kırklareli and Tekirdağ provinces. The work is expected to continue in 2020. In early 2019, Westwater Resources Inc. reported that the Turkish government had cancelled all exploration and operating licences held by Adur in June 2018 (Adur is Westwater's Turkish subsidiary Adur Madencilik Limited Sirketi). Adur and its predecessors have been developing the Temrezli and Şefaatli projects, carrying out drilling, testing and studies to move the projects towards production. The issue is the subject of an arbitration tribunal as Westwater seeks compensation for its investments.

In Ukraine, exploration and development expenditures varied between highs of USD 1.1 million in 2017 and USD 1.4 million in 2019, to lows of USD 484 000 in 2016 and USD 800 000 in 2018, with the majority of these expenditures devoted to mine development. During the 2016 to 2019 reporting period, a total of over 562 000 m of drilling (35 856 holes) was conducted, the majority of which was devoted to mine development activities, including sinking two 650 m shafts to the Severinske and Podgayscevske deposits in preparation for mining. SE Kirovgeology continued to focus on exploration around existing uranium mines and evaluating the thorium potential of the Ukrainian Shield.

Africa

In Algeria, no uranium prospecting or mine development work was reported between January 2007 and January 2019, with the exception of a 2017-2018 government-based mineral resource potential study of the Eglab region of southwestern Algeria, which among a number of other metallic commodities, included uranium (it was determined that the potential for economic uranium mineralisation was low).

Although no exploration and mine development expenditures were reported in Botswana, Australian company A-Cap Resources (now A-Cap Energy Limited) shifted efforts to optimising mining and processing, as well as maintaining the mining licence for its Letlhakane Uranium Project during the current period of low market prices. Letlhakane has been the focus of detailed evaluation and technical work by A-Cap Energy Ltd since 2006.

The last time the Democratic Republic of Congo (DRC) reported exploration activities to the Red Book was in 1988 (at that time DRC was known as Zaire). Recently, the IAEA has been providing support for the identification and evaluation of uranium and other radioactive resources in the DRC through the Technical Co-operation programme entitled, “Strengthening National Capacities for the Assessment of Uranium Resources and Other Radioactive Minerals and for the Regulation of Associated Mining Activities”. This programme began in 2018 and continued through.

Egypt reported government exploration and mine development expenditures for the first time since 2008. From 2016 to 2019, expenditures varied between USD 28 000 and USD 84 000 as the Egyptian Nuclear Materials Authority (NMA) focused effort on four prospects in the Eastern Desert and South Sinai. Mine development expenditures comprised 29% of the total spent in 2018 and 2019. Exploratory trenching (a total of 750 m in 34 trenches in 2018 and 2019) and drilling (a total of 4 500 m in 210 holes between 2017 and 2019), along with geophysical and geochemical surveys, were used to follow subsurface extensions of formations hosting uranium mineralisation.

Egypt has had ongoing support for over a decade in developing uranium exploration and production capacities through several IAEA Technical Co-operation projects. The most recent, including “Supporting Technological Separation and Purification of Naturally Occurring Radionuclides and Rare Earth Elements from Minerals” and “Supporting a Feasibility Study for Uranium and Rare-Earth Element Recovery from Unconventional Resources”, began in 2016 and 2018, respectively.

In 2015, the government of Madagascar, through the Office of National Mines and Strategic Industries (OMNIS), with IAEA assistance, revived uranium exploration in this, one of the earliest uranium producing countries. OMNIS began by examining the general geology of the Morondava Basin and uranium mineralisation previously discovered in the Karoo formations of the Makay mountain range, and in 2016, conducted ground surveys to verify preliminary geological maps and previously discovered radiometric anomalies. Trenching and sampling in 2017 (160 m in 16 trenches, 17 pits) led to more detailed exploration in two sectors of interest in 2018. In 2019, OMNIS continued detailed exploration activities in the Makay area, including geophysical and radiometric surveys (systematic scintillometer and radon coverage), coupled with tectonic/structural studies, trenching and pit sampling, stream-sediment sampling, and geological mapping.

For Malawi, no exploration and mine development expenses were reported, as activities ground to a halt when the government imposed a moratorium in 2015 on applications and grants for all mining and exploration tenements until a new cadastral system and a new minerals act is introduced. On 14 December 2018, the National Parliament of Malawi passed a new bill (Mines and Minerals Bill 2018), legislation that is intended to modernise current legislation. For the new bill to come into force it must receive Presidential assent and be gazetted. Presidential assent was reportedly received in February 2019, but as of August 2020 it had not been gazetted.

In Mali, reported private sector exploration and mine development expenditures declined from USD 773 514 in 2015 to USD 386 942 in 2016, USD 390 000 in 2017 and 354 000 in 2019 as a rebellion in the north-eastern part of the country limited activities. In June 2016, GoviEx Exploration (Canada) acquired the Faléa project in western Mali from Denison Mines, and in 2017 conducted a geophysical survey of the area that identified new targets, which are likely to increase project resources. No drilling was conducted in 2017-2018. In 2018, GoviEx applied for new exploration licences for the Bala and Madini areas and renewed the Faléa licence for a second term.

In Mauritania, no exploration and development expenditures were reported, although private sector activity to advance mine development continues, notably by Australia's Aura Energy at the Tiris (Reguibat) project. At Tiris, drilling (7 900 m in 1 428 holes) and shallow trenching (11 trenches of 4 m depth) in 2017 led to the development of new resource estimates and the completion of a definitive feasibility study in 2019. An Environmental and Social Impact Assessment of this shallow (3-5 m below surface) deposit overlain with loose windblown sand was completed in 2017.

Support in the uranium production cycle has been provided through IAEA Technical Co-operation project, "Establishing an Effective Monitoring Mechanism for Environmental Protection related to Uranium and Mining Activities". The project began in 2014 and continued through 2017. The specific objective of the project was to put in place a framework for environment management, build capacity for environmental and radiological site characterisation leading to baseline generation of potential uranium mining sites in Mauritania and building capacity for monitoring of radionuclides in the environment.

In Namibia, there has been limited exploration activity at known uranium projects in recent years due to continued low uranium prices. Exploration and mine development expenditures declined from USD 8.3 million in 2016 to USD 3.3 million and USD 3.7 million in 2017 and 2018 respectively and are expected to decline further to USD 1.6 million in 2019. Exploration activities accounted for just over 52% of total expenditures over these years.

The Australian company Deep Yellow Ltd. reported on exploration activities at the Reptile Project that focused on expanding calcrete-associated uranium mineralisation in the Tumas and Tubas areas, and at the Nova Joint Venture project, which resulted in the identification of calcrete uranium mineralisation in a newly delineated paleochannel. Most Namibian companies, however, which were active in exploration in the past, have been focused on improving operating efficiencies to optimise aspects of proposed developments. One new project of note is Headspring, owned by Russian Uranium One Holding through its daughter company Headspring. Ground geophysical and geochemical surveys through 2016-2017, metallurgical test studies in 2018, and exploration drilling in 2019, led to the identification of sandstone type uranium resources potentially suitable for development by ISL. In January 2017, the Namibian government lifted the 10-year moratorium on new applications for exploration licences on nuclear fuel minerals, and since then 52 new licences have been granted up to the end of 2019.

In November 2019 and February 2020, Marenica Energy announced positive results from its drilling programme on its Exclusive Prospecting Licence (EPL) 6987, commonly referred to as "Koppies". The results confirmed high grade uranium mineralisation at shallow depths of less than 20 metres. Marenica plans to carry out further drilling on this licence area.

In Niger, uranium exploration and development expenditures have varied over this reporting period from USD 4.5 million in 2016 to USD 322 000 in 2017 and USD 69 million in 2018 (expenses in 2019 were not available). In 2017 and 2018, Orano continued exploration and development activities within the perimeters of its mines in the Arlit area. Somaïr drilled 16 240 m in 2017, 8 150 m in 2018, with 11 863 m planned in 2019.

Several private exploration companies were active in recent years, despite geopolitical tensions in the area. Development of Global Atomic's Dasa deposit continued, with drilling amounting to 26 479 m in 2017 and 2018 resulting in upgraded resource estimates and a preliminary economic assessment of the project. Development of other deposits continued through the reporting period, notably GoviEx's Madaouela project that includes the Marianne, Marilyn, Miriam, MSNE and Maryvonne deposits, as well as the Dijy and Isakanan deposits in the Dasa project area. Although incomplete, company reports indicate that a total of 115 700 m of drilling was completed in Niger from 2017 to 2019.

For South Africa, no exploration and mine development expenditures were reported in this edition. Low uranium market prices have not only slowed exploration activity but have shelved projects, including two that had been advanced to the feasibility stage: Harmony Uranium TPM (Tshepong, Phakisa and Masimong) and the Free State Tailings Uranium Project, as well as the Henkries Project in the Namaqualand, Northern Cape Province, and the Ryst Kuil and

Quaggasfontein areas (Karoo projects). In 2018, Mintails Mining South Africa (Pty) Ltd and several related companies announced their liquidation. Mintails used to mine and process gold and uranium from waste piles and open pits in Krugersdorp near Johannesburg.

The Witwatersrand Basin contains about 79% of total identified uranium resources in South Africa, with 28% residing in associated tailings facilities. Since uranium production in these projects only includes the costs of transporting ore from the underground or tailings operations to the processing plants and the treatment costs to separate uranium, while gold carries all other costs, an improved uranium market conditions could stimulate recovery of uranium contained in South African gold mine tailings.

For Tanzania, exploration and development expenditures were not reported for this edition. The main focus of activity has been directed at the Nyota deposit (Mkuju River Project), where ISL tests were conducted over ten months in 2016 using a two-well pattern and a final report issued in 2017. The results confirmed the amenability of the portion of the resources situated below the water table for extraction by ISL. During 2017, rehabilitation of aquifers and the ground surface was completed following the ISL tests. In late December 2016, Mantra Resources (purchased by Atomredmetzoloto of Russia in 2011) applied to the Ministry of Energy and Minerals of Tanzania for suspension of its special mining licence due to unfavourable uranium market conditions. In September 2017, the ministry approved the request.

Uganda does not report data to the Red Book, but may in future since the IAEA is continuing to support Uganda's efforts to identify and evaluate uranium resources through the Technical Co-operation programme, "Strengthening the National Capacity for Uranium Exploration and Evaluation" from 2014 to 2017. The government continues to evaluate national uranium resources utilising their Geological Survey and Mines Department as part of long-term planning as the country considers adding nuclear energy to its future energy mix.

In Zambia, although total exploration and mine development expenditures were not reported, exploration expenditures by GoviEx amounted to USD 710 000 and USD 607 000 in 2017 and 2018, respectively. GoviEx, the most active company in Zambia, acquired the Mutanga and Chirundu uranium projects in 2016 and 2017 respectively, consolidating these adjacent projects. Zambia has upgraded its mining legislation to include uranium, following detailed consultation with the IAEA. In 2017, a further revision of regulations regarding uranium exploration and mining was undertaken.

Middle East, Central and Southern Asia

In India, government exploration and development expenditures remained relatively steady at above USD 60 million from 2017 to 2019, up from USD 40 million to USD 50 million since 2012.

In recent years, exploration activities have been concentrated on various Precambrian and Palaeozoic through Cenozoic basins, shear zones, fold belts, and metamorphic complexes. Extensive exploration, including ground and heliborne geophysical, ground geological, radiometric and geochemical surveys, and drilling, are planned in other geological domains of the country that have the potential to host uranium. These efforts have resulted in a 26% increase in RAR for India from 2017 to 2019, due to appreciable resource additions in the contiguous area of the stratabound deposit in the southern part of the Cuddapah Basin and the extension areas of known deposits in the Singhbhum Shear Zone, Bhima Basin, and North Delhi Fold Belt.

In Sri Lanka, the current exploration focus is on the identification of radioactive mineralisation with an emphasis on the future extraction of uranium from unconventional sources. Detailed high quality digital aeromagnetic and radiometric surveys have been initiated, or are planned, over a large portion of the country to locate uranium and thorium mineralisation to assess the country's nuclear raw material potential in support of future energy planning. The identification of radiogenic hazardous areas is another objective of this programme.

Iran reported government exploration and development expenditures of USD 17.3 million in 2016, up from USD 6.3 million in 2015, increasing to USD 39.2 million in 2017, then declining to USD 13.6 million in 2018, with USD 9.3 million expected in 2019. Exploration accounted for 53% of total expenditures over this period. Exploration drilling and trenching totalled 19 918 m (114 holes) and 8 043 m (244 trenches) respectively, whereas development drilling totalled 17 608 m (3 319 holes).

Exploration activities in Iran follow a general plan in favourable areas from reconnaissance to more detailed phases. Reconnaissance and prospecting phases are being undertaken over much of the country and uranium mineralisation with positive indications has been found in a variety of geological environments. Targets include granite-related, metasomatic, volcanogenic, intrusive and sedimentary types of deposits.

In Jordan, government exploration expenditures increased from USD 2.9 million in 2016 to USD 3.5 million in 2017 and USD 4.8 million in 2018, then are expected to decline to USD 3.5 million in 2019. From 2016 to 2018, the Jordan Uranium Mining Company (JUMCO) completed 14 952 m trenching (3 738 trenches), which was the main exploration activity undertaken. In June 2018, a third JORC compliant report was issued. Plans for 2019-2020 included a drilling programme on a 50 x 50 m grid in selected areas to upgrade the resources of the deep mineralised layer to the measured category prior to undertaking pre-feasibility studies.

Uranium production cycle activities in Jordan have been supported by several IAEA Technical Co-operation projects over the last few years, most recently the "Enhancing Capabilities in Extracting Uranium from Local Ores on a Pilot Scale Level" project in 2018 and 2019.

In Kazakhstan, exploration and development expenditures increased from USD 23.9 million in 2016 to USD 36.6 million in 2017 and USD 37.3 million in 2018 but are expected to decline to USD 28.6 million in 2019. These expenditures are the lowest made since Kazakhstan started ramping up its exploration and development activities in 2007 and 2008. In the most recent reporting period (2016-2019), 11% of the total expenditures was devoted to mine development activities, the remainder to exploration. Drilling over this same period amounted to 3 276 989 m (6 822 holes), with development drilling reportedly accounting for 868 709 m (2 109 holes).

During 2017 and 2018, exploration was undertaken at Inkai, Budenovskoye in the Shu-Sarysu Uranium Province, and at the Northern Kharasan and Zarechnoye deposits in the Syrdaria Uranium Province. This resulted in a significant increase of about 150 000 tU in identified resources spread among the Budenovskoye (sites No. 6 and No. 7), Inkai (sites No. 1 and 4), the Tortkuduk block at Moinkum, and Northern Kharasan (site Kharasan-1) deposits.

In Kyrgyzstan, in October 2019, a law was adopted by the Parliament of the Kyrgyz Republic that would prohibit exploration for and development of underground uranium and thorium resources. The purpose of the law is to protect the health of the population, land, water bodies, flora and fauna, and to ensure the rights of citizens to a favourable environment for life, work and leisure, as well as radiation and environmental safety.

In Uzbekistan, Nurlikum Mining, a French-Uzbek uranium joint venture established in December of 2019, will conduct uranium exploration and mining operations focusing on sandstone type uranium mineralisation in the Djengeldi region of the Kyzylkum province.

Box 1.2. **Potential recovery of rare earth elements, scandium and rhenium from uranium sandstone deposits (ISL mining)**

Resource analyses at deposits in Kazakhstan, Uzbekistan and Russia have identified rare earth elements, scandium, and rhenium in association with uranium. These valuable commodities are partially dissolved by sulphuric acid during the ISL mining process that mobilises and recovers uranium. ISL solutions may contain up to 1 mg/l of scandium and rhenium, and up to 50 mg/l of rare earth elements (primarily lanthanum, cerium, and neodymium). Using sorption by cationic exchange resins or chemical precipitation methods, technologies to extract these commodities as by-products from pregnant uranium-bearing solutions are being developed at various ISL operations.

Rare earth elements are recovered by chemical precipitation, while rhenium is partially absorbed together with uranium in anionic ion exchange resins. Rhenium was recovered in the mid-1980s during limited pilot applications at the Northern Kenimekh deposit in Uzbekistan and at some deposits in Kazakhstan (Kozhakhmetov et al., 2010). Scandium is currently being recovered as a by-product at the Dalur ISL operation in Russia. Kazakhstan has recently resumed research activities on by-product recovery. The key technological challenge is the proper selection of sorbents, which provides for selective extraction of commodities of interest while minimising or eliminating radioactive element impurities.

South-eastern Asia

In Indonesia, exploration expenditures declined from USD 233 000 in 2016 to USD 121 000 in 2017, USD 81 000 in 2018, and are expected to increase to USD 224 000 in 2019. A drilling programme of 425 m (6 holes) was planned for 2019. Exploration activities in 2017 were carried out in Kalan-Kalimantan and Mamuju-West Sulawesi. In Kalan this included re-estimating resources using a geostatistical approach, database formulation, application of the UNFC resources classification system and georeferencing of semi-regional maps. Mapping in 2018 in Kawat-East Kalimantan was aimed at identifying the distribution of favourable areas for uranium occurrence. In 2019, exploration was expected to continue in Mamuju-West Sulawesi, Harau-West Sumatera, and Kalan-West Kalimantan, including drilling in Mamuju in the Ahu and Takandeang sectors.

Although the Philippines does not report exploration and development expenditures, an IAEA Technical Co-operation project entitled, “Enhancing National Capacity for Extraction of Uranium, Rare Earth Elements and Other Useful Commodities from Phosphoric Acid” was conducted from 2014 to 2015. The Philippine Phosphate Fertilizer Corporation (Philphos) has an approximately 1 million tonne/year capacity to produce phosphoric acid that contains considerable concentrations of uranium and possibly other marketable commodities. The project conducted a laboratory-scale study on the possibility of extracting uranium, rare earth elements and other resources from the phosphoric acid. A follow-up to this effort began in 2018 with the IAEA Technical Co-operation project “Enhancing Bench-scale Simulation for the Development of Continuous Extraction Technology of Uranium and Other Valuable Elements from Phosphates: Phase II”, which is expected to continue through 2020.

For Thailand, no uranium exploration activities were reported, despite the identification of rare earth and associated radioactive elements through exploration conducted by the Department of Mineral Resources (DMR). From 2017 to 2018, DMR conducted reconnaissance/regional survey activities for rare earth elements in various parts of Thailand to define areas of high potential, focusing on granitic weathering crusts. According to the preliminary results, the associated uranium and thorium concentrations accumulated along the weathering profiles have been determined in the vicinities of Mae Hong Son, Chiang Mai and Tak provinces. In 2019, exploration for rare earth elements was put on hold due to budget constraints.

In Viet Nam, government uranium exploration expenditures amounted to USD 1.8 million and 1.5 million in 2016 and 2017, respectively. No expenditures were reported in 2018 and 2019, despite the continuation of activities to estimate uranium potential in the Palua-Parong area containing twelve orebodies. Exploration activities are aimed at increasing the resource base and determining the feasibility of mining the deposits.

East Asia

Total non-domestic development expenditures reported by China decreased during this reporting period from USD 378 million in 2016 to USD 108.1 million in 2017, and USD 41.5 million in 2018 and USD 23.6 million in 2019. This decline is primarily due to the acquisition and subsequent ramp up in development of the Husab mine in Namibia, which was acquired in 2012 by Uranium Resources Co., Ltd, a subsidiary of state-owned China General Nuclear Power Group (CGN). First production from Husab occurred in 2016.

In addition to development of the Husab mine, overseas expenditures occurred in several other uranium projects mainly in Kazakhstan, Namibia and Niger. State-owned China National Nuclear Corporation (CNNC) purchased a 25% equity stake of the Langer Heinrich uranium mine from Paladin Energy, acquiring a total of 934 tU under the shareholders’ equity in 2017 prior to the mine being placed on care and maintenance. On 26 November 2018, CNNC signed a share-sale agreement with Rio Tinto to buy a 68.62% equity stake of the Rössing uranium mine in Namibia. The CGN-Kazatomprom held Semizbay and Irkol mines in Kazakhstan provided 553 tU and 470 tU to CGN in 2017 and 2018, respectively. The CGN Husab project in Namibia produced 1 100 tU and 3 000 tU in 2017 and 2018, respectively.

Domestic uranium exploration and mine development expenditures in China were relatively stable from 2016 to 2019. Expenditures decreased from USD 128 million in 2016 to USD 125 million in 2017, then declined to USD 120 million in 2018. Expenditures in 2019 are however expected to increase to USD 154 million. Over 90% of these expenditures were exploration related.

In response to the challenges brought about by sustained low uranium prices and efforts to meet ecological goals announced by the central government, Chinese uranium companies reorganised in 2017 and 2018. A uranium industry focus of production dominated by ISL mining in Northern China and supplemented by underground mining in Southern China emerged, and the main exploration effort has shifted to ISL.

Industrial ISL tests are being carried out in some parts of the Erdos and Erlian sandstone-type uranium deposits in Inner Mongolia. Encouraging results have been achieved, which may result in these deposits becoming the principal uranium production centres in China.

Over the past several years, the IAEA has supported China through the Technical Co-operation programme. Some of the most recent projects include the project, "Developing Exploration Techniques for Deep Blind Deposits in Typical Hydrothermal Uranium Ore Fields", which was conducted from 2014 to 2016 and the current project, "Studying Identification Technology and Technical Economic Evaluation of Typical Sandstone-hosted Concealed Uranium Deposits", which began in 2018.

Box 1.3. **In situ bioleaching of sandstone-type uranium deposits**

Bioleaching is a generic term that describes the conversion of an insoluble metal compound into a soluble form and its mobilisation and extraction from solution using microbiological technology. It is an alternative to conventional hydrometallurgical leaching methods, and makes use of iron-oxidising bacteria to oxidise iron-sulphide minerals to produce sulphuric acid. This in turn results in the dissolution and transport in solution of metals from their mineral phases. Since the 1950s and 1960s, uranium was one of the first metals to be extracted by in situ and heap bioleaching methods. As interest in exploiting low-grade sandstone-type uranium deposits continues to grow, the application of in situ bioleaching, with its low-cost and environmentally friendly qualities, is becoming a more attractive method of solution mining (Liu et al., 2015).

There are two major groups of microorganisms that are utilised in uranium in situ bioleaching: heterophiles at neutral pH, and acidophiles at acidic pH. Heterophiles can enhance the solubility of uranium and other metals/metalloids by the formation of metal-complexing ligands, such as organic acids, but in practice little is known on commercial scales of application. Acidophiles, including iron and sulphur oxidising species, are typically involved with acid- and ferric sulphate-based processes for uranium mobilisation and extraction.

Acidic in situ bioleaching requires a sulphur nutrient source for the microorganisms to be present in the uranium-bearing host rock (ore), such as a metal sulphide mineral (e.g. pyrite, an iron-sulphide; FeS_2). A series of chemical reactions involving water, oxygen, iron, and sulphur produces sulphuric acid, and insoluble tetravalent uranium (U^{4+}) is electrochemically oxidised to hexavalent uranium (U^{6+}). Hexavalent uranium forms stable aqueous complexes, thus mobilising uranium from its host mineral phase and into solution. In less optimal subsurface environments, where temperature might be low and oxygen lacking, a two-stage process may be used to increase bioleaching kinetics: first by introduction of additional ferrous iron (Fe^{2+}), oxygen, and carbon dioxide into the ore body, thereby allowing the microbes to multiply, then second by injection of acidic ferric iron (Fe^{3+})-based lixiviants to oxidise and mobilise uranium into solution.

At the 512 uranium deposit, located in the northwest of China, one of the largest in situ leach operations in China, two-stage bioleaching field experiments have been carried out since 2008 using a variety of injection and recovery well configurations. Pilot tests revealed that uranium concentrations in the pregnant recovery solutions were 60%-170% higher compared to solutions recovered using conventional acid in situ leaching methods. It is expected that two-stage bioleaching will soon be implemented on a commercial scale at the 512 uranium deposit.

Non-domestic government exploration expenditures by Japan were not reported for this edition. The Japan-Canada Uranium Co. Ltd (JCU), which took over Japan Nuclear Cycle Development Institute's Canadian mining interests, is continuing exploration activities in Canada while Japan Oil, Gas and Metals National Corporation (JOGMEC) continues exploration activities in Australia, Canada, Namibia, Uzbekistan and elsewhere. Japanese private companies hold shares in companies developing uranium mines and with those operating mines in Australia, Canada, Kazakhstan and Niger.

In Mongolia, reported domestic exploration and development expenditures totalled USD 6.6 million and USD 7.2 million in 2016 and 2017 respectively, then declined to USD 4.9 million in 2018 and USD 1.7 million in 2019. No development expenditures were reported. Exploration drilling from 2016 to 2019 totalled 55 930 m, peaking at 23 655 m in 2017. Ten national and foreign investment companies are engaged in exploration activities in Mongolia.

In 2017 and 2018, uranium prospecting was most active in the south Mongolian sedimentary basins aimed at identifying sandstone-type uranium mineralisation amenable to extraction by ISL. Feasibility studies on eight projects have been approved by the Mongolian Professional Committee of Resources. One potential prospect for development is the Zuuvch Ovoo and Dulaan uul uranium project in Dornogobi province of southeast Mongolia. The deposit is expected be mined by acid ISL.

An IAEA Technical Co-operation project, Regional Asia Pacific, was initiated in 2016 and continued through 2019. The project, "Conducting the Comprehensive Management and Recovery of Radioactive and Associated Mineral Resources", is aimed at supporting member states in the Asia-Pacific region in developing sustainable mining of deposits with associated radioactive minerals. Uranium production is one potential aspect of economic development in the region where balancing consumption and production are of interest. Though the region (especially China) is expected to grow significantly in terms of nuclear power production, a large part of the current and future uranium requirements is expected to be met by imports. Though potential for increasing domestic uranium production exists, several factors preventing this from materialising will be addressed to strengthen capacities through the establishment of centres of excellence in member states.

Pacific

In Australia, domestic exploration expenditures by industry continued to decline from a recent high of USD 98.7 million in 2012. Since 2015, expenditures have declined from USD 33.7 million to USD 17.3 million in 2016, USD 15.1 million in 2017 and USD 9.0 million in 2018 (preliminary data were not available for 2019). During this period, uranium exploration was most active around known resources in Western Australia and South Australia, as low uranium prices limited greenfield activity.

In Western Australia, Vimy Resources was granted government approvals for development work on the Mulga Rock Uranium project in March 2017 and in 2018 released a definitive feasibility study on the project. Environmental approvals for the Yeelirrie project was received from the Western Australian government in 2017 and the Commonwealth Government in 2019. However, no work was planned at Yeelerie in 2019 and future development awaits improved market conditions. In 2018, Cameco acquired the 30% interest in the Kintyre project that was held by Mitsubishi Development Pty Ltd. Environmental approvals for the Kintyre project have been received from both levels of government, but no further work on the project is planned until market conditions improve. Toro Energy Ltd.'s expanded Wiluna project, encompassing the Lake Maitland and Millipede resources and construction of a processing facility at Centipede, received environmental approvals from both levels of government in 2017. Extensions to these approvals are now being sought as development awaits a projected global shortfall of uranium.

Although the Western Australian state election in March 2017 resulted in restatement of the policy banning new uranium mines, the newly elected Premier and Mines Minister confirmed that projects with "all necessary approvals in place for operation" would be permitted to proceed, pending further advice from the state Department of Mines and Petroleum.

In South Australia, plans for a large expansion at Olympic Dam have been scaled back, although BHP Billiton (BHP) plans to steadily increase production capacity and new underground operations in the "Southern Mining Area" began in 2018, under existing approvals. Although the sandstone-hosted Honeymoon deposit is currently in care and maintenance, it remains approved for mining and exploration as metallurgical test work continues. Project operator Boss Resources completed a programme of field leach trials in 2018 that successfully demonstrated the application of the ion-exchange process.

Through 2017 and 2018, Australian-listed mineral companies were involved in exploration activities for uranium in countries such as Namibia and Tanzania. However, non-domestic expenditures were not reported for this edition and the past several editions.

Uranium production

In 2018, 16 countries produced uranium, with the global total amounting to 53 516 tU. Kazakhstan's continuous growth in production came to an end in 2017 as production cuts were instituted to reduce supply to an oversupplied market. Kazakhstan, nonetheless, remained by far the world's largest producer, even as production was eased back to 23 391 tU in 2017 and 21 705 tU in 2018. Kazakhstan's production alone in 2018 totalled more than the combined production in that year from Canada, Australia and Namibia, respectively the second, third and fourth largest producers of uranium. Of the 16 producing countries, Hungary alone reported its entire uranium production as a result of mine remediation activities (neither Germany nor France produced uranium by this means in 2018, but produced a combined total of 32 tU in 2019 from mine remediation activities). Table 1.17 summarises major changes in uranium production and Table 1.18 shows production in all producing countries from 2015 to 2019. Figure 1.5 shows 2018 production shares, and Figure 1.6 illustrates the evolution of production shares from 2010 to 2019.

Table 1.17. **Production in selected countries and reasons for major changes**

(tonnes U)

Country	Production 2016	Production 2018	Difference	Reason for changes in production
Australia	6 313	6 526	213	Declining production from stockpiled ore at Ranger overcome by increased ISL production at Four Mile. Ranger to stop production in January 2021.
Canada	14 039	6 996	-7 043	Suspension of production at Rabbit Lake, McArthur River and Key Lake due to depressed uranium market prices.
China	1 650	1 620	-30	Suspension of production and closure of higher cost underground mines not yet overcome by increased ISL production.
Kazakhstan	24 689	21 705	-2 984	Production reduced due to depressed uranium market prices.
Namibia	3 593	5 520	1 927	Husab mine commissioning and first production combined with improved grades at Rössing boost production.
Niger	3 478	2 878	-600	Production at Somaïr open pit reduced in 2017 due to continued weak market conditions; Cominak to stop production on 31 March 2021 due to ore depletion and high operating costs.
South Africa	490	346	-144	Sibanye Gold closed its gold/uranium Cook 4 operation (Ezulwini) end of 2016. Early in 2018, Harmony Gold acquired Moab Khotsong gold-uranium mine from AngloGold Ashanti.
United States	979	277	-702	Uranium output decline as mine production is suspended or reduced at a number of facilities due to an extended period of low market prices.

Table 1.18. **Historical uranium production**
(tonnes U)

Country	Pre-2016	2016	2017	2018	Total to 2019	2019
Argentina	2 582	0	0	0	2 582	0
Australia	200 307	6 313	5 882	6 526	219 028	6 613
Belgium	686	0	0	0	686	0
Brazil	4 216	0	0	0	4 216	0
Bulgaria	16 364	0	0	0	16 364	0
Canada[a,d]	497 760	14 039	13 130	6 996	531 925	6 944
China	41 449	1 650	1 580	1 620	46 299	1 600
Congo, Dem. Rep. of	25 600	0	0	0	25 600*	0
Czech Republic[b]	111 917	138	64	34	112 153	39
Finland	30	0	0	0	30	0
France	80 973	3[c]	2[c]	0	80 978	2[c]
Gabon	25 403	0	0	0	25 403	0
Germany[e]	219 686	45[c]	34[c]	0	219 765	30[c]
Hungary	21 071	4[c]	3[c]	5[c]	21 083	3[c]
India*	11 783	385*	400*	400*	12 968	400*
Iran, Islamic Rep of	76	8	15	20	119	21
Japan	84	0	0	0	84	0
Kazakhstan	268 513	24 689	23 391	21 705	338 298	22 808
Madagascar*	785	0	0	0	785	0
Malawi	4 217	0	0	0	4 217	0
Mexico	49	0	0	0	49	0
Mongolia	535	0	0	0	535	0
Namibia	123 410	3 593	4 221	5 520	136 744	5 103
Niger	136 299	3 478	3 484	2 878	146 139	3 053
Pakistan*	1 484	45*	45*	45*	1 619	45*
Poland	650	0	0	0	650	0
Portugal	3 720	0	0	0	3 720	0
Romania	18 974	0	0	0	18 974	0
Russia	161 899	3 005	2 917	2 904	170 725	2 900
Slovak Republic	211	0	0	0	211	0
Slovenia	382	0	0	0	382	0
South Africa	159 903	490*	308*	346*	161 047	346
Spain**	5 028	0	0	0	5 028	0
Sweden**	200	0	0	0	200	0
Ukraine	130 628	808	707	790	132 933	750
United States	375 225	979	442	277	376 923	67
USSR[f]	102 886	0	0	0	102 886	0
Uzbekistan	130 291	3 325	3 400	3 450	140 466	3 500
Zambia	86	0	0	0	86	0
Total	2 885 362	62 997	60 025	53 516	3 061 900	54 224
Total OECD-only	1 517 979	21 521	19 557	13 838	1 572 895	13 698

(*) NEA/IAEA estimate. (**) For pre-2010, other sources cite 6 156 tU for Spain, 91 tU for Sweden. (a) Includes production from refinery wastes (14 tU in 2015, 17 tU in 2016 and 21 tU in 2017) and 61 tU recovered from cleaning out Key Lake mill circuits in 2018. (b) Includes 102 241 tU produced in the former Czechoslovakia and CSFR from 1946 through the end of 1992. (c) Production from mine rehabilitation efforts only. (d) Pre-2016 total updated after review of historic records. (e) Production includes 213 380 tU produced in the former GDR from 1946 through the end of 1989. (f) Includes production in former Soviet Socialist Republics of Estonia, Kyrgyzstan, Tajikistan, Uzbekistan.

Figure 1.5. **Uranium production in 2018**

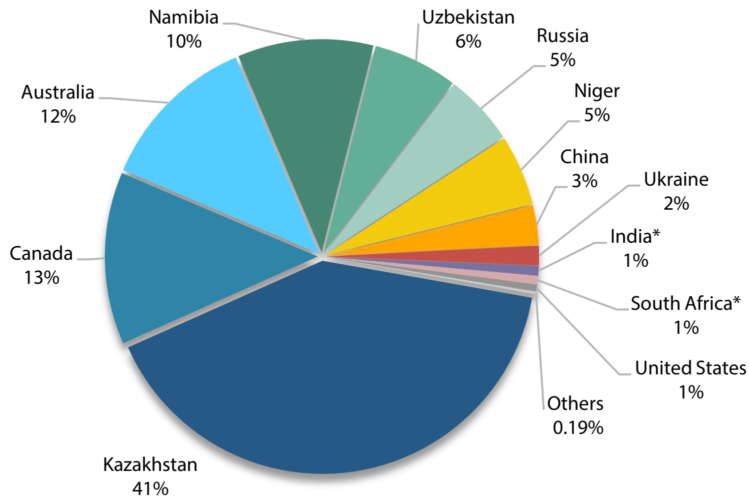
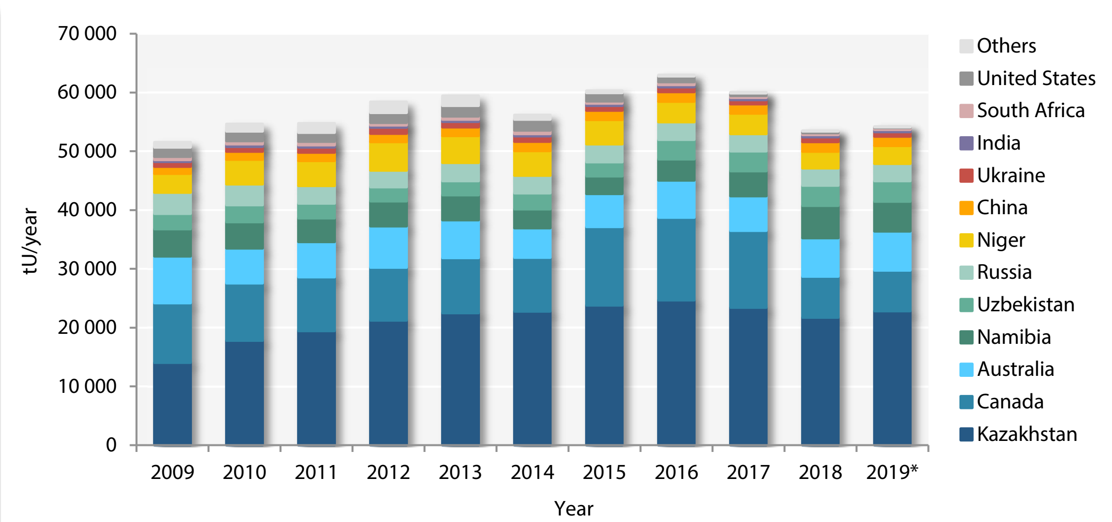


Figure 1.6. **Recent world uranium production (tU/year)**



"Others" includes the remaining producers (see Table 1.18 and previous Red Book editions).

* NEA/IAEA estimate.

Niger slipped to 7th place as 2018 production declined by 606 tU to 2 878 tU as production cuts continued at Somair, whereas Namibia solidified its 4th place ranking as Husab ramped up production after start-up in 2016. Official updated production figures for Uzbekistan moved it up to rank as the 5th largest producer in 2018 at 3 450 tU. The top five producing countries (Kazakhstan, Canada, Australia, Namibia and Uzbekistan) dominated uranium production, accounting for 83% of world production in 2018. Ten countries: Kazakhstan (40.6%), Canada (13.1%), Australia (12.2%), Namibia (10.3%), Uzbekistan (6.4%), Russia (5.4%), Niger (5.4%), China (3.0%), Ukraine (1.5%) and India (0.7%) accounted for over 98% of world production in 2018 (see Figure 1.5).

Overall, world uranium production decreased 4.7% from 62 997 tU in 2016 to 60 025 tU in 2017, then by a further 10.8% to 53 516 tU in 2018 as producers instituted production cuts to reduce supply in a saturated market. These planned reductions were greatest in Canada, Kazakhstan and Niger. Production also declined dramatically in the United States as mine production was suspended at several facilities due to an unfavourable market (Table 1.18). Within OECD countries, production decreased from 21 521 tU in 2016 to 19 557 tU in 2017 and 13 838 tU in 2018, primarily due to production cuts in Canada.

World production however increased marginally to 54 224 tU in 2019, mainly through increases in Kazakhstan. In Canada, mining at Rabbit Lake was suspended in mid-2016, then mining at the McArthur River and milling at Key Lake was suspended at the end of January 2018, all due to low uranium prices. In 2017, Kazatomprom announced that it planned to reduce production by a total of 20% through 2021 to better align production by the world's largest producer with demand.

On 23 March 2020, Cameco announced that it had suspended production at the Cigar Lake mine and Orano announced that it had suspended work at the McClean Lake mill in response to the COVID-19 global pandemic. Activities subsequently restarted in September 2020 at Cigar Lake mine and McClean Lake mill.

On 7 April 2020, JSC National Atomic Company Kazatomprom announced that it was reducing operational activities at all uranium mines for a period of three months due to the COVID-19 pandemic. On 3 August 2020, Kazatomprom announced that it could safely begin to gradually bring staff back to the mine sites during the first half of August. On 19 August 2020, Kazatomprom announced that it intended to extend its plan to flex down production by 20% through 2022.

The pandemic has also caused restrictions at other mining operations, such as in Namibia where activity at the Rössing mine was temporarily reduced to a minimum, and in Australia where a temporary suspension of travel by in-bound workers to the Ranger mine was implemented. At the time of writing, it is not clear how these temporary COVID-19 induced restrictions on mining and milling will impact uranium production in 2020 and beyond. Clearly, 2020 production targets will not be achieved and the disruption caused by the pandemic could ripple through 2021, constricting global supply of newly mined uranium.

Present status of uranium production

North American production of 7 273 tU amounted to 14% of world production in 2018, as production dropped by 7 745 tU (52%) since 2016. This decrease is due to production cuts in Canada and reduced competitiveness of US production in an oversupplied, low-price market.

Canada lost its standing as the world's largest producer in 2009 due to production increases in Kazakhstan, but it remains the dominant North American producer and the world's second-largest producer. Production at the McArthur River mine, the world's largest high-grade uranium mine with 153 700 tU of recoverable resources at an average grade of 5.5% U, totalled 6 183 tU in 2017. Mining activities were however suspended at McArthur River in early 2018 due to poor market conditions.

The Key Lake mill produced a total of 6 231 tU in 2017 through a combination of high-grade McArthur River ore slurry (6 183 tU) and stockpiled, mineralised Key Lake special waste rock (27 tU) that is used to blend down high-grade McArthur River ore to produce a mill feed grade of about 5% U. In addition, uranium refinery wastes from Ontario were processed at Key Lake, producing 21 tU in 2017. In 2018, 61 tU were recovered by cleaning out the mill circuits prior to the suspension of Key Lake operations.

The Rabbit Lake production centre, wholly owned and operated by Cameco, produced 1 621 tU and 428 tU in 2015 and 2016, respectively. Production at Rabbit Lake was suspended in mid-2016 due to low uranium prices and the facility was placed in care and maintenance. Exploratory drilling at the Eagle Point mine during the last several years has increased identified resources to 27 000 tU at an average grade of 0.63% U.

Cigar Lake, with recoverable resources of 115 100 tU at an average grade of 11% U, is the world's second-largest high-grade uranium deposit. The McClean Lake mill produced 6 925 tU and 6 935 tU from Cigar Lake ore in 2017 and 2018, respectively.

Box 1.4. **Innovative uranium mining technologies: Jet boring at the Cigar Lake ore deposit**

Jet boring is a relatively new technology that was developed over several years, beginning in the early 90s. It borrows from a variety of technologies including high-pressure jetting used in the oil sands industry, combined with other proven drilling methods employed in the mining and oil industries.

In the early 90s Cameco, supported by its joint venture partners, set out to develop a new mining method that could safely and successfully extract uranium at its high-grade Cigar Lake deposit in the Athabasca Basin, Canada. Due to the presence of water and ground instability issues in the ore body, mining by conventional methods was not possible. In 1992, researchers conducted underground tests in the ore body comparing various mining methods, and one year later, concluded that jet boring had the most potential. Jet boring uses water under high pressure to carve out cavities in the ore body. The resulting ore slurry is then collected through a network of pipes, run through underground grinding and thickening circuits, and then pumped to the surface.

At the Cigar Lake deposit a major challenge for mining was the water surrounding the deposit, and this resulted in significant delays in the start-up of mining due to water inflows in 2006 and 2008. To overcome this, they began freezing the ore body, which not only stabilises ground conditions and prevents water inflow, but also provides additional protection to workers from radon gas emissions. The freezing technique is also used at the McArthur River mine to provide ground control for development, while using the raisebore method to mine the orebody.

By 2000, Cigar Lake's first prototype jet boring system (JBS) was in place. However, the mining conditions were so challenging that many more years of technological development were required before mining could be done. Mining at Cigar Lake finally began in March 2014, but was suspended only a few months later to allow for the ore body to freeze more thoroughly. Commercial production at Cigar Lake using the customised JBS officially began on 1 May 2015.

For additional information and a video showing the process go to this website www.cameco.com/businesses/mining-methods#jet-boring.

In the United States, production totalled 277 tU in 2018, 72% less than in 2016 and 37% less than in 2017. Production in 2018 was from the White Mesa mill in Utah and a total of six ISL facilities located in Nebraska and Wyoming. The dramatic decline in uranium production from 2016 to 2018 is due to low market prices. Cameco announced in 2016 that production in the United States would be curtailed and that all wellfield development at its ISL operations would be deferred. US production in 2019 slumped even more dramatically to just 67 tU as the remaining operations struggled with persistent low prices.

At the end of 2018, one uranium mill (White Mesa in Utah) was operating with a capacity of 1 814 tonnes of ore per day. Two mills (Shootaring Canyon in Utah and Sweetwater in Wyoming) were on standby status with a combined capacity of 3 402 tonnes of ore per day. Both have been on standby status since the early 1980s and will require rehabilitation. After acquiring the Shootaring Canyon mill in 2015, Anfield Resources Inc. submitted a plan in 2016 to the Utah Division of Waste Management and Radiation Control to renew the mill's operating licence. The Piñon Ridge mill in Colorado is planned and fully licensed, but construction has not begun. The NRC received letters of intent for mill licence applications from Uranium Resources Inc. (Juan Tafoya mine area, New Mexico) and General Atomics (Mt. Taylor Mine area, New Mexico); however, licensing actions for both have been delayed by the applicant.

Six ISL mines were operating in 2018 with a combined nominal capacity of 4 683 tU per year (Crow Butte, Lost Creek, Nichols Ranch, Ross CPP, Smith Ranch-Highland and Willow Creek). Nevertheless, in the second quarter of 2020, five of the six mines were placed on standby status (Crow Butte, Nichols Ranch, Ross CPP, Smith Ranch-Highland and Willow Creek; US EIA, 2020). Only Lost Creek operation (769 tU) appears as active.

The ten-year contract between Centrus Energy Corporation and Techsnabexport (TENEX) to supply commercial-origin, Russian low-enriched uranium replaces some of the material previously sourced through the Megatons-to-Megawatts programme that came to an end in 2013. Deliveries under this contract began in 2013 and, in 2015, the contract term was extended through 2026. According to Centrus, the contract was modified to reflect the reduction in global enrichment demand since 2011.

On 16 January 2018, two domestic uranium mining and milling companies petitioned the US Department of Commerce to investigate whether uranium imports posed a threat to national security. On 12 July 2019, the US President declined to impose quotas or other trade measures on uranium imports; instead establishing a Nuclear Fuel Working Group to examine the current state of domestic nuclear fuel production and develop options to reinvigorate the entire nuclear fuel supply chain.

On 23 April 2020, the Nuclear Fuel Working Group released a report presenting a comprehensive strategy that outlines potential actions to, among other things, revive capabilities of the uranium mining, milling, and conversion industries. The report recommended taking immediate and bold action to strengthen the uranium mining and conversion industries and to restore the viability of the entire front-end of the nuclear fuel cycle. An initial step to this end is the inclusion of a budget request in fiscal year 2021 for USD 150 million to initiate a possible ten-year programme to stock a domestic uranium reserve, beginning with the purchase of uranium from US mines and of US conversion services.

There has been no uranium production in South America since 2015. Planning continues in Argentina to restart production at the Sierra Pintada mine of the San Rafael complex and to develop a new production centre near the Cerro Solo deposit, but regulatory and environmental issues remain to be addressed. Before restarting uranium production at San Rafael, it will be necessary to obtain both provincial approval and agreement to amend the provincial law that prevents the use of sulphuric acid and other chemicals that may be used in the operation. Before developing a new production centre at the Cerro Solo deposit in Chubut province, mining projects need to wait for the Chubut provincial territory zoning provisions since a provincial law that prevents open-pit mining remains in effect. The introduction of a regulatory framework for mining in the province, as well as jurisdiction and technical considerations, are also pending.

Production in Brazil amounted to only 55 tU in 2014 and 44 tU in 2015, but no production has been reported since as the open-pit portion of the Cachoeira deposit (Lagoa Real, Caetité) was entirely mined out in 2014. The licensing process to mine the remainder of the deposit by the underground mining method is under way and production is expected to start in 2026.

The expansion of the Lagoa Real, Caetité unit to 670 tU/year is also progressing but completion has been delayed to around 2026. The expansion involves replacement of the heap leaching process by conventional agitated leaching. The overall investment in this expansion is estimated to amount to USD 90 million.

Since 2014, Industrias Núcleares do Brasil S.A. (INB) has been working on the development of the Engenho deposit with the first ore extraction beginning in 2019. Initially, Engenho was planned as an additional ore source for increased production at the Caetité plant, but it is currently the only source of ore for the mill due to the delay in commissioning the Cachoeira underground mine. Development of the phosphate/uranium project of Santa Quitéria, under the terms of an INB-Brazilian fertiliser producer partnership agreement, remains in progress. In 2012, the project operators applied for a construction licence that was denied in 2018. INB and its partner are now working on a new model for the project and the operation is scheduled to begin in 2026.

Primary uranium production in 2018 within the European Union (EU) was from only one country, the Czech Republic, which produced 29 tU by ISL. Hungary contributed 5 tU from mine remediation activities only (an additional 5 tU of production resulted from similar activities in the Czech Republic). France and Germany have been producing minor amounts as a by-product of mine remediation activities, but neither reported production in this fashion in 2018, although preliminary figures show cumulative production totalling 33 tU in this way in 2019.

Total reported EU production in 2018 was 39 tU, a decline of 80% from the 190 tU reported for 2016. This is primarily the result of the decision to end underground mining at Rozná in the Czech Republic in 2017, in addition to reduced quantities recovered from mine remediation in France and Germany.

Output from non-EU countries in Europe in 2018 amounted to 3 694 tU, a 3% decrease from 2016. Production decreased in Russia by 101 tU and in Ukraine by 18 tU over this two-year period.

In 2018, uranium production in Russia amounted to 2 904 tU, of which 1 456 tU were produced by conventional underground mining at Priargunsky (119 tU of this total by heap leaching) and 1 448 tU by ISL. Since 2016, uranium production by underground mining has decreased by 22%, whereas ISL production has increased by 28%. Russia is working to develop new deposits for mining at Priargunsky to expand production capacity at this longstanding production centre and to increase ISL production by the development of new deposits (Dobrovolnoye, Vershinnoye and Istochnoye).

In Ukraine, 2018 production amounted to 790 tU, all of which was produced at three underground mines located in the central Ukrainian ore province (Ingulska, Smolinska and Novokostyantynivska). Long-term government plans include mining the Safonivske and Sadove deposits by acid ISL (ISL operations were conducted from 1966 to 1983 at the Devladovske and Bratske deposits that are now being monitored after decommissioning), as well as development of the Severinskie and Podgaytsevske deposits for underground mining.

African production increased by 16%, from 7 561 tU in 2016 to 8 744 tU in 2018. The Husab mine in Namibia, which began ramping up to full production capacity during this period, offset the impact of the closures of Kayelekera mine in Malawi and the Langer Heinrich mine in Namibia in 2014 and 2018 respectively, as well as planned production reductions in Niger and declining production in South Africa. These mine closures and production reductions are a result of a prolonged period of low uranium market prices.

Possible production in Botswana, Tanzania and Zambia, as well as several projects under investigation in Niger and South Africa, could contribute to future regional production increases, should market conditions and, to a lesser extent, security conditions improve. However, development of these projects has generally not proceeded with the current market conditions and are best viewed as possible additions in the longer term, should market prices increase significantly.

Production in the Middle East, Central and South Asia region declined by 10% from 28 577 tU in 2016 to 25 620 tU in 2018. This was driven principally by the world's largest producer Kazakhstan, where production was decreased from 24 689 tU in 2016 to 23 391 tU in 2017 and 21 705 tU in 2018 as planned production cuts were put in effect. Despite this decline, Kazakhstan accounted for 41% of global production in 2018. Uranium was mined at the Kanzhugan, Moinkum, Akdala, Uvanas, Mynkuduk, Inkai, Budenovskoye, North and South Karamurun, Irkol, Zarechnoye, Semizbay, Northern Kharasan deposits. All were mined by acid ISL. With the world's largest low-cost (<USD 40/kgU) resource base, 95% of which is associated with existing and committed production centres, and 25 000 tU/yr production capacity, Kazakhstan can be expected to remain the world's largest producer for the foreseeable future.

Box 1.5. **Mini-reagent technology in ISL mining of sandstone-type uranium deposits**

For in situ leaching (ISL) mining, selection of an effective leaching lixiviate is a key consideration. The most conventional leaching lixiviates are acid and alkaline solutions, with the selection of one or the other dependent on the carbonate content of the source rocks hosting uranium mineralisation (for alkaline lixiviates, this is usually > 2% CO_2). Various oxidants, such as peroxide, oxygen, and air, are used to increase the efficiency of leaching.

In Uzbekistan and Kazakhstan, where uranium host sediments have a carbonate content of 1.8% to 3%, conventional acid ISL methods are economically inefficient because of excessive acid consumption and the active "plugging process" (chemical and gas fluid flow-path plugging of the natural pores within the host sediments by mechanical particles and newly formed gypsum). This results in decreased uranium recovery due to low lixiviate flow rates, as well as associated economic inefficiencies due to elevated levels of acid consumption, significant decommissioning of wells, and a large amount of maintenance and re-building activities.

Mini-reagent mining technology, however, may help to alleviate this problem. In mini-reagent technology, carbonates are dissolved and transformed into bicarbonate HCO_3, which complexes with and transports U_6 (Geoinformcenter Ltd., 2002). During the process, sulphuric acid and oxidants react with carbonates raising the level of dissolved HCO_3 in the recovery solutions to 300-400 mg/l, thus forming an excess of the complex-forming agent. The agent oxidises and dissolves uranium-bearing minerals at the initial acidification stage, resulting in a "soft" mode of acid leaching, and producing a "bicarbonate effect". The resulting recovery solutions have a pH of about 4 to 5.

India and Pakistan do not report production figures, but their combined total is estimated to be about 445 tU in 2018, up slightly from an estimated 430 tU in 2016 as India added additional production capacity with the opening of the Tummalapalle mill in 2017. Official figures received from Uzbekistan show annual production of 3 300 tU to 3 500 tU between 2016 and 2019, replacing NEA/IAEA estimates that production remained steady at 2 400 tU over this period. These updated figures moved Uzbekistan up to the 5th largest producer in 2018. Iran continues to produce small amounts of uranium despite the cessation of mining the Gachin deposit and the opening of the Ardakan processing facility in 2017, with ore now supplied from the Saghand deposit. Production increased from 8 tU in 2016 to 15 tU in 2017 and 20 tU in 2018. The stated nominal production capacity of Ardakan is 50 tU/yr. Jordan continues to develop resources with the aim of producing uranium, and in addition to work on surficial deposits in central Jordan, interest in extracting uranium from phosphates continues with a goal of operating a pilot scale extraction plant in 2020.

China, the only producing country in East Asia, reported variable production from 1 650 tU in 2016 to 1 580 tU in 2017 and 1 620 tU in 2018 as the country transitions from higher cost underground mines, mainly in the south, to lower cost ISL production centres in the north.

In response to the challenges brought about by sustained low uranium prices and efforts to meet ecological goals set by the Chinese government, state-owned Chinese uranium companies reorganised in 2017 and 2018. Of the three hard-rock, underground uranium mines with depleted uranium resources or with high production costs, one (Qinglong) was closed for decommissioning and operations at two others (Chingyi, Lantian) were suspended. With higher uranium prices, the suspended uranium production centres are expected to be brought back into operation again. A uranium industry focus of production dominated by ISL mining in Northern China, supplemented by underground mining in Southern China, has emerged and the principal exploration effort has shifted to ISL.

Industrial ISL tests are being carried out in some parts of the Erdos and Erlian sandstone-type uranium deposits in Inner Mongolia. Encouraging results have been achieved and these deposits may be developed into the principal uranium production centres in China. ISL production capacity of the Yining centre in the Xinjiang Autonomous Region (north-west China), and the Tongliao centre in Inner Mongolia (north-east China) were expanded.

Australia is the only producing country in the Pacific region. Production decreased from 6 313 tU in 2016 to 5 882 tU in 2017, then increased to 6 526 tU in 2018. These changes can be attributed to the Beverley North ISL mine being placed on care and maintenance in 2018, increased production from the Four Mile ISL facility and the winding down of mining and processing activities at the Ranger mine as it prepares for closure in early 2021.

Ownership

Table 1.19 shows the ownership of uranium production in 2018 in the 16 producing countries and three others (Brazil, France and Germany) that have produced recently. Domestic mining companies controlled about 56% of 2018 production compared to 55% reported for 2016. Domestic government participation increased from 37% in 2016 to 42% in 2018, owing to increased shares in Kazakhstan and Namibia, whereas the share of domestic private companies declined from 18% in 2016 to 14% in 2018, owing to an increased share in Australia overcoming a decline in Canada. Non-domestic mining companies controlled 44% of production in 2018 (no change from 2016), principally the result of increasing non-domestic government ownership shares in Namibia and Niger. It should be noted that for this reporting period, the percentage of control (i.e. government vs. private) in this category, for both Australia and the United States, is not known as this data was not reported.

Table 1.19. **Ownership of uranium production**

(based on 2018 production output)

Country	Domestic mining companies				Non-domestic mining companies				Total
	Government-owned		Privately-owned		Government-owned		Privately-owned		
	tU	%	tU	%	tU	%	tU	%	tU
Australia	0	0	3 707	56.8	NC	NC	2 819	43.2	6 526
Brazil	0	0	0	0	0	0	0	0	0
Canada	0	0	3 512	50	2 591	37	893	13	6 996
China	1 620	100	0	0	0	0	0	0	1 620
Czech Republic	34	100	0	0	0	0	0	0	34
France	0	100	0	0	0	0	0	0	0
Germany	0	100	0	0	0	0	0	0	0
Hungary	5	100	0	0	0	0	0	0	5
India*	400	100	0	0	0	0	0	0	400
Iran, Islamic Rep of	20	100	0	0	0	0	0	0	20
Kazakhstan	11 842	55	0	0	6 171	28	3 692	17	21 705
Namibia*	374	7	0	0	3 357	61	1 789	32	5 520
Niger*	955	33.2	0	0	1 485	51.6	438	15.2	2 878
Pakistan*	45	100	0	0	0	0	0	0	45
Russia	2 904	100	0	0	0	0	0	0	2 904
South Africa*	0	0	346	100	0	0	0	0	346
Ukraine	790	100	0	0	0	0	0	0	790
United States	0	0	NC	NC	0	0	NC	NC	277
Uzbekistan*	3 450	100	0	0	0	0	0	0	3 450
Total	22 439	42	7 565	14	13 604	25	9 631	18	53 516

(*) Secretariat estimate.

NC – Data not available for reasons of confidentiality.

Employment

Although the data are incomplete, Table 1.20 shows that employment levels at existing uranium production centres declined by 24% from 2016 to 2018, owing to generally declining employment reported by most countries, most dramatically in Canada as a result of production cuts and in China as underground production centres were closed, as well as non-reporting from Namibia and Uzbekistan, offset somewhat by increased employment in Russia. Preliminary employment figures for 2019 are expected to decline by a further 13%, although 2019 data were not reported for Niger and Uzbekistan.

Table 1.20. **Employment in existing production centres**

(of listed countries, in person-years)

Country	2012	2013	2014	2015	2016	2017	2018	2019 (preliminary)
Argentina[(a)]	78	78	85	82	65	58	50	45
Australia[(b)]	5 574	5 620	5 805	4 481	3 630	4 488	4 559	3 198
Brazil	620	620	620	590	680	680	500	550
Canada[(c)]	2 109	2 148	2 874	2 676	2 246	1 418	652	650
China[(d)]	7 560	7 650	7 660	7 670	6 750	5 950	2 350	2 290
Czech Republic	2 126	2 110	2 072	2 040	1 955	1 672	1 557	1 556
Germany[(a)]	1 372	1 204	1 147	1 062	1 043	1 031	1 010	982
India	4 962	4 962	4 689	4 725	4 741	4 722	4 633	4 569
Iran, Islamic Rep of	350	500	500	350	340	290	280	280
Kazakhstan	9 760	7 682	7 728	8 042	8 222	8 120	7 822	7 802
Namibia*[(e)]	2 786	NA	5 101	8 107	4 331	4 881	NA	NA
Niger*	2 915	NA	NA	NA	3 935	3 843	3 011	NA
Russia	9 526	10 164	8 790	6 857	6 077	5 696	6 263	6 228
South Africa	237	1 742	4 141	3 815	NA	NA	NA	NA
Spain[(f)]	23	23	23	21	76	78	NA	NA
Ukraine	4 350	4 480	4 500	4 555	4 426	4 450	4 275	4 104
United States	1 017	957	626	509	462	324	234	NA
Uzbekistan	NA	NA	NA	NA	NA	NA	NA	NA
Total	55 365	49 940	56 361	55 582	48 979	47 701	37 196	32 254

(*) Secretariat Estimate. NA = Data not available. (a) Employment related to decommissioning and mine rehabilitation only. (b) Olympic Dam does not differentiate between copper, uranium, silver and gold production. Employment has been estimated for uranium-related activities. (c) Employment at mine sites only. (d) The decline in recent years is due to a shift from UG to less labour intensive ISL mining. (e) Peak in 2015 due to Husab mine construction. (f) Employment related to decommissioning and rehabilitation only from 2012 to 2015, but includes employment related to mine development activities from 2016 to 2019.

However, if future production expansions and restarts of mines currently on care in maintenance in countries such as Australia, Canada, China, India, Kazakhstan, Namibia, Niger, Malawi and Russia are successfully completed, employment should increase in the longer term. Because ISL production centres in China are highly automated, employment in China's uranium production sector will likely not recover to pre-2018 levels as ISL, now the favoured domestic method of production, requires fewer employees than underground mines.

Table 1.21 shows employment directly related to uranium production (excluding head office, research and development, pre-development activities, etc.) in selected countries. Figures show generally declining or relatively static employment as global production decreased. Declining employment was most pronounced in Canada, as temporary production cuts were implemented, and in China, as production focus shifts from underground to ISL mining.

Table 1.21. **Employment directly related to uranium production and productivity**

Country	2016		2017		2018	
	Production employment (person-years)	Production (tU)	Production employment (person-years)	Production (tU)	Production employment (person-years)	Production (tU)
Australia[(a)]	2 499	6 313	3 135	5 882	3 163	6 526
Brazil	310	0	310	0	310	0
Canada[(b)]	1 616	14 039	1 029	13 130	529	6 996
China	5 880	1 650	5 020	1 580	1 550	1 620
Czech Republic	985	138	819	64	786	34
Iran, Islamic Rep of	135	8	95	15	95	20
Kazakhstan	7 394	24 689	7 298	23 391	7 021	21 705
Namibia*	4 331	3 593	2 858	4 221	2 585	5 520
Niger*	1 800	3 478	1 745	3 484	1 478	2 878
Russia	4 956	3 005	4 646	2 917	4 601	2 904
South Africa	NA	490*	NA	308*	NA	346*
Ukraine	1 585	808	1 550	707	1 490	790
United States	424	979	274	442	207	277
Uzbekistan	7 183	3 325	7 266	3 400	7 340	3 450

(*) Secretariat estimate. (a) Olympic Dam does not differentiate between copper, uranium, silver and gold production. Employment has been estimated for uranium-related activities. (b) Employment at mine sites only.

Production methods

Historically, uranium has been produced mainly using open-pit and underground mining techniques, then processed by conventional uranium milling. Other mining methods include ISL (sometimes referred to as ISR); co-product or by-product recovery from copper, gold and phosphate operations; heap leaching and in-place leaching (also called stope or block leaching). Stope/block leaching involves the extraction of uranium from broken ore without removing it from an underground mine, whereas heap leaching involves the use of a leaching facility on the surface after the ore has been mined. Small amounts of uranium are also recovered from mine water treatment and environmental restoration activities.

Over the past two decades, ISL mining, which uses either acid or alkaline solutions to extract the uranium directly from the deposit, has become increasingly important. The uranium dissolving solutions are injected into and recovered from the ore-bearing zone using a system of wells. ISL technology is currently being used to extract uranium from sandstone deposits only and in recent years has become the dominant method of uranium production.

The distribution of production by type of mining or "material sources" for 2015 through 2019 is shown in Table 1.22. The category "other methods" includes recovery of uranium through treatment of water recovered during reclamation and decommissioning activities and more recently production from refinery wastes in Canada was included.

ISL technology continues to dominate uranium production, largely because of the rapid growth of this low-cost method of production in Kazakhstan as well as in Australia, China, Russia and Uzbekistan. Note that not all countries report production by method, and for this reporting period, the United States, where most production is by ISL, the information is not available. World uranium production by ISL amounted to 50.5% of total global production in 2016, increasing to an expected 57.4% in 2019. Increasing shares of open-pit mine production over this reporting period are mainly driven by increases in Namibia (principally Husab), whereas the decline in the underground mining share, beginning in 2018, is mainly driven by production cuts in Canada.

Table 1.22. **World production methods**

(by production method, in percent)

Production method	2015	2016	2017	2018	2019 (preliminary)
Open-pit mining	12.6	12.7	14.2	17.1	16.1
Underground mining	32.2	30.2	29.2	20.7	20.0
ISL	48.7	50.5	51.6	55.2	57.4
In-place leaching	-	-	-	-	-
Co-product/by-product	6.0	6.0	4.5	6.6	6.2
Heap leaching	0.4	0.4	0.3	0.2	0.2
Other[(a)]	0.1	0.1	0.1	0.1	0.1
Total	100.0	100.0	100.0	100.0	100.0

(a) Includes production from refinery wastes in Canada; 14 tU in 2015, 17 tU in 2016, 21 tU in 2017 and 61 tU recovered from cleaning Key Lake mill circuits in 2018.

Box 1.6. **Modelling and simulation in development and management of ISL mining operations**

The basic feature of the in situ leach (ISL) mining method is that uranium extraction occurs remotely at depth below the ground surface through an infrastructure of injection and recovery wells without direct visual control of the leaching process. As such, modelling and simulation of the leaching process and its implementation has become an important factor when designing and managing an ISL mining operation. This involves capital and operating costs reduction through the optimisation of operating procedures, improvement of decision-making and business planning quality and timeliness, reduction of consumption of ISL reagents, mining schedule optimisation, and increasing the efficiency of uranium extraction.

ISL modelling and simulation considers relationships among a set of integrated systems: geological, geochemical (leaching and transport of uranium), technological, wellfield design and development, mine planning and operation, and economics (Noskov et al. 2017). This practice may be applied at all stages of ISL mining design and management. Various elements of ISL modelling and simulation systems were developed by major uranium producers and applied at a number of ISL operations around the world. The results obtained have confirmed the effectiveness of ISL modelling and simulation and its potential for further future development and application at ISL operations.

Projected production capabilities

To assist in developing projections of future uranium availability, member countries were asked to provide projections of *production capability* through 2040 (Table 1.23). Projections are included for *existing and committed production centres* (A-II columns) and for *existing, committed, planned and prospective production centres* (B-II columns) in the <USD 130/kgU category through 2040 for countries that are either currently producing uranium or have plans and the potential to do so in the future. Note that both the A-II and B-II scenarios are supported by currently identified local RAR and IR in the <USD 130/kgU category, except in Pakistan. Also note that actual production seldom, if ever, matches full production capability.

Several current or potential uranium-producing countries including Argentina, Botswana, China, India, Mauritania, Mongolia, Namibia, Niger, Pakistan, South Africa, Spain, Tanzania, Ukraine, the United States, and Uzbekistan did not report, or only partially reported, projected production capabilities to 2040. In some countries, the NEA/IAEA suggested updates to the submitted data, to include recent and important changes since the cut-off date for data submission. As a result, estimates of production capability for many countries were developed by the NEA/IAEA using data submitted for past Red Books, company reports and other public data.

Table 1.23. **World production capability to 2040**

(in tonnes U/year, from RAR and inferred resources recoverable at costs up to USD 130/kgU)

Country	2025		2030		2035		2040	
	A-II	B-II	A-II	B-II	A-II	B-II	A-II	B-II
Argentina*	0	0	0	0	0	400	0	500
Australia	5 800	5 965	3 623	6 009	3 540	10 566	3 500*	10 500*
Botswana*	0	0	0	1 440	0	1 440	0	1 440
Brazil	300	300	300	1 600	300*	1 600	300*	1 600
Canada[(a)]	18 700	18 700	12 330	18 850	12 330	18 850	12 330	18 850
China*	1 700	1 700	1 700	1 700	1 700	1 800	1 800	2 000
Czech Republic	50	50	50	50	30	30	20	20
Finland*	0	250	0	250	0	250	0	250
Greenland*	0	0	0	0	0	400	0	400
India*	700	960	960	1 300	1 300	1 300	1 300	1 300
Iran, Islamic Rep of*	70	80	70	80	70	80	70	80
Kazakhstan	27 000	28 000	22 000	24 000	14 000	16 000	4 500	5 000
Mauritania*	0	0	0	0	0	400	0	600
Mongolia*	0	0	0	150	0	800	0	800
Namibia*	7 200	7 200	7 200	7 200	7 200	9 800	7 200	9 800
Niger*	1 700	3 500	5 000	5 000	5 000	6 800	5 000	6 800
Pakistan*	45	45	45	45	45	45	45	45
Russia	3 960	3 960	3 960	3 960	1 800	1 800	1 500*	1 500*
South Africa*	500	800	800	1 275	1 275	1 800	1 800	1 800
Spain*	0	0	0	0	0	1 690	0	1 690
Tanzania*	0	0	0	0	0	2 000	0	3 000
Ukraine*	1 500	1 500	1 700	2 000	1 700	2 000	2 000	2 000
United States[(b)]*	4 700	5 100	1 500	2 400	350	1 200	350	1 200
Uzbekistan*	3 500	3 500	3 000	3 000	2 500	2 500	2 000	2 000
Total	77 425	81 610	64 238	80 309	53 140	83 551	43 715	73 175

A-II = Production capability of existing and committed centres supported by RAR and inferred resources recoverable at <USD 130/kgU.

B-II = Production capability of existing, committed, planned and prospective centres supported by RAR and inferred resources recoverable at <USD 130/kgU.

(*) NEA/IAEA estimate. (a) For Canada, the projections consider McArthur/Key Lake operational by 2025. (b) For the United States, the projections consider the hypothetical case with all the existing and idled mines being operational in 2025.

The reported projected production capabilities for existing and committed production centres in the A-II category for 2025 is 77 425 tU and 81 610 tU in the B-II category, an increase of over 9 400 tU in the A-II category and 250 tU in the B-II category compared to 2025 production capability estimates reported in the 2018 edition of this report. Increased production capability will not translate into increased production in the early 2020s because, as of August 2020, uranium production targets were not being met as mining was either temporarily suspended at some sites or production was reduced due to workforce and work practice adjustments in response to the COVID-19 pandemic.

Projections beyond 2025 show generally decreasing global production capabilities as A-II category estimates decline in response to depletion of resources at existing and committed production centres. It should be noted, however, that production capability projections for 2030 and beyond reported in this edition are generally reduced by hundreds to thousands tU compared to those reported in the 2018 edition of this report, particularly for B-II category estimates. Only Brazil, Canada, and Kazakhstan reported production capability in 2040; the remaining projections for this date are NEA/IAEA estimates. These 2040 estimates show a dramatic drop in production capability from 2035 due to depletion of local resources (RAR and IR).

Actual production seldom, if ever, reaches stated A-II production capability. In 2017, production was 85% of listed capability. From 2003 to 2015, production has varied between 90% and 75% of listed production capability. From 2003 to 2011, the expansion of production capability was driven by increasing and what were considered sustainable uranium prices. Production also increased, although not as rapidly as the projected production capability. Since 2011, and despite a depressed uranium market, production continued to increase, mainly due to the start-up of the Cigar Lake mine in Canada, the continued expansion of production in Kazakhstan and development of the Husab mine in Namibia. The fact that production increased during a period of depressed uranium market prices can be attributed to the long planning times and investment required to establish new mines and bring new production to the market, as well as the time it takes to respond to changing market conditions. Increasing global production in this period was essentially a response to increased demand and uranium market prices beginning over a decade ago. However, producers have recently responded to the sustained uranium market downturn by delaying mine expansions, temporarily shuttering some operations (e.g. McArthur River and Cigar Lake, Canada) and scaling back production at others (e.g. Kazakhstan). Turning stated production capability into production takes significant amounts of time, expertise and investment. Moreover, uranium mining operations and production plans can be confounded by unexpected geopolitical events, legal issues, technical challenges and so-called "Black Swan" events, the most recent of which is the COVID-19 pandemic.

Projections of production capability have decreased somewhat compared to projections made in the 2018 edition of this report, as developments are being brought in line with the general slowdown in nuclear generation capacity growth since the Fukushima Daiichi accident. Compared to the 2018 edition, category A-II and B-II projections for 2025 have increased by 14% and 0.3%, respectively, but have declined by 1% and 7% for 2030, and further declined by 6% and 8% for 2035. Compared to projections in earlier reports there are greater differences, which can be expected because of the continuous updating of plans and responses to market conditions, along with the amount of time it can take to respond to these changes.

As currently projected, production capability of existing and committed production centres (category A-II) is projected to reach about 77 400 tU in 2025, then decrease to 64 000 tU in 2030, 53 100 tU in 2035, and finally fall to 43 000 tU in 2040. For the period of 2025 to 2035, the 31% decrease compares to a 17% decrease in projected production capability reported in the 2018 edition, and a 6% decrease reported in 2016 edition, continuing the downward trend in this edition. The overall decrease of 43% in projected production capability from 2025 to 2040 reported in this edition reflects the general decline in local resources (RAR and IR) at existing and committed production centres.

Total potential production capability (including planned and prospective production centres, category B-II) is projected to reach about 81 600 tU by 2025, then decline to 80 300 tU in 2030, increase to just over 83 500 tU in 2035, before falling to nearly 73 400 tU in 2040 (with several countries not reporting). The current projections for B-II category indicate slight growth in production capability with an increase of 2.4% from 2025 to 2035, but an overall drop by 10% from 2025 to 2040. Put into context, the projected rate of growth over the 2025 to 2035 period reported in the 2018 and 2016 editions were 11.5% and 13% (respectively), compared to 2.4% for the same period reported in this edition, reflecting the impact of an extended period of low uranium market prices on longer term plans to expand production capability.

Recent committed mines and expansions

As expected during a prolonged period of low market prices and more recently, planned production cuts at existing facilities, there were limited new production plans unveiled during this reporting period (Table 1.24). Since first production from the Husab mine in Namibia in 2016, no new major developments have been completed. In Australia, BHP announced efforts at Olympic Dam to improve copper production by removing bottlenecks, through plant upgrades and modernisation of infrastructure, but it is not possible to determine at this time the increase in uranium production that this may entail. In Brazil, over burden stripping of the Engenho deposit began in anticipation of first production in 2021. It is expected that by-product recovery from the Talvivaara deposit in Finland will begin in 2022. India plans to expand the Tummalapalle mine and processing plant, increasing national production capability by some 100 tU/yr, but firm dates for completion were not provided. Kazakhstan is committed to development of the Zhalpak deposit by ISL, but even though pilot production began in 2016, dates for completion and beginning production were not provided. In Russia, construction of the surface complex and infrastructure elements of new mine No. 6 at the Priargunsky production centre began in 2018. Completion, scheduled for 2023, will increase total production capacity of this operation by 2 300 tU. Production at the Lance (Ross) mine in the United States began in

December 2015 and drummed product was first delivered in June 2016. However, production was decreased in late 2016 in response to low uranium prices and the project operator is currently amending their licence to use a low pH (acid) leachate. As of this writing, it is unclear whether the mine will resume production if proposed acid leachate use is licensed, given the continuation of unfavourable uranium market prices.

Table 1.24. **Recent committed mines and expansions**

(nominal production capacity, tU/yr in parentheses)

Country	Production centre	NA	2020	2021	2022	2023	2024
Australia	Olympic Dam[1]						
Brazil	Lagoa Real/Caetité (Engenho)		E(300)				
Finland	Terraframe (Talvivaara)[2]				C(250)		
India	Tummalapalle	E (100)*					
Kazakhstan	Ortalyk LLP (Zhalpak)						
Russia	Priargunsky (Mine 6)					C (2 300)	
United States	Lance[3]						

E = Existing. C = Commited. Exp = Expansion. NA = Not available. (*) Secretariat estimate. (1) BHP has completed trials of heap leach technology, which should assist the company in assessing less capital-intensive mineral processing technology for ore mined underground. BHP scrapped the Brownfield Expansion project as October 2020. However, production may increase through debottlenecking of investments, plant upgrades and modernisation of infrastructure. (2) By-product of nickel, cobalt and zinc production. (3) In April 2020, Strata Energy received the approval to fully implement low-pH uranium recovery at the Ross mine (Lance). Commencement of operation remains subject to market improvement.

There are very few scheduled additions to the existing and committed production capacities through 2020, with production increases projected mainly in Namibia as the Husab mine ramps up production and reaches full capacity. Other additions to existing and committed production capacities in the longer term (through 2035) are projected in Australia, Brazil, India, Kazakhstan, Russia and the United States, in most cases provided that market prices rise to the level needed to support development.

Planned and prospective mines and expansions

Planned and prospective mines that could ramp up production through 2035 are listed in Table 1.25, but as with existing and committed expansions in Table 1.24, few firm dates of completion have been provided and those that have are years away. The main increases in the longer term are expected to come from Australia, Botswana, Brazil, Canada, Kazakhstan, Namibia, Niger, Russia, Spain, Tanzania, Ukraine, the United States and Zambia. However, since few of these developments have a firm date for first production, most will not be developed until uranium market prices increase to the level at which investment to increase production is justified.

With appropriate market signals, total annual production capacity could increase by as much as 40 000 tU by 2035. However, many of these increases in production capacity will only go forward with strengthening market conditions. Increased mining costs and development of new exploitation technologies, combined with risks of producing in jurisdictions that have not previously hosted uranium mining, mean that improved and lasting market conditions will be needed before the required investments to develop these mines are made.

While there is uncertainty surrounding the development of prospective and planned production centres, given current market conditions, the number of potential capacity additions listed in Table 1.25 underscores the availability of uranium deposits of commercial interest. Since these sites span several stages of approvals, licensing and feasibility assessments, it can reasonably be expected that at least some will take several years to be brought into production, whereas others may never be. Notwithstanding the time it takes to bring new deposits into production, these new mine developments may be timely since longstanding, significant production centres in Australia (Ranger), Namibia (Rössing) and Niger (Cominak), with cumulative production capacity of 7 900 tU/yr) are preparing for closure between early 2021 and the end of 2025.

Table 1.25. **Planned and prospective mines***
(nominal production capacity, tU/year in parentheses where available)

Country	Production centre	Starting year
Australia	Kintyre (2 290)	
	Yeelirrie (3 265)	
	Wiluna P (577)	
	Mulga Rock (1 346)	
	Honeymoon (769)	
Botswana	Letlhakane (1 440)	
Brazil	Itataia (970)	2026
Canada	Kiggavik (3 000)	
	Midwest (2 300)	
	Millennium (2 750)	
	Arrow	
	Triple R	
	Phoenix	
	Gryphon	
India	Gogi (130)	2024
	Lambapur-Peddagattu (130)	2024
	KPM (Kylleng) (340)	2028
Greenland	Kvanefjeld (425)	
Kazakhstan	Budenovskoe 6,7	
Malawi	Kanyika (60)	
Mauritania	Tiris (315)	
Mongolia	Dulaan uul - Zuuvch Ovoo	
	Emeelt	
	Gurvansaihan	
Paraguay	Yuty (350)	2035
Peru	Macusani (1 000)	2035
Namibia	Etango (2 770)	
	Norasa (2 000)	
Niger	Dasa (770)	
	Imouraren (5 000)	
	Madaouela (1 030)	2023
Russia	Elkon (5 000)	
	Gornoye (300)	
Spain	Retortillo/Alameda/Zona 7 (1 690)	
Tanzania	Mkuju River (3 000)	
Ukraine	Safonovskiy (150)	2021
	Severinskiy (1 200)	
United States	Dewey-Burdock	
	Burke Hollow	
	Reno Creek	
	Shirley Basin	
Zambia	Lumwana (650)	
	Mutanga (920)	

* As noted in country reports or from public data, in several cases the start-up dates and/or capacity are not known. Australia – uranium mining at Ranger will cease in January 2021. Niger – on 24 October 2019, Orano announced that Cominak (Akouta) will end its uranium production on 31 March 2021 due to the exhaustion of ore and high operating costs. Namibia – current mine plans foresee a cessation of Rössing production at the end of 2025. Russia – Elkon and Gornoye deposits development suspended. Spain – pending mine construction and exploitation licences.

Idled mines

With the continuation of poor market conditions in an oversupplied market, producers have been increasingly motivated to reduce production to reduce supply and, in turn, put upward pressure on prices. While some producers have reduced production at some facilities, others have opted to close operations entirely until market conditions improve sufficiently to justify re-opening. These temporarily closed operations, referred to as idled mines (Table 1.26), are defined as those with associated identified uranium resources and processing facilities that have all necessary licences, permits and agreements for operation and have produced commercially in the past, but were not producing uranium as of mid-2020.

Table 1.26. **Idled mines***

Country	Production centre	Year idled	Production capacity (tU/yr)	Resources (tU; recoverable)
Australia	Honeymoon**	2013	769	20 732
Canada	McArthur River/Key Lake	2018	9 600	153 700
	Rabbit Lake	2016	6 500	27 000
China	Chongyi	2017	200	Not available
	Lantian	2017	100	Not available
Malawi	Kayelekera	2014	1 270	9 725
Namibia	Langer Heinrich	2018	2 030	36 831
	Trekkopje***	2013	2 545	36 445
Niger	Azelik**	2015	700	9 648
United States	Smith Ranch/Highland	2016	2 116	Withheld
	Crow Butte	2017	385	Withheld
	Alta Mesa	2016	577	Withheld
	Palangana	2015	385	Not available
	Willow Creek	2018	500	Not available
Totals			27 677	294 081

(*) Idled mines are those with associated identified uranium resources and processing facilities that have all necessary licences, permits and agreements for operation and have produced commercially in the past, but were not producing uranium as of 1 May 2020. (**) Technical difficulties contributed to decisions to stop production. (***) Trekkopje, although not fully satisfying the definition of an idled mine, is included here because it produced 251 tU and 186 tU in 2012 and 2013 (respectively) as part of two pre-commercial operation pilot tests to demonstrate and confirm production technical processes and estimated costs (see the Namibia country report for additional details; includes both the Klein Trekkopje and Trekkopje deposits). Currently, a care and maintenance team regularly provides upkeep to the mine's infrastructure so that it can be recommissioned and brought on stream when economic conditions for uranium production become more favourable.

As shown in Table 1.26, annual production capacity could be potentially increased relatively rapidly if the listed idled mines are brought back into service with improved market conditions. Although each mine operation is unique in terms of operational costs and a threshold price for opening, the ability to raise capital if required to resume operation and regulatory requirements, idled mines could resume production within roughly one year, given that all permits and licences remain in place. Decisions to resume production rest principally on increased market prices. With the right market signals, idled mine facilities, associated with a total of at least 294 000 tU in local resources (recoverable), could potentially bring some 27 000 tU annually to the market if all are brought back into production. These facilities can be expected to be brought back online before new mines are established, should uranium market conditions improve.

Operations to recover uranium from gold tailings in South Africa could also contribute to increased global production relatively rapidly with the right market signals, and production at Somair (Niger) could be returned to full capacity (capacity reduced by 30% in 2017 due to poor market conditions). Moreover, operations that have progressed to pilot mining, such as Trekkopje (Namibia) or have operating permits but, pending more favourable market conditions, work to bring the site into production was suspended, such as Imouraren (Niger), could also contribute to the increase global annual production by over 7 500 tU (2 545 tU/yr for Trekkopje; 5 000 tU/yr for Imouraren). Improved market conditions and significant investment, however, would be required to bring operations like these on stream (note that Trekkopje is included in the list of idled mines, while Imouraren is listed in Table 1.25; see Table 1.26 footnotes for additional details).

Conclusions

Sufficient uranium resources have been identified to support even the most aggressive scenarios of growth in nuclear generating capacity. However, the majority of this in-ground uranium cannot be brought to the market without improved market conditions. Unattractive market conditions also slows uranium exploration investment, which in turn can affect further delineation of additional identified resources in the short term.

At market prices as of late 2020, less than 25% of the identified conventional resource base outlined in this edition could be economically brought into production, since resources with estimated mining costs greater than USD 80/kgU (USD 30.80/lb U_3O_8) cannot be profitably mined at these market prices.

However, since some producers have either idled production facilities or reduced production at other mines due to a lengthy period of low uranium prices, there is an ability to increase production more rapidly than the traditional lengthy mine development processes of the recent past. Except for idled projects, significant investment and time would be required to bring uranium resources into production, particularly for undiscovered or unconventional resources. Historically, significant proportions of identified resources have never been extracted, while, on average, the timelines for extraction of identified resources are on the order of a decade or more (IAEA, 2020), in addition to timeframes of several decades for the delineation of undiscovered resources.

Looking ahead, effects related to efforts to slow the spread of the COVID-19 virus at production facilities will likely lead to a further, unplanned reduction in production that will test the market's ability to continue supplying an adequate supply of uranium to the global nuclear fuel supply chain. As such, 2020 uranium production targets may be a challenge to achieve, and the consequences of pandemic-related restrictions on mining and milling could be felt through 2021, constricting global supply of newly mined uranium.

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Chapter 2. **Uranium demand and supply/demand relationship**

This chapter summarises the current status and projected growth in world nuclear electricity generating capacity and commercial *reactor-related uranium requirements*. Relationships between uranium supply and demand are analysed and important developments related to the world uranium market are described.

The COVID-19 pandemic has highlighted the importance of electricity security in modern societies. Although the long-term implications for electricity generation are difficult to assess, during the crisis, nuclear power continued to support the security of supply and has been one of the most resilient electricity sources, together with renewables. Nuclear power plants are a clear example of resilient facilities. The resilience is the result of the combination of high levels of safety, operational flexibility and continuous learning from previous events (NEA, 2020a).

Nuclear generating capacity and reactor-related uranium requirements

On 1 January 2019, a total of 450 commercial nuclear reactors were connected to the grid in 30 countries and 55 reactors were under construction.

During 2017 and 2018, 20 reactors were connected to the grid and 9 reactors were permanently shut down. Table 2.1 and Figures 2.1 and 2.2 summarise the status of the world's nuclear power plants (NPPs) as of 1 January 2019. The global NPP fleet generated a total of about 2 563 TWh of electricity in 2018 and about 2 657 TWh in 2019 (see Table 2.2).

In 2019, nuclear power and renewables combined, generated more electricity than coal for the first time (IEA, 2020).

World annual uranium requirements amounted to 59 200 tU as of 1 January 2019.

Global nuclear programmes

OECD

As of 1 January 2019, the 308 reactors connected to the grid in 18 OECD countries constituted about 73% of the world's nuclear electricity generating capacity. A total of 14 reactors were under construction. During 2017 and 2018, ten reactors were permanently shut down in Korea, Germany, Japan, Spain, Sweden and the United States. However, 14 reactors were considered firmly committed to construction. A number of OECD member countries, namely the Czech Republic, Finland, Hungary, the Slovak Republic and the United Kingdom, remain committed to maintaining or increasing nuclear generating capacity in their energy mix. To help enable the development of small and advanced reactors, several countries have set out frameworks designed to encourage the industry to bring technically and commercially viable small reactor propositions to the global marketplace.

The OECD reactor-related uranium requirements were 41 285 tU as of 1 January 2019.

Table 2.1. **Nuclear data summary**
(as of 1 January 2019)

Country	Operating reactors	Generating capacity (GWe net)	2018 uranium requirements (tU)+	Reactors under construction	Reactor grid connections in 2017 and 2018	Reactors shut down during 2017 and 2018	Reactors using MOX
Argentina	3	1.6	115	1	0	0	0
Armenia	1	0.4	60	0	0	0	0
Bangladesh	0	0.0	0	2	0	0	0
Belarus	0	0.0	0	2	0	0	0
Belgium	7	6.0	630	0	0	0	0
Brazil	2	1.9	400	1	0	0	0
Bulgaria	2	1.9	300 *	0	0	0	0
Canada	19	13.6	1 760	0	0	0	0
China[(a)]	46	42.9	6 865 *	11	10	0	0
Czech Republic	6	3.9	795	0	0	0	0
Finland	4	2.8	430	1	0	0	0
France	58	63.1	7 370	1	0	0	22
Germany	7	9.5	1 420	0	0	1	1[(b)]
Hungary	4	1.9	325	0	0	0	0
India	22	6.3	1 100	7	0	0	1
Iran, Islamic Rep. of	1	0.9	160	0	0	0	0
Japan	38	36.5	1 180 ϵ	2	0	5	4
Korea	24	22.4	3 800	5	0	1	0
Mexico	2	1.6	420	0	0	0	0
Netherlands	1	0.5	65	0	0	0	1
Pakistan	5	1.3	210 *	2	1	0	0
Romania	2	1.3	230	0	0	0	0
Russia	36	27.3	5 000	6	2	1	0
Slovak Republic	4	1.8	290 *	2	0	0	0
Slovenia	1	0.7	150	0	0	0	0
South Africa	2	1.8	290 *	0	0	0	0
Spain	7	7.1	910	0	0	1	0
Sweden	8	8.6	950	0	0	1	0
Switzerland	5	3.3	385	0	0	0	0
Turkey	0	0.0	0	1	0	0	0
United Arab Emirates	0	0.0	0	4	0	0	0
Ukraine	15	13.1	2 480	2	0	0	0
United Kingdom	15	8.9	1 065	1	0	0	0
United States	98	99.0	19 340	2	0	1	0
OECD	308	291.2	41 285	14	0	10	28
World Total[(a)]	450	396.3	59 200	55	13	12	29

* NEA/IAEA estimate. + Values rounded to 5 tU

(a) The following data for Chinese Taipei are included in the world total but not in the total for China: five NPPs in operation, 4.4 GWe net; 705 tU as 2018 uranium requirements; two reactors under construction; none started up and one shut down during 2017 and 2018.

(b) Number of units that are expected to have MOX fuel elements in the core. MOX not included in uranium requirements figures.

Source: i) Government-supplied responses to a questionnaire; ii) NEA *Nuclear Energy Data 2019* for OECD countries; and iii) IAEA *Energy, Electricity and Nuclear Power Estimates for the Period up to 2050* (IAEA, 2019a) for non-OECD countries.

Figure 2.1. **World installed nuclear capacity: 396 GWe net**
(as of 1 January 2019)

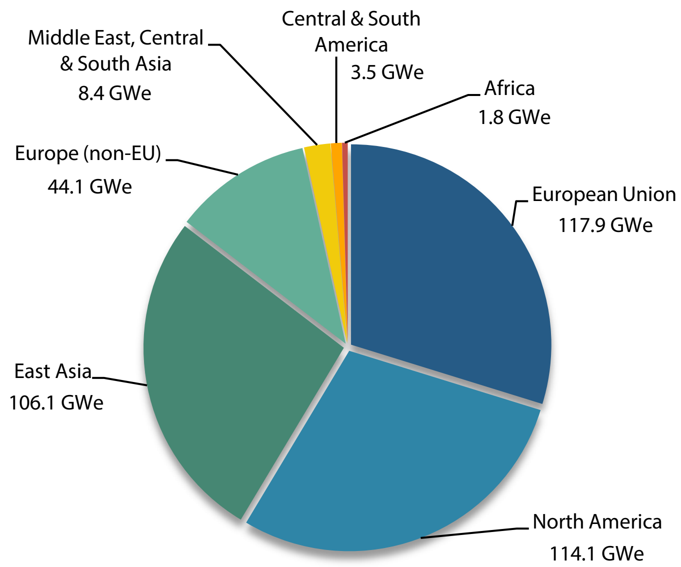


Figure 2.2. **World uranium requirements: 59 200 tU**
(as of 1 January 2019)

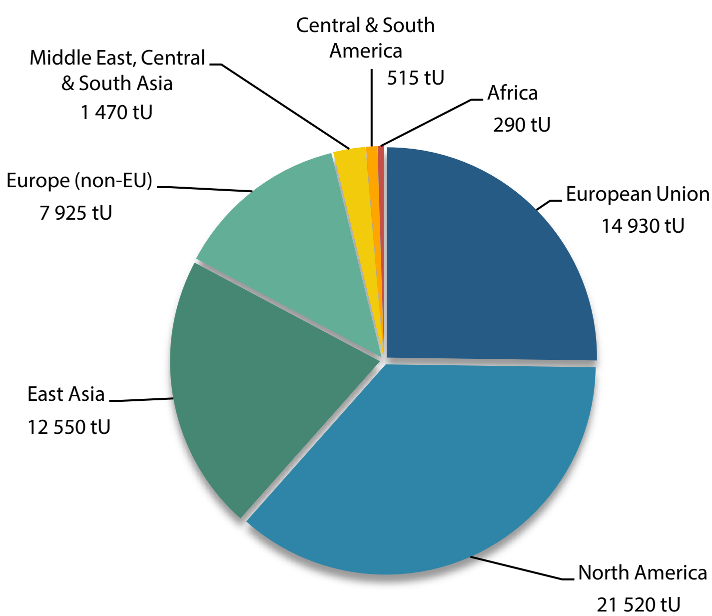


Table 2.2. **Electricity generated at nuclear power plants**

(TWh net)

Country	2015	2016	2018	2019
Argentina	6.5	7.7	6.5	7.9
Armenia	2.6	2.2	1.9	2.0
Belgium	25.0	41.0	27.3	41.4
Brazil	13.9	15.0	14.8	15.2
Bulgaria	14.7	15.1	15.4	15.9
Canada	96.0	95.4	94.4	94.9
China[(a)]	161.2	197.8	277.1	330.1
Czech Republic	25.3	22.7	28.3	28.6
Finland	22.4	22.3	21.9	22.9
France	416.8	384.0	395.9	382.4
Germany	86.8	80.1	71.9	71.1
Hungary	14.9	15.2	14.9	15.4
India	34.6	35.0	35.4	40.7
Iran, Islamic Rep. of	3.2	5.9	6.3	5.9
Japan	9.4	17.5	49.3	65.7
Korea	164.7	154.3	127.1	138.8
Mexico	11.6	10.3	13.2	10.9
Netherlands	3.9	3.7	3.3	3.7
Pakistan	4.3	5.4	9.3	9.1
Romania	10.7	10.4	10.5	10.4
Russia	182.4	183.3	191.3	195.5
Slovak Republic	14.1	14.7	13.8	14.3
Slovenia	5.6	5.4	5.5	5.5
South Africa	11.0	15.2	10.6	13.6
Spain	54.8	56.1	53.4	55.9
Sweden	54.3	60.5	65.9	64.4
Switzerland	22.0	20.0	24.5	25.4
Ukraine	82.4	76.1	79.5	78.1
United Kingdom	63.9	65.1	59.1	51.0
United States	797.2	805.7	808.0	809.4
OECD	1 888.7	1 874.0	1 877.7	1 901.7
World Total[(a)]	2 451.3	2 473.6	2 562.7	2 657.2

a) The following data for Chinese Taipei are included in the world total, but not in the total for China: 35.1 TWh in 2015 and 30.5 in 2016 and 26.7 TWh in 2018 and 31.1 in 2019.

Source: i) government-supplied responses to a questionnaire; ii) NEA *Nuclear Energy Data 2019* for OECD-NEA countries; and iii) IAEA *Energy, Electricity and Nuclear Power Estimates for the Period up to 2050* (IAEA, 2019a and 2020a) for non-OECD countries.

European Union

The European Commission (EC) is seeking greater diversification and modernisation of the electricity market. Recently released proposals call for a transition to a low-carbon society.

In 2018, the EC established a Technical Experts Group on Sustainable Finance (TEG) to assist in the development of a unified classification system for sustainable economic activities (i.e. the EU Taxonomy), along with methodologies for low-carbon indices and metrics for climate-related disclosure. In a 2019 report, the TEG recognised the potential substantial contribution of nuclear energy to climate mitigation objectives and low-carbon energy supply. However, the TEG recommends that more extensive technical work needs to be undertaken on the "do-no-significant-harm" aspects of nuclear energy, as well as on the existing and potential environmental impacts across all objectives. The Commission has asked the Joint Research Centre (JRC), its in-house research body, to assess whether nuclear power should be included in the EU taxonomy as an environmentally sustainable activity. The JRC will propose a technical report on the "do-no-significant-harm" aspects of nuclear energy in 2021.

In Belgium, seven nuclear power plants provide about 50% of domestic electricity generation. The country's security of electricity supply became a concern at the end of 2018, when only one out of seven reactors (Doel 3) was generating electricity due to a maintenance and refurbishment programme. Doel units 1 and 2 were also offline for their long-term operation (LTO) programme, which was already completed, and the nuclear regulator has approved the restart of operation for these units. Under current Belgian law, nuclear power is to be phased out by 2025. The Belgian Constitutional Court ruled in March 2020 that a law passed in 2015 to grant a ten-year extension to Doel units 1 and 2 was unconstitutional because a required Environmental Impact Assessment was never produced before granting extended operations. However, the Court said it would allow the law to remain in force until the end of 2022.

In Bulgaria, following the closure of four older reactors by the end of 2006, only two units (about 0.95 GWe net each) remain operational at the Kozloduy NPP. To compensate for the loss of nuclear generating capacity and to regain its position as a regional electricity exporter without increasing carbon emissions, the government has plans to build new reactors. A nuclear station at Belene was originally planned in the 1980s, but was stopped in the early 1990s due to environmental and financial concerns. In May 2019, the government advertised for a strategic investor to participate in the Belene project to build two new reactors.

In the Czech Republic, a total of six reactors were operational on 1 January 2019, with an installed capacity of 3.9 GWe net. After the modernisation and power uprate programme for all reactors at the Dukovany NPP, an upgrade of the Temelin units began in 2013 and resulted in a capacity increase to 1 078 MWe gross for each block. In May 2015, the Czech government announced a national energy policy that favours an ambitious increase in nuclear power from its current 35% to about 50-55% by 2050 as a means to reduce carbon emissions. The Czech utility ČEZ applied to the State Office of Nuclear Safety to construct two new reactors at its Dukovany site. Under the current schedule, the reactor supplier is to be selected by the end of 2022, with commissioning expected by 2036. The Czech government would loan 70% of the cost of building a single 1 200 MWe unit, with ČEZ funding the remaining 30%.

In Finland, four units (two each at the Olkiluoto and Loviisa NPPs) with a total generating capacity of 2.8 GWe were operational on 1 January 2019, providing about 32% of domestic electricity generation. Teollisuuden Voima Oyj (TVO), a non-listed public limited company, owns and operates the two plant units, Olkiluoto 1 and 2, and is building a new unit, Olkiluoto 3 (OL3). The OL3 construction has suffered numerous delays and cost overruns. TVO was granted an operating licence in 2019 and in April 2020 applied for permission to load fuel. In December 2013, Fennovoima signed a "turnkey" plant supply contract for an AES-2006-type water-water energetic reactor (VVER) with Rosatom Overseas. Fennovoima submitted the construction licence application at the end of June 2015. The preparatory works are continuing at the Pyhäjoki site. Fennovoima aims to obtain the plant's construction licence in 2021 with a view to commencing initial operations in 2028.

In France, 58 operational reactors generated 72% of domestically produced electricity in 2018. Construction of a new EPR at the Flamanville NPP began in late 2007. Hot functional testing of the Flamanville 3 EPR reactor started in 2019. The French Nuclear Safety Authority (ASN) decided in 2019 that repairs to the reactor's main secondary system penetration welds would be needed and that this would further delay fuel loading until the end of 2022. The government passed legislation in 2015 for the transition to a low-carbon economy, restricting nuclear power to its current level of capacity, with a goal of ultimately reducing the percentage of nuclear power to 50% by 2025 through increased deployment of renewable capacity. However, in November 2018, a draft of the country's new energy plan postponed by ten years the plans to reduce the nuclear share. This would require 14 of the country's nuclear reactors to shut down by then. The plan also outlines that the option to build new nuclear reactors remains. In February 2020, Fessenheim unit 1 was closed, followed by the closure of unit 2 in June 2020. The closure of the Fessenheim reactor was imposed as part of the current energy policy.

In Germany, seven reactors were operational on 1 January 2019, producing about 12% of domestic electricity generation in 2018. Following the Fukushima Daiichi accident, the German Cabinet announced that it was accelerating the nuclear phase-out by permanently shutting down the reactors. The remaining reactors are to be permanently shut down no later than the end of 2022 in the following order: Grohnde, Gundremmingen C and Brokdorf by the end of 2021, and the three most recently built facilities – Isar 2, Emsland and Neckarwestheim – by the end of 2022. With reduced nuclear generating capacity, renewable energy sources are being added at a rapid rate, but it has also been necessary to increase the use of coal-fired plants, which in turn increases greenhouse gas emissions. In addition, coal power plants are planned to remain as part of the generation mix until 2038.

In Hungary, four operational VVER reactors at the Paks NPP (1.9 GWe net) accounted for over 50% electricity generation at the end of 2018. In January 2020, the government approved the new National Energy Strategy 2030 and the National Energy and Climate Plans 2030. The revised strategic framework is based on three strategic pillars: clean, smart and affordable energy. While focusing on energy consumers, the most important strategic objectives are: climate-friendly transformation of the energy sector, further strengthening of security of supply and focus on innovation and economic development. As for nuclear energy, it will be essential for ensuring sector integration and a climate neutral economy. The preservation of nuclear generation capacity by replacing existing units at the Paks NPP nearing the end of their lifetime is one of the key strategic measures for further decarbonisation of the electricity sector. Plans are well advanced for the construction of two new VVER-1200 reactors at the Paks site and preliminary work began in June 2019.

In Lithuania, following the election of a new coalition government in 2012, led by a party that had opposed the construction of the proposed Visaginas NPP on economic grounds, prospects for a new nuclear plant diminished. In 2016, the government released its national energy strategy and announced a delay of the nuclear project until more favourable market and economic conditions arise. With no nuclear generating capacity, Lithuania relies heavily on imports, in particular natural gas from Russia.

In the Netherlands, the single operational reactor (0.5 GWe net) supplied 3% of domestically generated electricity in 2018. There are currently no plans for new nuclear build in the Netherlands. Nevertheless, it is stated in the National Climate Agreement that nuclear power is one of the options for the future energy mix.

In Poland, where coal-fired plants currently generate more than 90% of domestic electricity, the government continues to advance plans to construct about 6 GWe of new nuclear power generation in the next 20 years. The legal framework for the development of nuclear power was established in 2011 and the Council of Ministers instructed the Ministry of Economy to prepare a new national strategy concerning radioactive waste and spent fuel management. In 2020, the government recommitted to launching a nuclear program with the release of a draft consultation that targets start of construction on the first of four to six reactors by 2033. In its draft plan, the government aims to select a financial investor of up to 49% in the first plant by next year, but it does not outline any firm mechanisms to support construction or operation of a nuclear plant, such as loans, government subsidies or power purchase agreements.

In Romania, the two Candu reactors at the Cernavoda NPP provided 17.2% of the electricity generated in the country in 2018. A tender for the construction of Cernavoda units 3 and 4 was launched and in 2015, China General Nuclear was designated initially as the selected investor for the construction of these two units. However, the partnership with the Chinese had apparently collapsed early in 2020. In March 2019, a MoU was signed with NuScale Power in order to evaluate the potential for SMRs in Romania. Nuclearelectrica has also announced plans to refurbish unit 1 of Cernavoda NPP by 2026 in order to extend the lifetime operation. In October 2020, an intergovernmental agreement was signed with the United States by which the US intends to support the construction of two new Cernavoda reactors and help refurbish Cernavoda-1.

In the Slovak Republic, a total of four reactors with a combined capacity of 1.8 GWe net were operational as of 1 January 2019. In 2018, the reactors provided 55% of the total electricity generated in the country. Fuel with higher enrichment (4.87% ^{235}U) has been used in the Mochovce reactors since 2011 and in the Bohunice units since 2012. The completion of the construction of two additional units at the Mochovce NPP has been delayed as a result of design safety improvements and technology updates. Mochovce 3 completed hot testing in April 2019, and the draft permit of the Nuclear Regulatory Authority for fuel loading was released in 2020. As of May 2020, the Mochovce-3 unit was 99.7% complete, and Mochovce-4 at 87.3%. When in operation, the new units will add 0.9 GWe of electrical generating capacity to the grid.

In Slovenia, the single nuclear reactor in operation (Krško, 0.70 GWe) is jointly owned and operated with Croatia by Nuklearna Elektrana Krško (NEK). The Krško reactor began commercial operation in 1983 and was recently granted a 20-year lifetime extension to 2043. The single unit accounted for about 36% of the electricity generated in Slovenia in 2018, although a proportion of this is exported to meet about 15-20% of Croatia's electricity requirements. An ambitious programme of safety upgrades has been in place at Krško plant since the Fukushima accident, and is due to be concluded in 2021. The government of Slovenia will make a decision by 2027 on whether to build a second unit at the existing Krško NPP site.

In Spain, nuclear energy provided 20.4% of total domestically generated electricity in 2018. The government drafted its national energy and climate plan in 2019, which includes the phasing out of nuclear energy by 2035. In May 2020, the Spanish Nuclear Safety Council granted permission for Almaraz 1 and 2 to operate until 2027 and 2028, respectively. In addition, Vandellós 2 applied for a licence extension to 2030.

In Sweden, eight operational reactors (a total of 8.6 GWe net) generated about 40% of domestic electricity supply in 2018. At the end of 2019, Ringhals 2 was shut down after 44 years of operation. Ringhals 1 went offline from March 2020 for a maintenance outage but returned to service in June to provide grid stability. In June 2019, the Swedish Radiation Safety Authority approved Forsmark 1 and 2 to operate for a further ten years, until 2028. For the remaining reactors, plans remain to continue operation for at least 60 years.

In the United Kingdom, 15 operational reactors with a combined capacity of 8.9 GWe net as of 1 January 2019 provided 18.5% of total domestic electricity generation. In the upcoming decades, the current UK fleet will be shut down, with the first units expected to come offline in 2023 and the last currently expected to close by 2035. The government has taken a series of actions to encourage nuclear new build. Current plans to develop new nuclear power at several sites in the United Kingdom are set out below: i) Électricité de France (EDF) and China General Nuclear Power Group (CGN) are currently constructing two EPRs at Hinkley Point C (3.2 GWe) and have plans for an additional two EPRs at Sizewell (3.2 GWe). The two companies also intend to deploy HPR1000 technology at Bradwell; ii) Horizon Nuclear Power has proposed to build two advanced boiling water reactors (ABWRs) at each of its sites in Wylfa and Oldbury (2.7 GWe each). However, work has been suspended since January 2019 on proposals to construct new reactors at Wylfa and Oldbury; and iii) in 2020, two consortia showed interest in developing new build projects at Moorside site. The first consortium is Rolls-Royce, planning to build indigenous small modular reactors (SMRs), and the second is Atkins consortium, proposing a Clean Energy Hub at Moorside including two EPRs and potentially one SMR. To help enable the development of both SMRs and advanced modular reactors (AMRs) in the United Kingdom, the government is investing more than GBP 100 million of innovation and industrial strategy funding into advanced nuclear research and development.

The reactor-related uranium requirements for the EU amounted to about 14 930 tU as of 1 January 2019.

North America

Abundant supplies of low-cost natural gas and competition from renewable energy sources currently limit prospects for growth in nuclear generating capacity in this region.

In Canada, nuclear energy provided about 15% of the country's electricity needs in 2018 (over 60% in Ontario and 36% in New Brunswick) and should continue to play an important role in the future. The province of Ontario has 18 of Canada's 19 operating nuclear power reactors across three power plants: Pickering, Darlington, and Bruce. CAD 26 billion is being invested in the province of Ontario to refurbish 10 reactors over the 2016-2031 period: four at Darlington, owned and operated by Ontario Power Generation (OPG), and six units at Bruce operated by Bruce Power. These projects, which will enable the plants to operate for an additional 25-30 years, represent a combined investment of approximately CAD 26 billion by OPG and Bruce Power, collectively Canada's largest infrastructure project.

Since the release of the report, "A Call to Action: A Canadian Roadmap for Small Modular Reactors" (SMRs), in November 2018, Natural Resources Canada (NRCan) has continued to build on the momentum created by the publication of the roadmap. The federal government and other enabling partners have advanced efforts in priority areas, such as developing SMR research and development and exploring business partnerships for potential deployment in the late 2020s. In December 2019, the provinces of Ontario, New Brunswick and Saskatchewan signed a Memorandum of Understanding (MOU) to collaborate on SMRs. In April 2018, Canadian Nuclear Laboratories (CNL) initiated an Invitation for Demonstration, inviting further discussions with SMR vendors interested in building a demonstration unit at a CNL-managed site. Several SMR designs are currently under consideration, with one vendor in the initial stages of site licensing with the Canadian Nuclear Safety Commission. The CNSC continues to work to ensure readiness to regulate SMRs in Canada.

In Mexico, the two units at Laguna Verde NPP (a total of 1.6 GWe net) typically provide about 4% of the electricity generated in the country. Laguna Verde units received permission from the national regulator to operate at the extended power uprate level (120%). In 2015, an application for a licence renewal of Laguna Verde units was submitted to the Mexican regulatory authority, which could authorise its operation for an additional 30 years.

In the United States, 98 reactors were operational as of 1 January 2019, contributing 19.3% of the total electricity generated in the country. Two AP1000 reactors are under construction at the Vogtle power plant in the state of Georgia. In April 2020, Indian Point 2 was shut down four years before the expiry of its operating licence. In the United States, several initiatives are taking place at the state level to support the existing nuclear fleet (e.g. Connecticut, New Jersey, Ohio and Pennsylvania). For example, in March 2019, a draft law updating the Alternative Energy Portfolio Standards Act to include nuclear energy was introduced to the state legislature. At the national level, the United States continues to support advanced nuclear projects and SMRs through the Industry Opportunities for Advanced Nuclear Technology Development programme. The programme started awarding funds in 2018. The US Nuclear Regulatory Commission approved a 20-year licence extension for Turkey Point 3 and 4, authorising the reactors to operate for up to 80 years. In July 2020, the US International Development Finance Corporation lifted its legacy prohibition on funding nuclear energy projects overseas.

Annual uranium requirements for North America were about 21 520 tU as of 1 January 2019.

East Asia

Prospects for nuclear growth are greater there than in any other region of the world, principally driven by rapid growth underway in China. However, political developments and public dissent in Japan and Korea could somewhat limit the overall expected growth in the region.

In China, 46 operational reactors provided about 4.2% of national electricity production in 2018 and a total of 11 reactors were under construction as of 1 January 2019. Recent developments include the grid connection in June 2019 of Taishan 2, the second EPR to start operation. In November 2019, China's first commercial nuclear heating project began operating at the Haiyang NPP plant with two AP1000 units. Yangjiang 6 reactor (ACPR-1000) and Tianwan 5 were connected to the grid in 2019 and 2020, respectively. Early in 2020, hot testing was completed at the Fuqing 5, one of the first Hualong One domestic design reactors under construction in China.

Projected nuclear growth remains strong in China. However, taking into consideration the capacity of all reactors currently under construction, it is most likely that China will not achieve the initial target of 58 GWe by the end of 2020. Nevertheless, China is moving ahead with the planning and construction of new nuclear power plants and the development of its own Gen III technologies. The government plans to add significant nuclear generating capacity in order to meet rising energy demand and limit greenhouse gases and other atmospheric emissions since poor air quality, mainly due to emissions from coal-fired plants, is a significant health issue.

In Japan, new regulations for reactor restarts came into force in July 2013, leading a number of utilities to apply to restart reactors. With most NPPs out of service, Japanese utilities have been importing large amounts of oil and natural gas for electricity generation, driving electricity prices and greenhouse emissions upward. Reactor restarts and rejuvenation of the industry is however proving to be challenging given the stringent new regulatory requirements and public resistance. Nevertheless, the finalisation in 2015 of a new long-term energy policy that envisions nuclear power representing 20-22% of total energy supply in 2030 represented an important step for a sustained nuclear comeback. Sendai 1 and 2 were the first reactors to restart in 2015, and a further seven have restarted since then. As of mid-2020, 18 reactors are in the process of restart approval and a further eight are yet to apply. Reactors that have restarted are also required to construct bunkered backup control centres within five years of regulatory approval to restart.

In Korea, 24 operational units produced 22.3% of the total electricity generated in 2018. Construction of five reactors is underway. The first nationally designed advanced pressurised reactor APR-1400, unit 3 at the Shin Kori NPP, was connected to the grid in 2016. Shin Kori 4 reached its first criticality in April 2019 and was connected to the grid in August 2019. The government decided to shut down Kori 1, the first commercial NPP to start operation in 1978, in June 2017. An energy transition policy was announced in October 2017, outlining a long-term fading out of nuclear power. The ongoing construction of Shin Kori units 5 and 6 was highlighted during the public debate on nuclear energy in 2017. These units are expected to start operation by 2024.

Although Mongolia does not currently have nuclear generating capacity, it has signalled an interest in the use of small and medium-sized reactors.

The reactor-related uranium requirements for the East Asia region were 12 550 tU as of 1 January 2019.

Europe (non-EU)

This region is also undergoing strong growth with reactors under construction. Several countries in this region continue to support nuclear power and overall growth in nuclear generating capacity is expected.

In Armenia, the single operational reactor (Metsamor 2, 0.4 GWe) provided about 30% of the electricity generated in the country in 2018. In 2015, the nuclear plant began a large-scale life extension maintenance program with the help of Russia's Rosatom. According to the Armenian energy sector development plan, construction of one new unit is envisaged by 2027.

In Belarus, a USD 10 billion agreement was signed with Atomstroyexport in 2012 to build the country's first NPP, consisting of two VVER-1200 reactors, with expected completion dates by 2020 for unit 1 and 2021 for unit 2. The first fuel load for unit 1 was delivered in May 2020.

In Russia, 36 operational reactors (27.2 GWe net) provided about 17% of the total electricity generated in the country in 2018. Russia has brought nine reactors online over the last ten years and four reactors are currently under construction. Novovoronezh 2-2 was connected to the grid in May 2019. Unit 3 of the Kalinin NPP was officially approved for lifetime extension in June 2019. Akademik Lomonosov, the floating NPP, received an operating licence for ten years in June 2019. Rosatom has confirmed its intention to commission two other floating NPPs by 2027. In April 2020, the Russian nuclear regulator extended the operating licence of the Beloyarsk BN-600 fast reactor by five years to 2025. In addition to an active domestic programme, the state-run energy company Rosatom is currently involved in new reactor projects in several countries (e.g. Bangladesh, Belarus, China, Hungary, India, Iran, Turkey and Uzbekistan).

In Switzerland, five operating reactors produced 38.5% of the electricity generated in the country in 2018. Switzerland's first NPP, Mühleberg, with an approximate output power of 373 MW, was permanently shut down on 20 December 2019. In 2017, a public referendum was organised on the new Energy Strategy 2050. Under the new law, no permits for the construction of new NPPs or any basic changes to existing NPPs will be delivered. The existing NPPs may remain in operation for as long as they are declared safe by the Federal Nuclear Safety Inspectorate.

In Turkey, the government continues to advance its nuclear development programme as its fast growing economy faces rapidly escalating electricity demand. The Akkuyu Project Company applied for an electricity generation licence and a construction licence in early 2017, paving the way for construction activities at the first NPP in Turkey that will comprise four units (VVER-1200 reactors type). Construction of unit 1 started in April 2018. The core catcher for unit 1 has been installed and hydraulic tests on the reactor pressure vessel were completed in July 2020. A construction licence for unit 2 was issued in September 2019.

In Ukraine, 15 reactors with a combined installed capacity of 13.1 GWe net were operational on 1 January 2019, producing 53% of the electricity generated in the country in 2018. The national energy programme foresees that nuclear energy will continue to generate about 50% of total electricity production by 2035. In June 2019, Holtec International, Energoatom and the country's State Scientific and Technology Centre entered into a partnership to advance the SMRs deployment in Ukraine.

Reactor-related uranium requirements for the Europe (non-EU) region amount to about 7 925 tU as of 1 January 2019.

Middle East, Central and Southern Asia

Growth in nuclear generating capacity in this region is expected in the coming years as governments continue to work towards implementing plans to meet rising electricity demand without increasing greenhouse gas emissions.

In Bangladesh, Cabinet ratified a deal with Rosatom in 2012 to build two reactors at the Rooppur site. Under the terms of the agreement, Russia will reportedly provide support for construction and infrastructure development, supply fuel for the entire lifetime of the reactors and take back spent fuel. The first safety-related concrete for unit 1 was poured in 2017, with the pour for unit 2 in 2018. The Bangladesh Atomic Energy Commission planned to commission the two VVER-1200 in 2023 and 2024, respectively. However, it is still not clear the extent to which the coronavirus may have slowed the works further.

In India, 22 reactors (6.2 GWe net) were operational on 1 January 2019, providing about 2.3% of domestic electricity generation in 2018. Agreements in 2008 that granted India the ability to import uranium and nuclear technology have resulted in improved reactor performance through adequate uranium supply. However, concerns about the nuclear liability legislation have slowed the development of agreements on imported technology. Construction of seven new reactors is in progress with four indigenous pressurised heavy water reactors [PHWRs], two VVERs and one sodium fast reactor. The Russian-built second unit of Kudankulam nuclear power plant entered commercial operation in 2017. As other countries with PHWRs fleet have done, India has started the process of refurbishing its reactors to allow for extended operation. The national plan is to increase installed nuclear capacity to 15.7 GWe by 2031, following the 2019 announcement of India's Department of Atomic Energy.

In the Islamic Republic of Iran, commissioning of the Bushehr-1 reactor (about 0.9 GWe net) supplied by Atomstroyexport took place in 2011. The government plans to develop up to 8 GWe net of installed nuclear capacity by 2030 in order to reduce its reliance on fossil fuels, beginning with the installation of additional units at Bushehr. Construction works of Bushehr 2 started in 2017. The reactor is expected to start up in 2024.

In Jordan, a plan to construct two reactors to generate electricity and desalinate water, along with development of the country's uranium resources, has been moving forward since as early as 2004, driven by rising energy demand and the current need to import around 95% of its energy needs. However, the Fukushima Daiichi accident has created some local resistance in Jordan. The country is now considering to have SMRs instead of large reactors and had signed several co-operation agreements with CNNC, Rolls-Royce, NuScale, X-energy and Rosatom.

Kazakhstan has no active nuclear power generation capacity. In May 2014, Russia and Kazakhstan signed a preliminary co-operation agreement regarding the construction of a new nuclear power plant with a generating capacity of between 300 and 1 200 MWe. Discussions on the possibility of building an NPP in Kazakhstan are still pending.

In Pakistan, five reactors (1.3 GWe net) were operational on 1 January 2019, supplying about 7% of domestic electricity production in 2018. As part of an effort to address chronic power shortages, a growing population and increasing electricity demand, the government established the Energy Security Action Plan with a target of installing additional nuclear generating capacity by 2030. Chasma 3 reactor (300 MWe) was completed in December 2016 and Chasma 4 unit was connected to the grid in June 2017. The Pakistan Atomic Energy Commission signed a contract with China (CNNC) in 2017, for the country's third Hualong One reactor, after the two units at Karachi. Similar to those units, China's Import and Export Bank is expected to provide the major part of the financing for Chashma-5.

In the United Arab Emirates, a consortium from Korea led by the Korea Electric Power Corporation (KEPCO) won a contract in 2009 to build four APR-1400 reactors (a total of 5.4 GWe net). Construction of the first and second units (Barakah 1, 2) officially began in 2012 and 2013, respectively. In September 2019, unit 1 was undergoing commissioning and testing, prior to regulatory review and receipt of an operating licence. Grid connection of Barakah 1 was achieved on 19 August 2020. In July 2020, construction of unit 2 was completed. Increasing energy demand, combined with policies to reduce greenhouse gas emissions and domestic consumption of natural gas in order to maintain the inflow of foreign capital through exports, were central considerations in the government's decision to develop the Barakah NPP.

Saudi Arabia is seeking to build its first nuclear power plant and has solicited information from various vendors from China, France, Korea, Russia, and the United States.

Other countries in the region, currently without NPPs, have been considering the development of such facilities, including Uzbekistan.

The Uzbek Agency for the Development of Nuclear Energy (UzAtom) and Russia's Rosatom are working on finalising an Engineering, Procurement, Construction (EPC) contract for Uzbekistan's first two commercial reactors. In 2020, a ten-year plan for Uzbekistan's electricity sector was developed with the Asian Development Bank and the World Bank. It aims to develop up to 30 GW of additional power capacity by 2030, including 5 GW of solar power, 3.8 GW of hydro energy, 2.4 GW of nuclear energy, and up to 3 GW of wind power.

Reactor-related uranium requirements for the Middle East, Central and Southern Asia region were about 1 470 tU as of 1 January 2019.

Central and South America

Governments in Argentina and Brazil continue to support nuclear power, suggesting some growth in nuclear generating capacity in the long term, despite other countries in the region reportedly turning away from plans to install nuclear generating capacity following the Fukushima Daiichi accident.

In Argentina, three reactors were operational on 1 January 2019, accounting for 5% of domestic electricity production in 2018. The Embalse reactor returned to service in 2020 following a three-year upgrade and refurbishment programme that will allow it to operate for a further 30 years. This included increasing its net capacity by around 35 MWe. In addition to providing electricity, Embalse can now also produce Cobalt-60 for medical and industrial applications. An operating lifetime extension project at Atucha 1 was resumed in April 2020. In addition, the National Atomic Energy Commission (CNEA) is completing the development and construction of the CAREM-25 (25 MWe), a small locally designed power reactor, and is planning to build other larger units by 2032.

In Brazil, two reactors (Angra 1 and 2, 0.5 GWe net and 1.3 GWe net, respectively) were operational on 1 January 2019, providing about 3% of electricity generated in the country in 2018. Construction of the Angra-3 reactor (1.2 GWe net) was restarted in 2010 but was then suspended in 2015 following cost overruns and corruption issues. Recently, Brazil approved a plan to complete Angra 3 Brazil's Investment Partnership Program. The plan allows for Electronuclear to recruit a partner to help finance the project and share its ownership (minority stake) and operation. The national long-term electricity supply plan includes a total of 4 GWe nuclear generating capacity installed by 2030 in order to help meet rising energy demand.

Other countries in the region, currently without NPPs, have been considering the development of such facilities, including Bolivia, Chile, Cuba, Uruguay and Venezuela. Venezuela has put its nuclear development plans on hold. Legislation in Uruguay promotes development of renewable energy sources, which means putting nuclear development plans on hold for the time being.

The uranium requirements for Central and South America amount to about 515 tU as of 1 January 2019.

Africa

Nuclear capacity remained constant in Africa with the region's only two operational reactors located in South Africa. However, government plans to increase nuclear generating capacity are projected to drive growth in this region. Although several countries are considering adding NPPs to the generation mix to help meet rising electricity demand, development of the required infrastructure and human resources could delay these ambitions.

In Egypt, plans are advancing to host four VVER-1200 units at the El Dabaa site on the Mediterranean coast. The construction permit is expected in the second half of 2021. In December 2017, Egypt's energy minister and Russian Rosatom signed several separate contracts, including a "turnkey" contract, the nuclear fuel supply for the plant's 60-year lifetime, operation and maintenance for the first 10 years, and a contract for the training of Egyptian personnel. Previously, in May 2016, the Egyptian President issued a decree approving a USD 25 billion loan from Russia to Egypt covering 85% of project costs.

In South Africa, two operational units (a total of 1.86 GWe net) accounted for about 5% of the total electricity generated in the country in 2018. Coal-fired plants dominate current electricity generation. In order to meet electricity demand, avoid additional power shortages and reduce carbon emissions, South Africa solicited bids from several reactor vendors during the past years, but the process was put on hold owing to cost concerns. Early in 2020, South Africa's government issued a nuclear energy roadmap calling for the development of 2.5 GWe in the medium-term to bolster employment, enhance energy security, and reduce carbon emissions. In June 2020, the government revived prospective nuclear new build plans by issuing a Request for Information to vendors of both large conventional reactors and SMRs for information on their technologies and possible financing strategies.

Although no other countries in Africa have NPPs at this time, several have expressed interest in developing nuclear power for electricity generation and desalination in recent years, including Algeria, Ghana, Kenya, Morocco, Namibia, Niger, Nigeria, Tanzania, Tunisia and Uganda.

In 2018, the Ghana Nuclear Power Programme Organisation launched "Nuclear Power Ghana" and the government is aiming to commission Ghana's first reactor after 2030. However, any new nuclear plant would likely rely on selling output to the West African Power Pool and on building up an infrastructure that could endorse such a programme.

Annual reactor-related uranium requirements for Africa amounted to about 290 tU as of 1 January 2019.

South-eastern Asia

No reactors were operational in this region at the end of 2018, but several countries are considering nuclear development plans, as the region continues to experience strong economic growth. Concerns about climate change, security of energy supply and energy mix diversification along with volatile fossil fuel prices are driving nuclear development policies, but political support has generally been weak owing to public safety and cost concerns.

In Malaysia, driven by an emerging gap in electricity production and the need to diversify the energy mix, a target of 2 GWe of nuclear generating capacity was adopted in 2011. However, it was reported that the programme was postponed as a result of public distrust following the Fukushima Daiichi accident. Nevertheless, work continues through efforts to promote public acceptance, adopt the necessary regulations, sign required international treaties and obtain low-cost financing.

In Thailand, the revision of the National Energy Policy Council scaled back the planned contribution from nuclear energy from 10% to 5% and set back the schedule for the installation of the first unit from 2020 to 2028. The postponements were implemented in order to ensure safety and improve public understanding of nuclear energy. Currently, Thailand relies on natural gas to generate over 70% of its electricity. Domestic fossil fuel energy reserves are in decline and electricity demand is expected to double by 2024.

In Viet Nam, as a result of increasing electricity demand, along with a reliance on hydropower with little prospect for expansion and a shortage of fossil fuels, the government has established a master plan with a goal of nuclear power supplying as much as 25% of domestic electricity production by 2050. In 2013, it was announced that construction of a centre for nuclear science technology would be undertaken, funded by loans from Russia to further accelerate training. In 2015, Rosatom and Electricity of Vietnam signed a framework agreement for the construction of unit 1 at the proposed Ninh Thuan nuclear power plant. However, in November 2016, the Vietnamese Parliament voted on a decision to abandon its nuclear programme.

The governments of Indonesia, the Philippines and Singapore have considered the use of nuclear power to help meet rising electricity demand despite recurring large-scale natural hazards. In July 2020, the president of Philippines announced an executive order to put in place an interagency panel to look at creating a national policy for nuclear energy. Coal-fired power generation accounts for more than half of the Philippines' electricity.

Pacific

This region has no commercial nuclear capacity at present. Current policy prohibits the development of commercial nuclear energy in Australia. However, a new interest in nuclear power was prompted by the South Australian premier in 2015 when it was announced that a Royal Commission would investigate South Australia's future role in the nuclear fuel cycle. In 2019, Australia's House of Representatives Standing Committee on the Environment and Energy commenced an inquiry into the prerequisites for nuclear energy production in Australia. The committee considered a range of matters including energy affordability and reliability, economic feasibility and workforce capability, waste management, health and safety, environmental impacts, community engagement and national consensus.

Projected nuclear power capacity and related uranium requirements to 2040

Factors affecting nuclear capacity and uranium requirements

Reactor-related requirements for uranium over the short term are fundamentally determined by installed nuclear capacity, or more specifically by the number of kilowatt-hours of electricity generated in operating NPPs. Since the majority of the anticipated near-term capacity is already in operation or under construction, short-term requirements can be projected with greater certainty. However, both short-term and long-term requirements are much more challenging to project following the accident at the Fukushima Daiichi NPP and the shift towards liberalisation of electricity markets.

Uranium demand is also directly influenced by changes in the performance of installed NPPs and fuel cycle facilities, even if the installed base capacity remains the same. Energy availability and capacity (or load) factors have increased to over 80% in the period 2000-2010 (IAEA, 2020). Increased load factors tend to increase uranium requirements. However, unexpected events in recent years have disrupted the trend of increasing load factors. The world average load factor declined to 77.4% in 2011 and further to 73.1% in the period 2012-2015 (IAEA, 2020b) following the Fukushima Daiichi accident. Nevertheless, in 2019 the global average load factor was 76.2%, up from 74.5% in 2018 and 73.0% in 2016, (IAEA, 2020b).

Other factors that affect uranium requirements (see Table 2.3.) include fuel cycle length, enrichment level, burn-up, improved fuel design, as well as strategies employed to optimise the relationship between the price of natural uranium (NatU) and enrichment services. A reduction of the enrichment tails assays from 0.3 to 0.25% ^{235}U would, all other factors being equal, reduce uranium demand by about 9.5% and increase enrichment demand by about 11%. The tails assays selected by the enrichment provider is dependent on many factors, including the ratio between natural uranium and enrichment prices. Generally, increased uranium prices have provided an incentive for utilities to reduce uranium requirements by specifying lower tails assays at enrichment facilities, to the extent possible, in contracts and the ability of the enrichment facilities.

Table 2.3. **Key takeaways on uranium sensitivity to various parameters**

Factor	Base value	Change	Impact on uranium requirements
Capacity (or load factor)	80%	+5% -5%	+6% -6%
Tails assays	0.25%	+0.03% -0.03%	+6% -6%
Burn-up	40 GWd/tU	+5 GWd/tU +10 GWd/tU	-3% -4-5%
Cycle length	12 months	+6 months +12 months	+7% +18%

Source: WNA, 2019; NEA/IAEA estimate.

Overcapacity in the enrichment market since the Fukushima Daiichi accident has provided incentive to operators to "underfeed" enrichment facilities by extracting more ^{235}U from the uranium feedstock. This reduces the amount of uranium required to produce contracted quantities of enriched uranium and, in turn, creates a stockpile of uranium. In recognition of these recent market trends, uranium requirements for the operational lifetime of projected new reactors in this publication have been reduced from 175 tU/GWe/yr, assuming a tails assay of 0.30% (2012 edition), to 160 tU/GWe/yr, assuming a tails assay of 0.25% over the lifetime of the reactor. In the absence of data provided by governments, this uranium requirement factor has been applied in this edition of the Red Book.

Enrichment providers have indicated that they are considering re-enrichment of depleted uranium tails in modern centrifuge facilities as an economic means of creating additional fissile material suitable for use in civil nuclear reactors. In addition, technological development of laser enrichment led to an agreement in 2013 between the US Department of Energy (DOE) and Global Laser Enrichment (GLE) to further develop the technology using a portion of the US inventory of high assay uranium tails. Successful deployment of laser enrichment to re-enrich depleted uranium tails could bring a significant source of secondary supply to the uranium market in the mid-term, although technological hurdles remain to be overcome before commercial deployment can be achieved. In the United States, development of the GE-Hitachi laser enrichment technology has slowed, reflecting depressed market conditions.

The combined impact of strategies to optimise reactor operation and fuel costs, as well as unanticipated reactor closures and the idling of reactors in Japan, are evident in the uranium requirements data collected for this edition, since global requirements have decreased from 63 875 in 2011 to 57 980 tU in 2015 and increased to 59 200 tU as of 1 January 2019. Uranium requirements (defined in the Red Book as anticipated acquisitions, not necessarily consumption) are, however, expected to increase in the coming years as the significant amount of capacity currently under construction comes online, particularly in Asia.

Current reactors and new nuclear capacity will impact uranium requirements

The strong performance and economic competitiveness of existing plants, chiefly because of low operating, maintenance and fuel costs, has made retention and improvement of existing plants desirable in many countries. This has resulted in a trend to keep existing plants operating as long as this can be achieved safely and upgrading existing generating capacity where possible. This strategy has been undertaken in the United States, and other countries have or are planning to upgrade their generating capacities and/or extend the lives of existing NPPs (e.g. Canada, the Czech Republic, Hungary, Mexico, the Netherlands, the Slovak Republic and Russia).

Competition from renewable energy sources and low natural gas prices as a result of technological advances in shale gas recovery have nevertheless rendered some plants uneconomic in liberalised energy markets in the United States, thus leading to shut downs before the end of the originally planned operational lifetime (e.g. Kewaunee, Vermont Yankee, Fort Calhon 1 or Pilgrim). As end of 2019, another five US reactors had announced to shut down before 2026, primarily due to historical low electricity prices in deregulated markets and other economic pressures. Regulatory responses to the Fukushima Daiichi accident have also increased operating costs that may affect the competitiveness of other reactors, in particular the smaller, single units operating in liberalised markets.

Installation of new nuclear capacity will increase uranium requirements, particularly since first load fuel requirements are roughly some 60% higher than reloads for plants in operation, providing that new build capacity outweighs retirements. A wide range of factors must be taken into consideration before any new significant building programmes are undertaken. These factors include projected electricity demand, security and cost of fuel supplies, the cost of financing these capital-intensive projects, the competitiveness of nuclear power compared to other generation technologies and environmental considerations, such as greenhouse gas emission reduction targets. Proposed waste management strategies and non-proliferation concerns stemming from the relationship between the civil and military nuclear fuel cycles also must be addressed. Following the Fukushima Daiichi accident, public acceptance of the safety of nuclear energy will require greater attention and this remains a pivotal issue in Japan.

Declining electricity demand in several developed countries, the low cost of natural gas in the United States, competition from renewable energy sources and the challenge of raising the significant investment required for capital-intensive projects with lengthy regulatory approval and construction times like NPPs, has made nuclear power development generally more challenging, particularly in liberalised energy markets.

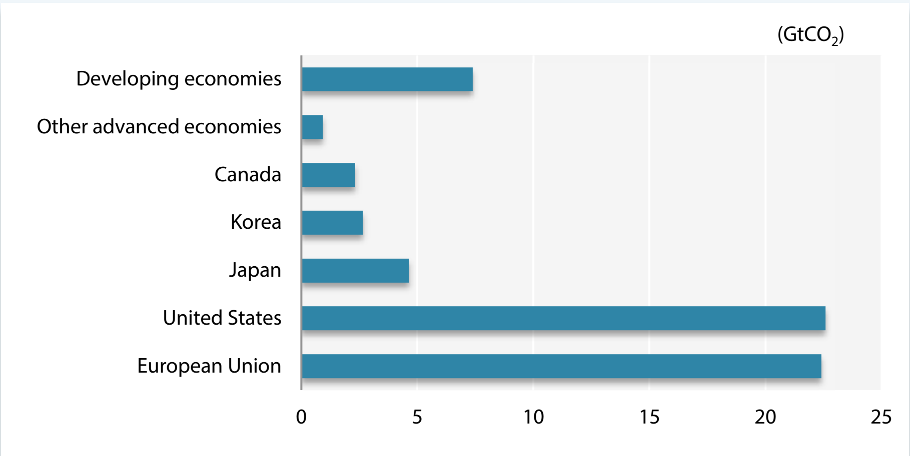
However, despite these challenges and the reaction of a few countries to back away from nuclear power following the Fukushima Daiichi accident (i.e. the strengthening of nuclear phase-out programmes in Belgium and Germany), many countries have decided that, on balance, objective analysis of these factors supports development of nuclear power. This is particularly so in countries with air pollution issues like China and India where coal-fired generation still provides a major part of electricity. Significant nuclear build programmes are underway in China and are continuing in India. Although the impacts of the global financial crisis have slowed the implementation of ambitious new build plans in some countries (e.g. South Africa), several other nations remain committed to long-term growth in nuclear generating capacity. Smaller scale programmes to increase nuclear generating capacity are underway in the Czech Republic and Finland, for example, while Poland continues to work towards the construction of its first reactors. In the United States, despite the unexpected closure of some reactors and the Westinghouse bankruptcy, construction activities are underway at the two units of the Vogtle plant.

The 2020 World Energy Outlook (IEA, 2020) outlined that the COVID-19 pandemic has caused a major disruption to the energy sector, leaving impacts that will be felt for years to come. The IEA estimated that global energy demand is set to decrease by 5% in 2020, CO_2 emissions by 7%, and energy investment by 18%. The impacts vary by fuel, with falls of 8% in oil demand and 7% in coal use, in contrast to 4.5% for nuclear and a slight rise in the contribution of renewables. Global electricity demand is estimated to drop only by 2% for 2020. Prior to the COVID-19 crisis, energy demand was projected to increase by 12% between 2019 and 2030. Growth over this period is now set to 9% in the Stated Policy Scenario, and 4% in the Delayed Recovery Scenario with increases coming from emerging markets and developing economies, led by India (IEA, 2020). However, a different pathway, the Sustainable Development Scenario (SDS) together with the Sustainable Recovery Plan, was set by IEA, showing governments the opportunity to boost economic recovery, create jobs and reduce greenhouse gas emissions. Full implementation of this scenario will require major investments in clean energy technologies over the next ten years, directed towards improvements in efficiency, low-emissions power and electricity grids, and more sustainable fuels. To achieve the clean energy transition identified in the IEA's SDS, near-term actions to boost nuclear power, including supporting lifetime extensions and expanding new build projects including small modular reactors, are required.

Box 2.1. **Nuclear power and clean energy transitions**

Nuclear power has avoided about 63 Gt of CO_2 emissions over the past 50 years equivalent to 2 years of global energy-related CO_2 emissions (IEA, 2019). Without nuclear power, emissions from electricity generation would have been almost 20% higher. About 90% of the avoided emissions were in advanced economies with the European Union and United States each avoiding approximately 22 $GtCO_2$ (see Figure 2.3). Without nuclear power, emissions from electricity generation would have been 25% higher in Japan, 45% higher in Korea and over 50% higher in Canada over the period 1971-2018 (IEA, 2019). In order to be on track with sustainability targets, including international climate goals, the expansion of clean electricity would need to be three times faster than at present (IEA, 2019). It would require 85% of global electricity to come from clean sources, by 2040, including nuclear, compared with just 36% today. In the absence of further lifetime extensions and new nuclear projects, it could result in additional 4 billion tonnes of CO_2 emissions, underlining the importance of the nuclear fleet to low-carbon energy transitions around the globe.

Figure 2.3. **Cumulative CO_2 emissions avoided by nuclear power in selected countries over the period 1971-2018**



Source: IEA, 2019

The extent to which nuclear energy is seen as beneficial in meeting low-carbon reduction targets could have an effect on the role that nuclear energy plays in meeting future electricity demand.

Projections to 2040

Projections of nuclear capacity and reactor-related uranium requirements are based on official responses from member countries to questionnaires circulated by the NEA/IAEA and projections established by an expert group (IAEA/NEA) and published in the IAEA report *Energy, Electricity and Nuclear Power Estimates for the Period up to 2050*. Because of the uncertainty in nuclear programmes in the years 2020 onward, high and low values are provided. The low case forecast assumes current market and technology trends continue with few additional changes in policies and regulations affecting nuclear power and includes implementation of phase-out or reduced nuclear generation policies. The high case assumes that current rates of economic and electricity demand growth continue. It also assumes changes in country policies towards the mitigation of climate change.

Forecasts of installed capacity and uranium requirements, although uncertain because of the factors mentioned in the previous section, continue to point to long-term growth. Installed nuclear capacity is projected to increase from about 400 GWe net at the beginning of 2019 to between about 354 GWe (low case) and 626 GWe (high case) by the year 2040. The low case represents a decrease of about 11% from 2018 nuclear generating capacity, while the high case represents an increase of about 58% (see Table 2.4 and Figure 2.4). By 2030, high case scenario projection sees an increase of 26%, indicating that significant expansion activities are already underway in several countries, compensating the announced NPPs closure programmes in other countries (e.g. Germany, Belgium).

Table 2.4. **Installed nuclear generating capacity to 2040***

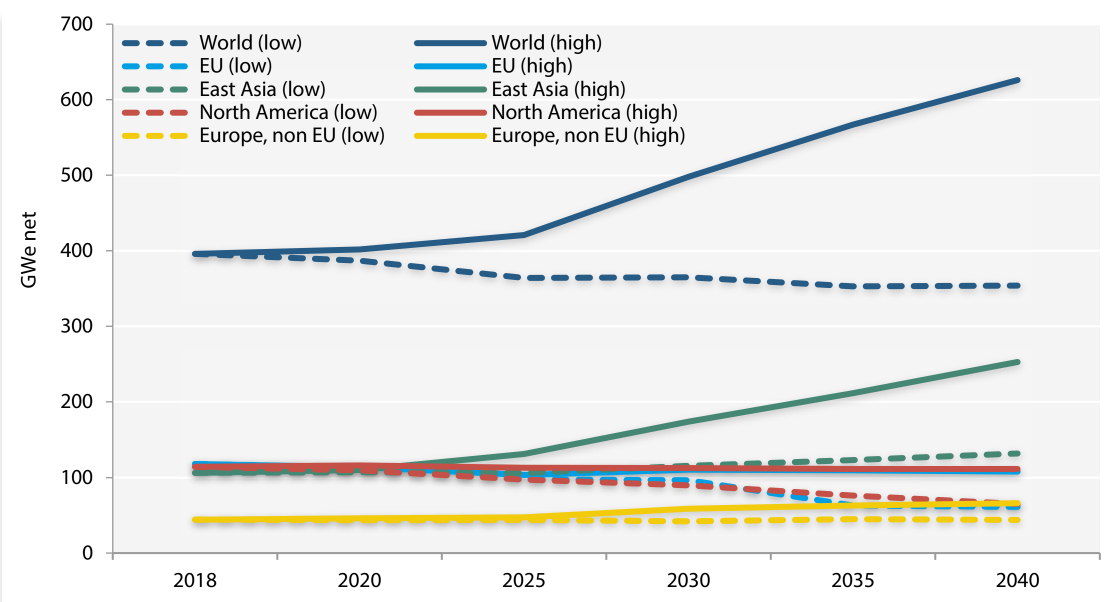
(GWe net)

	2018	2020 Low	2020 High	2025 Low	2025 High	2030 Low	2030 High	2035 Low	2035 High	2040 Low	2040 High
European Union	117.9	113.4	113.9	97.1	103.4	86.6	110.3	62.8	109.5	61.1	108
North America	114.1	109.5	116	97.2	112.8	89.8	112.5	76.2	111.4	65	111.3
East Asia	106.1	106.8	110.1	105.8	131.2	115.3	173.8	123.3	211.8	131.8	252.9
Europe (non-EU)	44.1	43.3	46.2	43.8	47.2	42	58.8	44.9	63.1	43.7	66
Central and South America	3.5	3.5	3.5	3.2	3.5	4.5	5.6	7	9.7	6.4	10.7
Middle East, Central and South Asia	8.4	8.4	10.1	15.2	21.3	24	33.2	36.7	53.1	41.6	63.8
South-eastern Asia	0	0	0	0	0	0	0	0	0	1	3
Africa	1.8	1.8	1.8	1.8	1.8	3	4.2	2.4	8.7	3.4	10.7
Pacific	0	0	0	0	0	0	0	0	0	0	0
World Total	396	387	402	364	421	365	498	353	567	354	626

* NEA/IAEA estimate based on government-supplied responses to a questionnaire and data established by a group of experts (IAEA/NEA) and published in IAEA, 2020a.

Figure 2.4. **Projected installed nuclear capacity to 2040**

(low and high projections)



However, these projections are subject to uncertainty, since the role that nuclear power will play in the future generation mix in some countries has not yet been determined. Over the short term, in both low and high case, competitive challenges from other electricity generation sources, along with nuclear policy hurdles, will continue to affect nuclear growth in some regions of the world. In addition, new safety requirements have in general strengthened the robustness of responses to extreme events, but the costs of implementing these measures could reduce the competitiveness of nuclear power in some liberalised markets.

The low case installed nuclear capacity projection to 2025 has increased by 5% compared to the last edition of this publication in 2018. The low case scenario incorporates the current phase-out policies in Belgium and Germany and reduced expectations of capacity additions or delays in nuclear projects in several countries (e.g. India, Korea, Romania, Sweden and the United States). Nevertheless, France delayed the timeline of planned reduction of nuclear power in the share of electricity mix from the previous 2025 target to 2035. In Japan, installed nuclear capacity is projected to decline from 36.4 GWe in 2018 to about 26.2 GWe by 2025 (low case) as reactors are permanently shut down owing to a range of factors including location near active faults, technology, age and local political resistance.

The high case projection to 2025 has increased by 5% compared to projections made in 2018. In the Unites States, state-level price support in the form of zero-emission credits or zero-emission certifications, has resulted in the reversal of previously announced NPP shutdowns in some states (e.g. New York, Illinois). In the United Arab Emirates, Barakah 1, started operation in August 2020 and will be followed by three more reactors. However, expectations of nuclear capacity additions in a number of countries (e.g. Argentina, Armenia, Brazil, China, the Czech Republic, Korea, Ukraine, the United Kingdom and the United States) have been delayed or reduced. Construction launches have been low in China in recent years (0.6 GWe in 2017 and 2.1 GWe in 2019). The high case global projection to 2035 is similar to the last edition of this publication in 2018. Several currently operating reactors, mainly in the OECD area, were set on a path for early decommissioning as a result of economic challenges or policy decisions. Nevertheless, in 2018, construction started on the first of four planned reactors in Turkey and the first formal start of nuclear construction in the Western Europe since 2007 began at Hinkley Point C in the UK. The high case projection for Japan sees installed capacity staying about the same, as several reactors remain in service and ageing units are replaced by new reactors.

Nuclear capacity projections vary considerably from region to region. The East Asia region is projected to experience the largest increase and could result in the installation of between 26 GWe and 147 GWe of new capacity in the low and high cases, respectively, by the year 2040, representing increases of about 24% and 138% over 2018 capacity. While representing significant regional capacity increases, it is important to note that countries of this region, namely China and Korea have demonstrated the ability to build multiple reactors with predictable costs and schedules.

Other regions projected to experience significant nuclear capacity growth include the Middle East, and the Central and Southern Asia region, with India's ambitious expansion plan and several potential newcomer countries (Kazakhstan, Saudi Arabia or Uzbekistan). Nuclear capacity in non-EU member countries on the European continent is also projected to increase considerably, with 66 GWe of capacity projected by 2040 in the high case (increases of about 50% over 2018 capacity). More modest growth is projected in Africa, Central and South America and the South-eastern Asia regions.

For North America, the projections see nuclear generating capacity decreasing by 2040 in both the low and high case, depending largely on future electricity demand, lifetime extension of existing reactors and government policies with respect to greenhouse gas emissions. The reality of financial losses in several reactors in the United States, have resulted in a larger number of premature shutdowns to be assumed. In Canada, despite the reactor refurbishment programme that will result in the long-term operation of the actual fleet, there is little support for new reactor construction in the period to 2040, with the exception of small modular reactors. In the EU, nuclear capacity in 2040 is projected to decrease by 52% in the low case scenario and decrease by 8% in the high case. The low case projection includes the implementation of phase-out or reduced nuclear generation policies, continued growth of intermittent renewable energy sources and weak growth in electricity demand. In the high case, phase-out policies are maintained, but plans for the installation of additional nuclear generation capacity are assumed to be successfully realised in the Czech Republic, Finland, Hungary, Romania, Poland, and the United Kingdom.

World reactor-related uranium requirements by the year 2040 are projected to increase to a total of between 56 640 tU/yr in the low case and 100 224 tU/yr in the high case (see Table 2.5 and Figure 2.5). As a result of slight variations in installed nuclear capacity projections, projected uranium requirements to 2035 have increased by 7% in the low case and remained constant in the high case compared to the last edition of this publication in 2018.

Table 2.5. **Annual reactor-related uranium requirements to 2040**

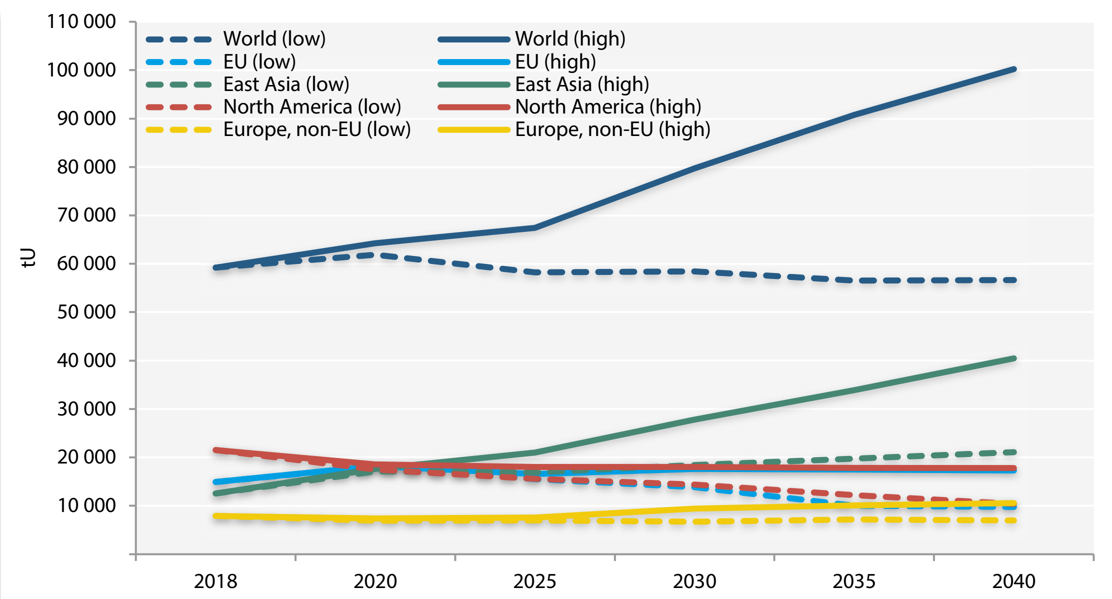
(tonnes U)

	2018	2020	2020	2025	2025	2030	2030	2035	2035	2040	2040
		Low*	High*	Low*	High*	Low*	High*	Low*	High*	Low*	High*
European Union	14 930	18 144	18 224	15 536	16 544	13 856	17 648	10 048	17 520	9 776	17 280
North America	21 520	17 520	18 560	15 552	18 048	14 368	18 000	12 192	17 824	10 400	17 808
East Asia	12 550	17 088	17 616	16 928	20 992	18 448	27 808	19 728	33 888	21 088	40 464
Europe (non-EU)	7 925	6 928	7 392	7 008	7 552	6 720	9 408	7 184	10 096	6 992	10 560
Central and South America	515	560	560	512	560	720	896	1 120	1 552	1 024	1 712
Middle East, Central and South Asia	1 470	1 344	1 616	2 432	3 408	3 840	5 312	5 872	8 496	6 656	10 208
South-eastern Asia	0	0	0	0	0	0	0	0	0	160	480
Africa	290	288	288	288	288	480	672	384	1 392	544	1 712
Pacific	0	0	0	0	0	0	0	0	0	0	0
World total	59 200	61 872	64 256	58 256	67 392	58 432	79 744	56 528	90 768	56 640	100 224

* NEA/IAEA estimate.

Figure 2.5. **Annual reactor uranium requirements to 2040**

(low and high projections)



As in the case of nuclear capacity, uranium requirements vary considerably from region to region, reflecting projected capacity increases and possible inventory building. Annual uranium requirements are projected to be largest in the East Asia region, where increased installed nuclear generating capacity (particularly in China) drives significant growth in uranium needs.

Uranium supply and demand relationships

Uranium supply has been adequate to meet demand for decades, and there have been no supply shortages since the last edition of this report. However, a number of different sources of supply are required to meet demand. The largest is the primary production of uranium that, over the past few years, has satisfied as much as 50 to 99% of world requirements. The remainder has been provided or derived from secondary sources including stockpiles of natural and enriched uranium, blending down weapons-grade uranium, reprocessing of spent fuel, underfeeding and uranium produced by the re-enrichment of depleted tails.

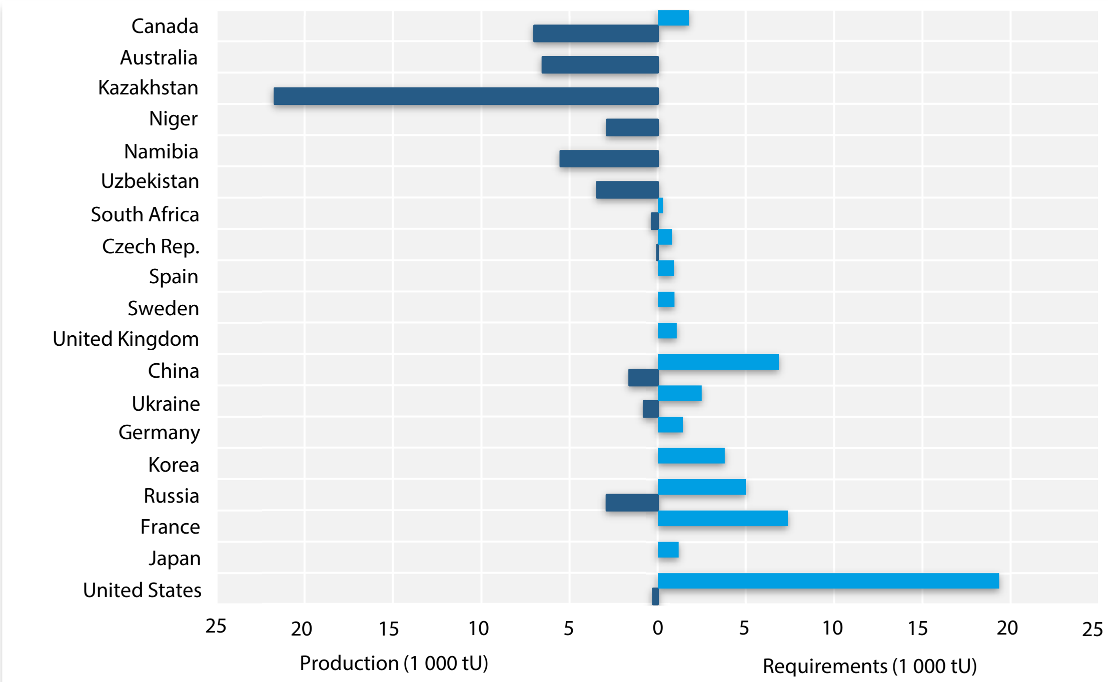
Primary sources of uranium supply

Uranium was produced in 18 countries in 2018 and 2019, with total global production amounting to 53 516 tU in 2018 and 54 224 tU in 2019 (see Table 1.18 and Figure 1.6). Of these 18 producing countries, three reported limited production through mine remediation efforts only (France, Germany and Hungary). Kazakhstan surpassed Canada in 2009 to become the world's largest producer and remained in this position through 2019, continuing its run of production increases over the past few years (24 689 tU in 2016), albeit levelling off from more increase in 2018 (21 705 tU) and 2019 (22 808 tU). The top six producing countries in 2018 (Kazakhstan, Canada, Australia, Namibia, Uzbekistan and Russia) accounted for 88% of world production and 12 countries – Kazakhstan, Canada, Australia, Namibia, Uzbekistan, Russia, Niger, China, Ukraine, India, South Africa and the United States – accounted for over 99% of global mine production. The COVID-19 pandemic triggered a decrease in the supply of uranium as main producers suspended uranium operations and closed temporarily their mines. In April 2020, Kazatomprom, Kazakhstan's state-owned uranium production company announced that it would halt new wellfield development, reduce the number of staff onsite to minimum possible levels and a reduction in production volumes by up to 4 000 tU is expected. In August, the company began returning staff to the mine sites and has continued with remote work where possible. Similarly, at the Cigar Lake mine and the McClean Lake uranium mill in northern Saskatchewan, Canada, production was temporarily suspended during the COVID-19 crisis with the workforce onsite declining. Since September, Cigar Lake/McClean restarted gradually their operations, nevertheless, a reduction of about 40% of production output is expected for 2020. Mining activities were also suspended in Namibia and South Africa. However, from the end of April, mines in South Africa were allowed to open but could only operate at 50% capacity. The Rössing mine in Namibia had also discontinued mining operations. Nevertheless, the suspension of uranium mining activity is not expected to create performance disruptions of nuclear power reactors in the near term due to significant stocks held by utilities and fuel cycle producers (see further section on stocks and inventories).

Of the 30 countries currently using uranium in commercial NPPs, only Canada and South Africa produced enough uranium in 2018 to meet domestic requirements (see Figure 2.6), thereby creating an uneven distribution between producing and consuming countries. All other countries with nuclear power must make use of imported uranium or secondary sources and, as a result, the international trade of uranium is a necessary and established aspect of the uranium market. Given the uneven geographical distribution between producers and consumers, the safe and secure shipment of nuclear fuel will need to continue without unnecessary delays and impediments. Difficulties that some producing countries have encountered with respect to international shipping requirements and transfers to international ports have therefore always been a matter of concern. However, efforts to objectively inform port authorities on the real risks involved and better recognition of the long-standing record of successful shipments of these materials, have helped avoid unnecessary delays.

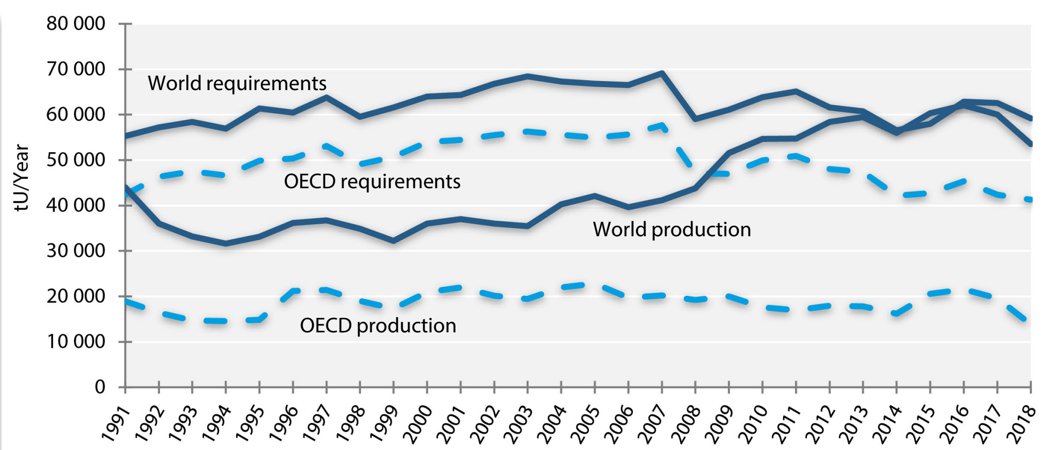
Figure 2.6. **Uranium production and reactor-related requirements for major producing and consuming countries**

(data as of 1 January 2019)



Because of the availability of secondary supplies, primary uranium production volumes have been significantly below world uranium requirements for some time. However, this trend changed in recent years as production has increased and requirements have declined. In 2017, world uranium production provided 95% of world reactor requirements, whereas in 2018, global primary production provided about 90% of requirements. In OECD countries, the gap between production and requirements has changed little as both have declined in the past years. In 2018, production of 13 838 tU provided only 34% of OECD requirements (41 285 tU; Figure 2.7). Remaining reactor requirements were met by imports and secondary sources.

Figure 2.7. **OECD and world uranium production and requirements**



Secondary sources of uranium supply

Uranium is unique among energy fuel resources in that historically, a significant portion of demand has been supplied by secondary sources rather than direct mine output. These secondary sources include: stocks and inventories of natural and enriched uranium, both civilian and military in origin; nuclear fuel from the reprocessing of spent reactor fuels and from surplus military plutonium; underfeeding; and uranium produced by the re-enrichment of depleted uranium tails.

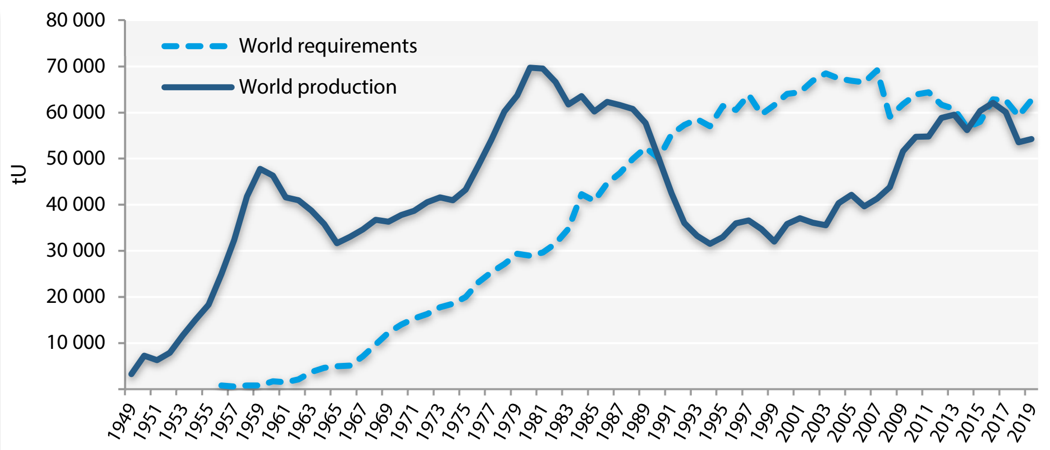
Natural and enriched uranium stocks and inventories

From the beginning of commercial exploitation of nuclear power in the late 1950s to 1990, uranium production consistently exceeded commercial requirements (see Figure 2.8). This was mainly the consequence of a lower than projected growth rate of nuclear generating capacity combined with high levels of production for strategic purposes. This period of over production created a stockpile of uranium potentially available for use in commercial power plants. After 1990, production fell well below demand and secondary supplies fed the market. Since 2008, requirements increased slightly before declining again in the last few years owing to unplanned reactor closures in Germany and Japan following the Fukushima Daiichi accident. The decline in requirements in 2018 was likely related to the reduced number of reactors being refuelled in Japan. Uranium production since 2007 has generally increased and has partially closed the gap between production and reactor requirements. However, more recently, producers have responded to the sustained uranium market downturn by temporarily shutting some operations and scaling back uranium production at other mines, thus a slight gap between supply and demand appeared again.

Following the political and economic reorganisation in Eastern Europe and the former Soviet Union in the early 1990s, steps have been taken to move towards the development of an integrated global commercial market. More uranium is now available from the former Soviet Union, most notably from Kazakhstan, but also from Russia and Uzbekistan. Despite these developments and more information being available on the amount of uranium held in inventory by utilities, producers and governments, uncertainties remain regarding the size and the mobility of these inventories, as well as the availability of uranium from other potential secondary supply sources. These latter uncertainties combined with uncertainty about the desired levels of commercial inventories, continues to influence the uranium market.

Figure 2.8. A**nnual uranium production and requirements**

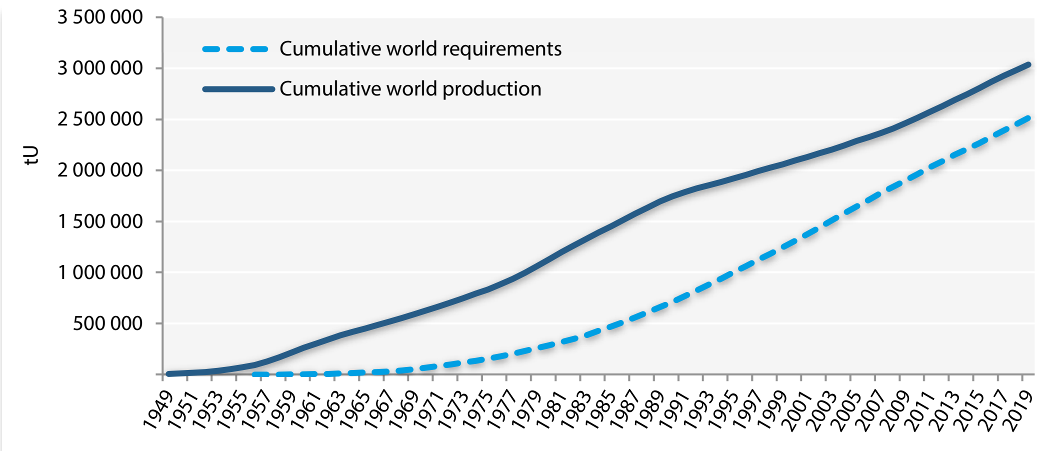
(1949-2019)



Data from past editions of this publication, along with information provided by member states, give a rough indication of the possible maximum upper level of the potential inventories commercially available. This leaves an estimated remaining stock of nearly 525 000 tU, which is a rough estimate of the upper limit of what could potentially become available to the commercial sector (see Figure 2.9). This base of already mined uranium has essentially been distributed into two sectors, with the majority used and/or reserved for the military and the remainder used or stockpiled by the civilian sector. However, since the end of the Cold War, increasing amounts of uranium, previously reserved for strategic purposes, have been released to the commercial sector.

Figure 2.9. **Cumulative uranium production and requirements**

(1949-2019)



Civilian inventories include strategic stocks, pipeline inventory and commercial stocks available to the market. In recent years, material held by financial investors has been a part of the inventory. Utilities are believed to hold the majority of commercial stocks because many have policies that require them to carry the equivalent of one to several years of natural uranium requirements. Despite the importance of this secondary source of uranium, information about the size of these stocks is limited because few countries are able or willing, because of confidentiality concerns, to provide detailed information on stockpiles held by producers, consumers or governments.

Nonetheless, available data suggest that industry has been decreasing inventories in recent years. In the United States, as of 1 January 2019, total commercial inventories (utilities and producers stocks) were 50 200 tU, a 8% decrease from the 54 488 tU of inventories held in 2017 (EIA, 2019). Nearly 85% of the commercial inventories were held by owners and operators of commercial reactors. Enriched uranium inventories held by utilities (including fuel elements in storage) decreased 7% from 2017 to 2018, whereas natural uranium inventories held by utilities (including UF_6 in storage) decreased 12% from 2017 to 2018.

In the European Union, uranium inventories held by utilities at the end of 2019 totalled 42 912 tU, enough for an average of three years' fuel supply, a slight decrease of 5% since the end of 2018 and a 17% reduction since 2015 (ESA, 2019, 2020) (see Table 2.6). These data from the two largest regions of nuclear power generation (EU and the US) suggest that commercial inventories have been generally decreasing.

Table 2.6. **Uranium inventories held by EU and US utilities**

(tonnes natural U equivalent at the end of the year)

Year	Inventories held by EU utilities (tU)	Inventories held by owners and operators of the US NPPs
2015	51 892	46 589
2016	51 514	49 217
2017	49 004	47 635
2018	45 342	42 759
2019	42 912	43 385[a]

Source: ESA Annual Report, 2019 and 2020; US EIA Uranium Marketing Annual report 2019 and 2020.

a) Preliminary data.

Uranium requirements are growing rapidly in East Asia, in particular in China. By 2035, demand in this region is expected to surpass both that of North America and the EU. Questionnaire responses received during the compilation of this edition revealed little about national inventory policies in the East Asia region. However, based on import statistics, it is estimated that China had accumulated an inventory of over 138 800 tU as of 1 January 2018. At the 2018 level of consumption, these inventories represent approximately 20 years of reactor uranium requirements. It is assumed that China held these stocks in anticipation of increasing uranium requirements due to the significant number of reactors under construction and planned, and also for strategic purposes. In 2015, the government of India announced its intention to create a “uranium reserve” by importing uranium into the country. It is estimated that India held an inventory level of approximately 9 430 tU as 1 January 2019 (WNA, 2019).

In recent years, commercial entities other than utilities have been holding quantities of uranium for investment purposes. Although commercially confidential, variable and largely dependent on uranium price dynamics, the US Energy Information Administration notes that US-based traders and brokers held about 4 000 tU as 1 January 2019 (EIA, 2019), a 25% increase compared to the levels at the end of 2016. Financial investors also hold a certain amount of uranium inventory. The Uranium Participation Corporation (UPC), for example, held about 6 192 tU as U_3O_8 and 400 kg as UF_6 as October 2020 (company website). Some banks have also purchased uranium stocks (e.g. Macquarie, Deutsche Bank). However, because of stricter regulations related to commodities activities, some banks have withdrawn from the uranium market.

Excess uranium inventories held by the US government were last reported in 2013. At that time, the government possessed 56 031 tU, which includes 17 596 tU of uranium concentrates, 12 485 tU of enriched uranium, and 25 950 tU of depleted uranium. In May 2014, the US Government Accountability Office reported that as of 31 December 2012, the US Department of Energy maintained an excess uranium inventory of 29 tU in highly enriched uranium (HEU); 48 tU in low-enriched uranium (LEU); 12 939 tU in natural uranium; 114 000 tU in high-assay depleted uranium tails; and 387 000 tU in low-assay depleted uranium tails. A DOE Secretarial Determination must be made in advance of sales or transfers of these inventories in order to provide assurance that the transactions will not have an adverse material impact on the domestic uranium mining, conversion or enrichment industries.

In the calendar year 2015, the DOE Secretarial Determination authorised the transfer of up to 2 000 tU to DOE contractors for clean-up services at the Portsmouth gaseous diffusion plant and up to 500 tNatU to the National Nuclear Security Administration (NNSA) for blending down HEU to low-enriched uranium (LEU). Other transactions involved the transfer of up to 9 082 t of depleted uranium (DU) to Energy Northwest in 2012 and 2013, the majority of which would be enriched for use in the company’s power reactor and the remainder sold to TVA as part of a commercial transaction to support future power generation and tritium production from 2013 through 2030. In 2016, the US DOE Secretary determined that exchange of LEU to HEU down-blending services serves national security purposes and that in this case the transfers no longer require a Secretarial Determination.

In 2017, the US DOE issued a new Secretarial Determination that further reduces transfers of material to support Portsmouth gaseous diffusion plant clean-up work to 1 200 tU as natural UF_6.

In 2018, the Secretary of Energy issued a determination covering the transfer of low-enriched uranium in support of the tritium production mission. The Secretarial Determination establishes the national security purpose of these transfers, therefore these uranium transfers were conducted under Section 3112(e)(2) of the USEC Privatisation Act of 1996.

Large stocks of uranium, previously dedicated to the military in both the United States and Russia, had become available for commercial applications, bringing a significant secondary source of uranium to the market. Despite the programmes outlined below, the remaining inventory of HEU and natural uranium held in various forms by these governments is significant, although official figures on strategic inventories are not available. If additional disarmament initiatives are undertaken to further reduce strategic inventories, several years of global supply of NatU for commercial applications could be made available.

HEU from Russia

Russia and the United States signed a 20-year, government-to-government agreement in February 1993 for the conversion of 500 t of Russian HEU from nuclear warheads to LEU suitable for use as nuclear fuel (referred to as the Megatons to Megawatts agreement). The United States Enrichment Corporation (USEC), the executive agent for this agreement, purchased the enrichment component of the LEU, about 5.5 million SWU per year from Techsnabexport (TENEX) of Russia. Under a separate agreement, the natural uranium feed component of the HEU purchase agreement was sold under a commercial arrangement between three western corporations (Cameco, Areva and Nukem) and TENEX. Deliveries under this government-to-government agreement were finalised at the end of 2013.

HEU from the United States

As of June 2015, the US DOE reported 15 t of unallocated HEU. Following the current campaign, the National Nuclear Security Administration (NNSA) plans to conduct HEU down-blending offering for tritium (DBOT) programme in fiscal years 2019-2025.

Fuel banks

Efforts by governments and international agencies have also resulted in actions to create nuclear fuel banks – another form of inventory.

Driven by rising energy needs, non-proliferation and waste concerns, governments and the IAEA have made a number of proposals aimed at strengthening non-proliferation by establishing multilateral enrichment and fuel supply centres.

In December 2010, the first LEU reserve was inaugurated in Russia at the International Uranium Enrichment Centre in Angarsk under IAEA auspices. This LEU reserve is comprised of 120 t LEU in the form of UF_6 enriched to 2%-4.95% ^{235}U. Under IAEA safeguards, the reserve will be made available to IAEA member states whose supplies of LEU are disrupted for reasons unrelated to technical or commercial issues. The LEU reserve is not intended to distort the functioning of the commercial market, but rather to reinforce existing market mechanisms of member states.

Also in December 2010, the IAEA Board of Governors authorised the IAEA Director-General to establish an LEU bank to serve as a supply of last resort for nuclear power generation. The IAEA reserve, is a backup mechanism to the commercial market in the event that an eligible member state's supply of LEU is disrupted and cannot be restored by commercial means. In May 2015, Kazakhstan signed a draft agreement with the IAEA to host the IAEA LEU bank at the Ulba Metalurgical Plant. The IAEA LEU bank is a physical reserve of up to 90 metric tons of low-enriched uranium suitable to make fuel for a typical light water reactor. In 2018, the IAEA signed contracts to purchase LEU from two vendors. The establishment and operation of the IAEA LEU bank is fully funded by voluntary contributions. Donors have provided a total of USD 150 million to establish the LEU Bank and operate it for at least ten years. Donors include the Nuclear Threat Initiative (NTI), the United States, the European Union, the United Arab Emirates, Kuwait, Norway and Kazakhstan.

Nuclear fuel produced by reprocessing spent reactor fuels and surplus weapons-related plutonium

The constituents of spent fuel from NPPs are a potentially substantial source of fissile material that could displace primary uranium production. When spent fuel is discharged from a commercial reactor, it is potentially recyclable since about 96% of the original fissionable material remains, along with the plutonium. The recycled plutonium can be reused in reactors licensed to use MOX. The uranium recovered through reprocessing of spent fuel, known as reprocessed uranium (RepU), is not routinely recycled; rather, it is stored for future reuse.

The use of MOX has not altered world uranium demand since only a relatively small number of reactors are using this type of fuel. As of January 2019, there were 29 reactors, or about 7% of the world's operating fleet, licensed to use MOX fuel, including reactors in France, Germany, India, Japan and the Netherlands (see Table 2.1). Reprocessing and MOX fuel fabrication facilities exist or are under construction in France, India, Japan and Russia. China is also building a pilot processing plant (200 tHM/yr), planned to be operational in the mid-2020s.

Following on basic research and MOX fuel fabrication for experimental reactors by the Japan Atomic Energy Agency (JAEA), Japan Nuclear Fuel Ltd (JNFL) began testing plutonium separation at the Rokkasho reprocessing facility in 2006. Japanese utilities began using MOX initially in fuel manufactured overseas. The use of imported MOX fuel was to be followed by the use of MOX produced at JNFL's MOX fuel fabrication facility (JMOX) adjacent to the Rokkasho reprocessing plant. JMOX construction began in 2010. Commercial operation of JMOX is expected to begin around 2022 (130 tHM/yr capacity).

Following the closure in 2003 of the Cadarache MOX fuel production plant in France and the MOX fuel plant in Belgium (Belgonucleaire) in 2006, the MELOX plant in Marcoule, France was licensed in 2007 to increase annual production from 145 tHM to 195 tHM of MOX fuel (corresponding to 1 560 tNatU). Annual MOX production in France varies below this licensed capacity, in accordance with contracted quantities. Most of the MOX production is used to fuel French NPPs (a total of about 120 t/yr; 960 tNatU) and the remainder is delivered abroad under long-term contract arrangements.

The Euratom Supply Agency (ESA) reported that the quantity of plutonium contained in the MOX fuel loaded into NPPs in the EU was 5 241 kg in 2019, a 35% decrease over the 8 080 kg used in 2018. Use of plutonium in MOX fuel reduced natural uranium requirements in the EU by an estimated 470 tU in 2019 (ESA, 2020). In the 1996-2019 period, MOX fuel use in EU reactors has displaced a cumulative total of 25 002 tU through the use of 228.05 t of Pu (ESA, 2020). Since the great majority of world MOX use occurs in Western Europe, this figure provides a reasonable estimate of the impact of MOX use worldwide on uranium requirements during that period. Responses to the questionnaire provide some additional data on the production and use of MOX (see Table 2.7).

Uranium recovery through reprocessing of spent fuel, known as RepU, has been conducted in the past in several countries, including Belgium and Japan (see Table 2.8). It is now routinely undertaken only in France and Russia, principally because the production of RepU is a relatively costly endeavour, in part because of the requirement for dedicated conversion, enrichment and fabrication facilities. Available data indicate that it represents less than 1% of projected annual world requirements. Reprocessing could become a more significant source of nuclear fuel supply in the future if China successfully commercialises the process. It was reported that China planned to move beyond conducting research and development of reprocessing and recycling technologies to build and operate a large-scale commercial facility with a capacity of about 800 tHM/yr in order to achieve maximum utilisation of uranium resources, given the country's rapidly rising requirements. Since 2007, China and France have reportedly been discussing the possibility of France supplying a commercial scale recycling facility.

Table 2.7. **MOX production and use**

(tonnes of equivalent natural U)

Country	Pre-2016	2016	2017	2018	Total to 2018	2019 (preliminary)
MOX production						
Belgium	523	0	0	0	523	0
France	21 781*	992	880	744	24 397	870
Japan	684	0	0	0	684	0
United Kingdom	NA	NA	NA	NA	NA	NA
MOX use						
Belgium	520	0	0	0	520	0
France	NA	960	712	582	NA	NA
Germany	6 730	NA	NA	NA	NA	NA
Japan	984	18	NA	NA	NA	NA
Switzerland	1 407	0	0	0	1 407	0

NA = Not available or not disclosed.

* Includes Cadarache historical production and Marcoule production adjustment.

Table 2.8. **Reprocessed uranium production and use**

(tonnes of equivalent natural U)

Country	Total to end of 2015	2016	2017	2018	Total to end of 2018	2019 (preliminary)
Production						
France	25 904	1 026	1 026	1 026	28 982	1 026
Japan(a)	645	0	0	0	645	0
Russia	NA	NA	NA	NA	NA	NA
United Kingdom(a)	15 000	0	0	0	NA	0
Use						
Belgium(b)	508	0	0	0	508	0
France(a)	5 300	0	0	0	5 300	0
Germany	NA	NA	NA	NA	NA	NA
Japan	217	0	0	0	217	0
Switzerland(a)	1 698	273	149	149	2 573	116
United Kingdom(a)	1 726	0	0	41	1 767	39

NA = Data not available.

(a) 2019 edition of *NEA Nuclear Energy Data*.

MOX produced from surplus weapons-related plutonium

In September 2000, the United States and Russia signed the Plutonium Management and Disposition Agreement that committed each country to dispose of 34 t of surplus weapons-grade plutonium at a rate of at least 2 tonnes per year in each country, once production facilities are in place. Both countries agreed to dispose of the surplus plutonium by fabricating MOX fuel suitable for irradiation in commercial nuclear reactors.

In the United States, the MOX fuel was to be fabricated at the DOE's Savannah River complex in South Carolina. The DOE's NNSA awarded a contract for construction of the Mixed Oxide Fuel Fabrication Facility (MFFF) in 2001 and construction was officially started in 2007. In mid-2013, however, it was reported that the project had encountered technical difficulties and was running over budget. Since 2014, the project has seen progressive cuts to its funding as the DOE's National Nuclear Safety Administration embarked on a review of its plutonium disposition strategy. The DOE NNSA terminated the MOX project in October 2018. The facility was being built as part of the 2000 agreement with Russia whereby each country would dispose of 34 tonnes of weapons-grade plutonium. Russia – which had agreed to dispose of the material in fast reactors – suspended the agreement in October 2016.

The Russian MOX facility was reportedly abandoned in favour of burning excess plutonium in fast breeder reactors (WNA, 2017). A MOX fuel fabrication facility established by Mining and Chemical Combine (MCC) Zheleznogorsk, a Rosatom subsidiary, was officially started in 2015. Russia has no commercial reactors using MOX fuel, but its BN-800 fast neutron reactor will use MOX fuel. In August 2020, the MCC has received a five-year licence for the industrial production of MOX fuel for the Beloyarsk-4 BN-800 fast neutron reactor.

Uranium produced by re-enrichment of depleted uranium tails[2] *and uranium saved through underfeeding*

Depleted uranium stocks represent a significant source of uranium that could displace primary production. However, the re-enrichment of depleted uranium has been limited since it is only economic in enrichment plants with spare capacity and low operating costs.

At the end of 2018, the inventory of depleted uranium was estimated to amount to about 1 210 100 tU (WNA, 2019). Following the construction of new centrifuge enrichment facilities and declining demand since the Fukushima Daiichi accident, spare enrichment capacity is currently available, and it has been reported that tails assays are being driven downward at enrichment facilities to underfeed the centrifuge plants and create additional uranium inventory.

Deliveries of re-enriched tails from Russia had been an important source of uranium for the EU, representing 1 to 3.7% of the total natural uranium delivered annually to EU reactors between 2005 and 2009 (see Table 2.9). However, contracts with EU utilities came to an end in 2010. EU enrichers are now putting in place long-term strategies to manage enrichment tails remaining from enrichment activities, including deconversion of UF_6 to the more stable form U_3O_8. Currently, deconversion takes place in France, and Urenco UK is constructing a tails management facility.

Table 2.9. **Russian supply of re-enriched tails to EU end users**

Year	Re-enriched tail deliveries (tU)	Percentage of total natural uranium deliveries
2007	388	1.8
2008	688	3.7
2009	193	1.1
2010	0	0.0

Source: ESA *Annual Report*, 2011.

2. Depleted uranium is the by-product of the enrichment process having less ^{235}U than natural uranium. Normally, depleted uranium tails contain between 0.25 and 0.35% ^{235}U compared with the 0.711% ^{235}U found in nature.

In the United States, the DOE and the Bonneville Power Administration initiated a pilot project to re-enrich 8 500 tonnes of the DOE's enrichment tails inventory. Between 2005 and 2006, this project produced approximately 1 940 tU equivalent for use between 2007 and 2015 at Northwest Energy's 1 190 MWe Columbia generating station. In mid-2012, Northwest Energy and USEC, in conjunction with the DOE, developed a new plan to re-enrich a second portion of DOE's high assay tails. The resulting LEU is to be used to fuel Northwest Energy's Columbia generating station through 2028.

As noted above, GE-Hitachi Global Laser Enrichment proposed to build and operate a tails processing plant using Silex laser enrichment technology on land adjacent to the closed Paducah gaseous diffusion enrichment plant. Successful development of laser enrichment could potentially result in an additional supply of uranium to the market in the longer term. However, GE-Hitachi Global Laser Enrichment recently announced plans to slow development of its laser technology because of poor market conditions. Some other commercial enrichment providers (e.g. Urenco) have indicated an interest in using centrifuge enrichment capacity for tails re-enrichment.

Additional information on the production and use of re-enriched tails is not readily available. However, the information provided in questionnaire responses (see Table 2.10) indicates that its use has been limited between 2016 and 2019.

Table 2.10. **Re-enriched tails production and use**

(tonnes of equivalent natural U)

Country	Total to end of 2015	2016	2017	2018	Total to end of 2018	2019 (preliminary)
Production						
France	NA	NA	NA	NA	NA	NA
United States	5 678	0	0	0	5 678	0
Netherlands[(a)]	9 207	3 064	3 252			
Use						
Belgium[(b)]	345	0	0	0	345	0
Finland	843	0	0	0	843	0
France	NA	NA	NA	NA	NA	NA
Sweden[(a)]	3 079	200	200	200	3 679	200
United States	1 940	0	0	0	1 940	0

NA = Data not available.

(a) 2019 edition of *NEA Nuclear Energy Data*.

(b) Purchased for subsequent re-enrichment.

Underfeeding

The potential for *underfeeding* of enrichment plants is also a source of secondary supply, which has become more important in the last few years. Overcapacity in the enrichment market since the Fukushima Daiichi accident has provided incentive to operators to "underfeed" enrichment facilities by extracting more ^{235}U from the uranium feedstock. This reduces the amount of uranium required to produce contracted quantities of enriched uranium and, in turn, creates a stockpile of uranium that can be sold. It is estimated that global underfeeding and tails re-enrichment contribute up to 6 000 tU of supply per year (WNA, 2019).

In recent years, secondary supply has shown a downward trend resulting from the end of the "Megatons to Megawatt" agreement. However, the level of secondary supply is currently around 10 000 tU/yr and is likely to decrease to about 5 000 to 6 400 tU/yr by 2040 (WNA, 2019).

Uranium market developments

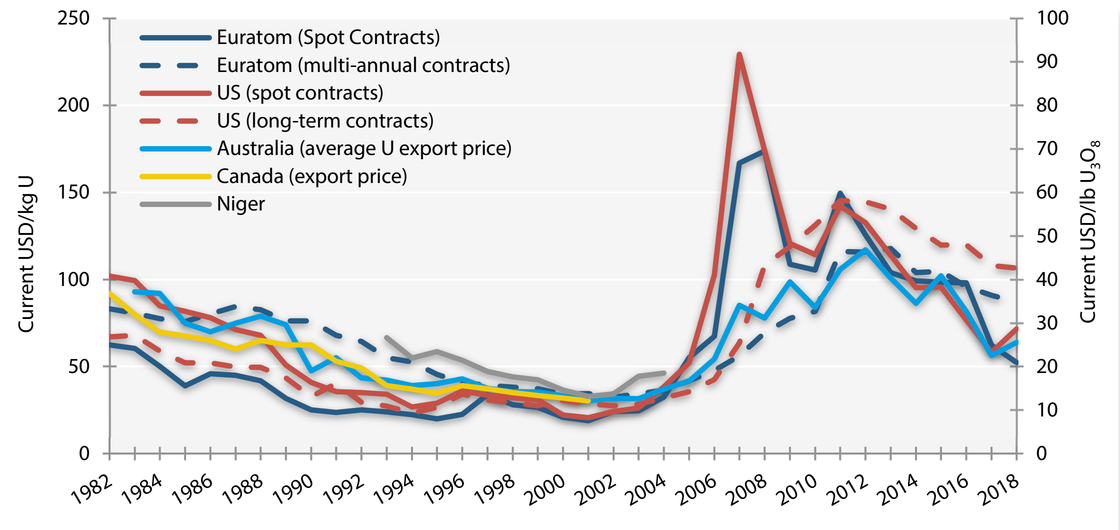
Uranium price developments

Some national and international authorities (Australia, the United States and Euratom), publish price indicators to illustrate uranium price trends for both long-term and short-term (spot price) contract arrangements. Australian data record average annual prices paid for exports, whereas Euratom (ESA) and US data show costs of uranium purchases in a particular year. Canada and Niger published export prices for some years, but neither continue to do so. Figure 2.10 displays this mix of annual prices reported for both short-term and longer-term purchases and exports.

The overproduction of uranium, which lasted through 1990 (see Figure 2.8), combined with the availability of secondary sources, resulted in uranium prices trending downward from the early 1980s through the mid-1990s, bringing about significantly reduced expenditures in many sectors of the world uranium industry, including exploration and production. The bankruptcy of an important uranium trading company resulted in a modest recovery in prices from late 1994 through mid-1996, but the regime of low prices returned shortly thereafter.

Beginning in 2002, uranium prices began to increase, eventually rising to levels not seen since the 1980s, then rising more rapidly through 2005 and 2006 with spot prices reaching a peak through 2007 and 2008, then falling off rapidly, recovering somewhat in 2011 and declining in 2012 (see Figures 2.10 and 2.11). In contrast, EU and US long-term price indices continued to rise until 2011 before levelling off in 2012 and then starting to decline until 2019. Fluctuations in these indicators do not rival the peak in spot market in 2007 and 2008 or the degree of declining prices since 2011 since they reflect contract arrangements made earlier under different price regimes. The Australia average export price has generally followed the trend of other long-term price indices, but with greater variation since it is a mix of spot and long-term contract prices. Depending on the nature of the purchases (long-term contracts versus spot market), the information available indicates that prices ranged between USD 52/kgU and USD 107/kgU (USD 20/lb U_3O_8 and USD 41/lb U_3O_8) at the end of 2018.

Figure 2.10. **Uranium prices for short- and long-term purchases and exports (1982-2019)**

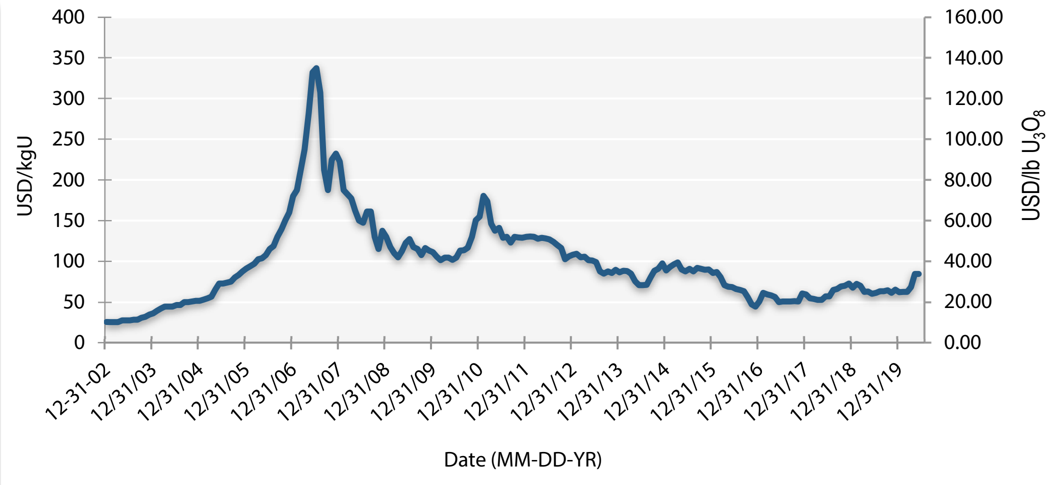


Source: Australia, Canada, ESA, Niger and the US EIA.

1. Euratom (ESA) prices refer to deliveries during that year under multi-annual contracts.

2. Beginning in 2002, Natural Resources Canada (NRCan) suspended publication of export prices pending policy review. Niger has also suspended publication of export prices since 2004.

Figure 2.11. **Uranium spot price dynamics**
(TradeTech Exchange Value trend, 2002-2020)



Source: Trade Tech (www.uranium.info).

Note: The Exchange value is Trade Tech's judgement of the price at which spot and near-term transactions for significant quantities of natural uranium concentrates could be conducted as of the last day of the month.

In addition to this information from government and international sources, spot price indicators for immediate or near-term delivery (less than one year) that typically amount to 15% to 25% of all annual uranium transactions, are provided by the industry trade press, such as TradeTech and the Ux Consulting Company LLC (UxC). While the trend of increasing prices outlined above is evident for spot market transactions since 2002, and in particular after 2004, the spot price shows more volatility than long-term price indicators since 2006 (see Figure 2.11). In June 2007, the spot market price reached as high as USD 136/lb U_3O_8 (USD 354/kgU) before declining to USD 40.50/lb U_3O_8 (USD 105/kgU) in February 2010. It recovered to USD 72.25/lb U_3O_8 (USD 188/kgU) at the end of January 2011, before declining to USD 27/lb U_3O_8 (USD 70.2/kgU) at the end of 2018 (see Figure 2.11). In May 2019, the spot market price declined to USD 24/lb U_3O_8 (USD 62.4/kgU) and one year after, in May 2020, the spot price increased to USD 33.85/lb U_3O_8 (USD 88/kgU).

A variety of factors have been advanced to account for the spot price dynamics between 2003 and 2020, including problems experienced in nuclear fuel cycle production centres that highlighted dependence on a few critical facilities in the supply chain, as well as changes in the value of the US dollar, the currency used in uranium transactions. The expected expansion of nuclear power generation in countries such as China, India and Russia, combined with the recognition by many governments of the role that nuclear energy can play in enhancing security of energy supply, contributed to the strengthening market through 2007. The influence of speculators in the market helped accelerate upward price movement at this time. The downturn in the spot price since June 2007 began with the reluctance on behalf of traditional buyers to purchase at such high prices and the global financial crisis that stimulated sales by distressed sellers needing to raise capital.

In late 2007, the uranium spot price began a gradual decline that settled in the USD 40/lb U_3O_8 (USD 104/kgU) to USD 50/lb U_3O_8 (USD 130/kgU) range in 2009. Proposed US government inventory sales appeared to offset rising demand as government programmes in China and India to increase nuclear generating capacity began to be implemented. In the second half of 2010, the spot price began to rally once again on news that China was active in the long-term market, stimulating speculative activity on perceptions of tightening supply-demand. However, the Fukushima Daiichi accident precipitated an initial rapid decline in price that continued more gradually through to the end of 2019. Projects to increase uranium production, implemented before the accident, resulted in increasing production even as demand weakened and the market became saturated with supply, putting further downward pressure on prices through to the end of 2019. In addition, the excess uranium inventories and the decline in uranium needs as a result of the substitution of enrichment (underfeeding) contributed to the downdraught in uranium prices. However, significant uranium production cuts have been made during 2018-2019 (e.g. McArthur River mine in Canada) contributing to high spot purchasing levels as producers and traders bought material to cover near term delivery commitments.

The significant rise in the spot price seen in March and April 2020, was precipitated largely by additional curtailments to primary production brought on by the COVID-19 pandemic.

The uranium market was also impacted by macroeconomic trends. The strengthening of the US dollar in recent years, especially in relation to the currencies of major uranium producers (e.g. Canadian dollar, Kazakh tenge, Russian rouble and South African rand) contributed to the uranium price volatility. Non-US mining companies have benefited from USD appreciation against these currencies, as most of their operating costs, including labour, are in their domestic currencies. This allowed them to keep operating the mines despite falling uranium market prices, expressed in US dollars.

Regarding the uranium market, evolution could be pushed further by developments on both the demand and supply side. Demand factors include Japanese restarts and successful global new builds. On the supply side, uranium production levelling off in the short term, as well as possible limitations on government inventories are viewed as critical considerations. When looking at the longer-term outlook, there is a general agreement that nuclear growth is likely to continue. Asia and the Middle East are the most critical markets for new reactors, and new uranium production will be needed in the coming decades. However, new uranium supply capacity would need the right price signals for producers to make investments.

Policy measures in the EU and uranium prices

Since its establishment in 1960 under the Euratom Treaty, the ESA has pursued a policy of diversification of sources of nuclear fuel supply in order to avoid overdependence on any single source. Within the European Union, all uranium purchase contracts by EU end users (i.e. nuclear utilities) must be concurred by the ESA. Based on its contractual role and its close relations with industry, the ESA monitors the market with a particular focus on supplies of natural and enriched uranium to the EU. The ESA continues to stress the importance of maintaining an adequate level of strategic inventory and using market opportunities to increase inventories, where possible. It also recommends that utilities cover the majority of their needs under long-term contracts with diverse suppliers and continues with efforts to promote transparency and predictability in the market.

Nuclear materials for EU reactors came from diverse sources in 2019 (ESA, 2020). Russia-origin uranium supplied 19.8% of the natural uranium delivered to the EU operators, followed by Kazakhstan (19.6%), Niger (15.3%), Australia (14.4%) and Canada (11.6%). European uranium delivered to EU utilities originated in Romania, covering approximately 2% of the EU's total requirements. These deliveries were made under terms and conditions contained in a number of contracts of variable duration, with 90.4% of total deliveries covered under long-term contracts and 9.6% under spot market contracts (purchase/sale by an EU utility/user). In 2019, the ESA processed a total of 104 natural uranium contracts and amendments, of which 41 were new contracts, 27 involved EU utilities, and the remainder were signed by EU intermediaries or producers.

Since uranium is sold mostly under long-term contracts and the terms are not made public, the ESA traditionally published two categories of natural uranium prices on an annual basis, i.e. multi-annual and spot, both being historical prices calculated over a period of many years. With at least some uranium market participants seeking greater price transparency, the ESA introduced a new natural uranium multi-annual contracts index price (MAC-3) in 2009. This index price, developed to better reflect short-term changes in uranium prices and to more closely track market trends, is a three-year moving average of prices paid under new multi-annual (long-term) contracts for uranium delivered to EU utilities in the reporting year.

In 2019, the MAC-3 average price index was EUR 80.00/kgU (USD 34.45/lb U_3O_8), an increase of 8% from 2018, and the long-term contract price increased by 8% over the same period to EUR 79.43/kgU (USD 34.20/lb U_3O_8). The average spot price for deliveries in 2016 decreased only by 0.2% from 2015 to EUR 88.56/kgU (USD 37.71/lb U_3O_8), whereas in 2017 the average spot price increased by 25% from 2018 to EUR 55.61/kgU (USD 23.94/lb U_3O_8), (see Table 2.11). In 2019, spot price data and the multi-annual contract prices were widely distributed. On average, the multi-annual contracts that led to deliveries in 2019 had been signed 8 years earlier, in contrast to spot contract deliveries, which are concluded over a maximum period of 12 months (ESA, 2020).

Table 2.11. **ESA average natural uranium prices (2011-2019)**

Year	Multi-annual contracts		Spot contracts		New multi-annual contracts (MAC-3)	
	EUR/kgU	USD/lb U_3O_8	EUR/kgU	USD/lb U_3O_8	EUR/kgU	USD/lb U_3O_8
2011	83.45	44.68	107.43	57.52	100.02	53.55
2012	90.03	44.49	97.80	48.33	103.42	51.11
2013	85.19	45.32	78.24	39.97	84.66	43.25
2014	78.31	40.02	74.65	38.15	93.68	47.87
2015	94.30	40.24	88.73	37.87	88.53	37.78
2016	86.62	36.88	88.56	37.71	87.11	37.09
2017	80.55	35.00	55.16	23.97	80.50	34.98
2018	73.74	33.50	44.34	20.14	74.19	33.70
2019	79,43	34.20	55.61	23.94	80.00	34.45

Source: ESA, 2019 and 2020.

Since uranium is priced in US dollars, fluctuation of the EUR/USD exchange rate influences the level of the price indices calculated. The annual average ECB EUR/USD rate in 2019 stood at 1.12, which was 5% lower than in the previous year.

Supply and demand to 2040

Market conditions are the primary driver of decisions to develop new or expand existing primary production centres. Market prices have generally increased since 2003, and even with declining prices since the onset of the financial crisis and following the Fukushima Daiichi accident, plans for increasing production capability continued through 2019. A number of countries, notably Australia, Brazil, Canada, China, India, Namibia, Niger, Russia and South Africa, have plans for significant additions to future production capability. Some other countries, notably Botswana, Denmark/Greenland, Finland, Mauritania, Mongolia and Tanzania are working towards producing uranium in the near future. These developments are important as global demand is projected to increase in the longer term, and secondary sources are expected to decline somewhat in availability.

However, with rising mining and development costs and the long pause in nuclear development following the Fukushima Daiichi accident, along with the continuing decline of market prices through 2019, delays in some of the planned mine developments have been announced. Uranium production has also slowed at a number of existing facilities because of poor market conditions. The most significant of these changes was the suspension of Canada's McArthur River mine and Key Lake mill, following a series of production cuts to Kazakh production, a reduction to Niger uranium output, and cessation of production at Langer Heinrich project in Namibia. Meanwhile, many ISL mines in the United States are facing a situation in which no new capital is being invested into developing new wellfields. In addition, over the first part of the 2020, the Covid-19 pandemic significantly impacted production to the downside with many mines temporarily closed. An improvement of uranium market conditions should see at least some of the delayed projects or the mines in care and maintenance reactivated in order to ensure supply to a growing global nuclear fleet. Since several of these projects have advanced through regulatory and other development steps, the time required to bring these facilities into production should be reduced overall, and production will likely be able to respond more rapidly to increasing demand.

Despite some uncertainties and challenges in raising investment for mine development, producers have moved to increase production capability in recent years and governments are laying the groundwork (e.g. legislation and regulations) for mine development in countries that have not previously hosted uranium production. However, should uranium demand increase as projected, producers would still face a number of significant and unpredictable issues in bringing new production facilities on stream, including geopolitical and policy factors (e.g. from the ban on new uranium mine development in Western Australia, to terrorist attacks in Niger), technical challenges and risks at some facilities, the development of more stringent regulatory requirements and also heightened expectations of governments hosting uranium mining (e.g. increased taxes and contributions to regional socio-economic development).

As reactor requirements are projected to rise through 2040, an expansion of production capability is also projected to occur (see Figure 2.12a). As of 1 January 2019, these mining expansion plans, if successfully implemented, would cover low case demand requirements through 2035, even without secondary supplies. The secondary supplies have met from 1% to 50% of annual requirements between 2000 and 2019 (see Figures 2.12 and 2.8). As noted above, secondary sources can be expected to continue to be a source of supply for some years to come, despite a general downward trend.

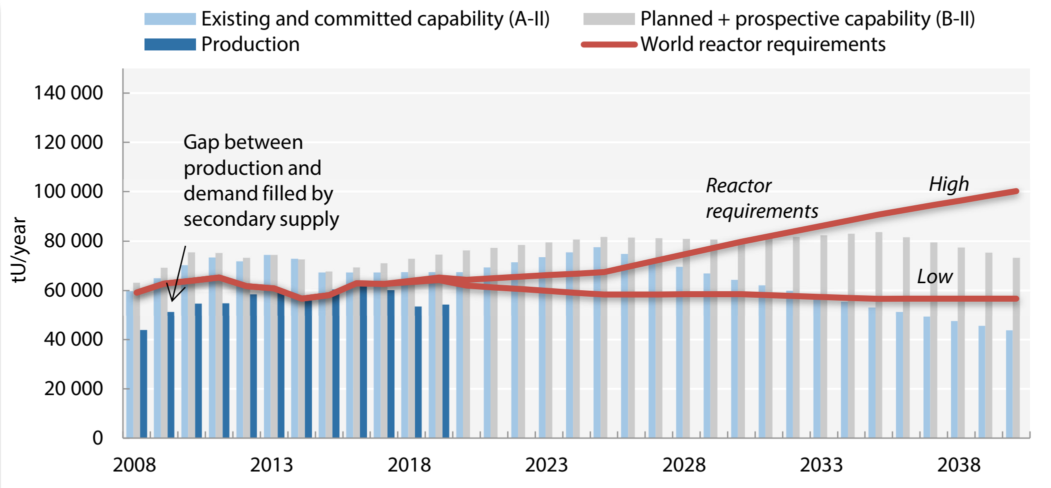
If all existing and committed mines produce at or near stated production capability, high case demand is projected to be met through 2025 (without taking into account the secondary supplies). If planned and perspective production capability is included, high case demand requirements are projected to be met through 2030. Planned capability from all existing and committed production centres is projected to cover 77% of low case requirements through 2040 and about 44% of high case requirements. With the inclusion of planned and prospective production centres, primary production capability would more than satisfy low case requirements through 2040. However, real mine production is rarely more than 85% of mine production capability and, as noted above, several challenges will need to be overcome in order for all planned and prospective uranium projects to be successfully brought into production. Figure 2.12b summarises the supply/demand picture with global production capability at 85% recovery. In this case, a gap is identified for the high case reactor requirements scenario starting with 2025 and can be filled with secondary supply or new projects.

The total identified uranium resource base in 2019 is adequate to meet even high case projections of growth in nuclear generating capacity. Meeting high case demand requirements would consume approximately 28% of the total 2019 identified resource base by 2040, considering resources recoverable at a cost of <USD 130/kgU (USD 50/lb U_3O_8). However, if lower cost resources are considered (<USD 80/kgU; USD 30/lb U_3O_8), the high case demand would consume 87% of the resource base by 2040. With the appropriate market signals, as significant new nuclear generating capacity is added, additional resources of economic interest are likely to be identified with additional exploration efforts.

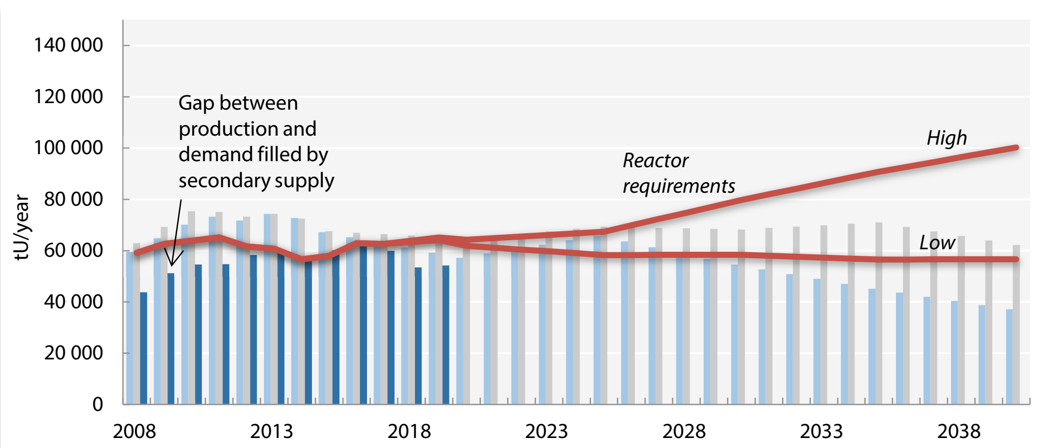
The gap between production and requirements from 2008 (and earlier) to 2014 has been met by drawing down secondary supplies. In 2014, producers almost closed the gap between world production and reactor requirements, albeit with requirements temporarily depressed owing to reactor closures and idling of reactors in Japan following the Fukushima Daiichi accident. However, following the production cuts the last three years and the reductions due to COVID-19 pandemic, the gap between demand and primary supply appeared again. Furthermore, it should be noted that production capability is not production. Maintaining production at the level required to meet reactor requirements in the coming years, particularly in light of uncertainties related to COVID-19 pandemic and also depressed market prices for uranium the recent years, will be a challenge.

Figure 2.12. **Projected world uranium production capability to 2040 (supported by identified resources at a cost of <USD 50/lb U_3O_8) compared with reactor requirements***

(a) 100% of total production capability



(b) 85% of total production capability



Source: Tables 1.24 and 2.5.

* Includes all existing, committed, planned and prospective production capability centres supported by reasonably assured resources and inferred resources recoverable at a cost of <USD 130/kgU (USD 50/lb U_3O_8). Does not include the secondary supply forecast.

World production has varied between 70% and 90% of full production capability since 2008. In addition, delays in the establishment of new production centres can reasonably be expected, especially in the prevailing risk-averse investment environment. As always, technical and geopolitical challenges in the operation and development of mine and mill facilities will need to be effectively dealt with. These factors can be expected to reduce and/or delay development of planned and prospective centres. Hence, even though the industry has responded vigorously to the market signal of generally higher prices since 2003, compared to the previous 20 years, additional primary production will likely be required. After 2020, secondary sources of uranium are generally expected to decline somewhat in availability and reactor requirements will have to be increasingly met by primary production. Therefore, despite the significant additions to production capability reported here, bringing facilities into production in a timely fashion remains important. To do so, strong uranium market conditions will be fundamental to bringing the required investment to the industry.

A key uncertainty of the uranium market continues to be the availability and the mobility of secondary sources, particularly the level of stocks available and the length of time remaining until those stocks are exhausted. However, the possibility that at least a portion of the potentially large inventory (including from the military) will continue to make its way to the market after 2020 cannot be discounted. These uncertainties complicate investment decisions on new production capability. Another limiting factor for investment decisions is that uranium demand outlook in the near- to medium-term is driven primarily by the large number of reactors that are scheduled to close (e.g. Europe and the United States), which offset the positive growth from new nuclear power plants in other countries (e.g. China).

It is clear that the generally stronger market of the 2003-2011 period, compared to the last two decades of the 20th century has driven exploration activity, thus building up an important uranium resources base. However, history shows that periods of low prices for uranium and reliance on secondary supplies have had dramatic impacts on the industry in terms of consolidation of producers and significant reductions in primary production capability.

The long-term perspective

Uranium demand is fundamentally driven by the number of operating reactors, which ultimately is driven by the demand for electricity. The role that nuclear energy will play in helping meet projected electricity demand will depend on government policy decisions affecting nuclear development and how effectively a number of factors discussed earlier are addressed (e.g. economics, safety, security of energy supply, waste disposal, environmental considerations). Public acceptance of nuclear technology in some countries remains an issue that needs to be addressed.

Several international agencies have noted that if governments follow the current path of energy policy, severe climate change impacts can be expected, and greenhouse gas emissions from electricity production are at the heart of this issue (IAEA, 2020c; IEA, 2019; NEA, 2015). In setting a goal of stopping growth in emissions, several policy measures have been proposed: implementation of select energy efficiency policies, limiting the use of inefficient coal power plants, reducing methane emissions from upstream oil and gas facilities, phasing out fossil fuel subsidies and increasing investment in renewable energy technologies. However, without action to provide more support for nuclear power, global efforts to mitigate climate change will become drastically harder and more costly (IEA, 2019). The "World Energy Investment 2017" report (IEA, 2017) also outlined that nuclear energy can make a significant contribution to decarbonisation, but the industry must receive clear and consistent policy support for existing and new capacity with nuclear also included in clean energy incentive schemes.

The 2020 World Energy Outlook (IEA, 2020) notes that following the COVID-19 pandemic, the impact on 2020 global energy demand varies by fuel, with falls of 8% in oil demand and 7% in coal use, in contrast to 4.5% for nuclear and a slight rise in the contribution of renewables. Global electricity demand is estimated to drop only by 2% for 2020. Prior to the COVID-19 pandemic, energy demand was projected to increase by 12% between 2019 and 2030. Growth over this period is now set to 9% in the Stated Policy Scenario, and 4% in the Delayed Recovery Scenario with increases coming from emerging markets and developing economies, led by India. However, a different pathway, the Sustainable Development Scenario (SDS) together with the Sustainable Recovery Plan, was set by IEA, showing governments the opportunity to boost economic recovery, create jobs and reduce greenhouse gas emissions. Full implementation of this scenario will require major investments in clean energy technologies over the next ten years, directed towards improvements in efficiency, low-emissions power and electricity grids, and more sustainable fuels. To achieve the clean energy transition identified in the IEA's SDS, near-term actions to boost nuclear power, including supporting lifetime extensions and expanding new build projects including small modular reactors, are required. Nevertheless, global investments in nuclear capacity continue to be insufficient, taking into account the small number of new build projects being started. According to the World Energy Outlook, USD 1.42 trillion in investment would be required between 2019 and 2040 to be on line with the SDS.

The expansion of nuclear power is mainly policy driven and can be limited by public opposition and long-permitting processes. Nuclear power plants also face challenges due to their large upfront capital costs and complex project management requirements. A recent NEA study, *Unlocking Reductions in the Construction Costs of Nuclear: A Practical Guide for Stakeholders* (NEA, 2020b) highlights that while the industry has made major efforts in terms of organisational restructuring and integration of a number of recent technological advances, governments also have a role regarding significant construction costs and risk reductions by committing to the next set of new build projects. With several projects under completion in OECD countries, the next decade offers opportunities to capitalise on the experience accumulated to improve the economic performance of both traditional large reactors and new innovative designs.

Nuclear energy can play a key role in decarbonising electricity systems by providing a stable source of low-carbon baseload electricity. Recognising the security of supply, reliability and predictability that nuclear power offers and promoting incentives for all types of low-carbon electricity production are key conditions for a faster deployment of nuclear power. In addition, the NEA study, *The Full Costs of Electricity Provision* (NEA, 2017), outlines the most recent research on the social and environmental impacts of electricity generation that are not captured by market prices. It discusses and tries to quantify different impacts of electricity provision such as climate change, local pollution, impacts of accidents, or land use. It concludes that air pollution, climate change and system costs constitute the largest un-internalised costs (NEA, 2017). The transition to a low-carbon electricity system also creates challenges. The growing shares of variable renewable energy technologies have prompted a discussion among policy makers, regulators and system operators on the extent to which deregulated electricity markets can deliver the transition to a low-carbon power system while ensuring an adequate level of supply security and sufficient investment in network and generation capacities (NEA, 2018).

Several alternative uses of nuclear energy also have the potential to increase nuclear power installation worldwide, including desalination and heat production for industrial and residential purposes. The prospect of using nuclear energy for desalination on a large-scale is attractive since desalination is an energy intensive process that can make use of either the heat from a nuclear reactor and/or the electricity produced. About one-third of the world's population lives in water stressed areas, with a majority in Sub-Saharan Africa, the Middle East and South Asia, and with climate change, access to fresh water could become increasingly challenging (IAEA, 2020). In recent years, several governments have been actively evaluating the possibility of using nuclear energy for desalination (e.g. China, Jordan, Libya and Qatar), building on experience gained through the operation of integrated nuclear desalination plants in India, Japan and Kazakhstan. Global installed desalination capacity has more than doubled between 2006 and 2019, with the majority operating on fossil fuels.

Cogeneration, combining industrial heat applications with electricity generation, is not a new concept; some of the first civilian reactors in the world were used to supply heat as well as electricity. District heating using heat generated in reactors has been used in some countries for decades. Industrial process heating has also been used and potential for further development exists, but the extent to which reactors will be used for such applications will depend on the economics of heat transport, international pressure to reduce CO_2 emissions and national desires to reduce dependence on imported fossil fuels, as well as competition with alternative heat or combined heat and power (CHP) technologies (IAEA, 2019b). It should be noted that since the public and decision makers are not sufficiently aware of the potential of non-electric applications of nuclear energy, better communication practices should be developed.

Energy use for transport, which is projected to continue to grow rapidly over the coming decades, is also a major source of greenhouse gas emissions. Both electric and hydrogen-fuelled vehicles are seen as potential replacements for those powered by fossil fuels. Nuclear energy offers baseload electricity production that could be used to power electric vehicles; it also has the potential of producing hydrogen on a massive scale that could make this alternate energy carrier available with significantly less greenhouse gas emissions compared to current methods of hydrogen production.

There is increasing interest in small modular reactors (SMRs) in both established nuclear countries (e.g. Argentina, Canada, the United States), and in newcomer countries in Europe, the Middle East, Africa and Southeast Asia. SMRs, with capacities generally in the range of 30-300 MWe, could be suitable for areas with small electrical grids and for deployment in remote locations. SMRs offer smaller upfront investment costs and reduced financial risks compared to larger reactors typically being built today (1 000-1 700 MWe) and may be deployed as alternatives to larger nuclear power plants in locations where such plants cannot be built, or to fossil-fired plants of similar sizes. The developments in design and technology, technical feasibility, the economic aspects and the factors affecting the competitiveness of SMRs are described in various reports (IAEA, 2020d; NEA, 2016). A large number of SMR designs are under development (more than 70 designs in different stages), and others are under construction in Argentina (CAREM) and in China (HTR-PM). Russia connected the world's first floating nuclear power plant (KLT-40), Akademik Lomonosov, to the grid and started commercial operation in May 2020. The NuScale SMR design is in the final stage of design certification by the US NRC. Plans to construct the first modules of a new plant in Idaho have advanced with the manufacturers having been chosen and further support confirmed by the US DOE. In March 2020, Oklo submitted the first combined licence application for an advanced reactor technology to the NRC. Oklo is developing a 1.5-MW micro-reactor to supply energy at remote sites.

Technological developments also promise to be a factor in defining the long-term future of nuclear energy and uranium demand. In recent years, the nuclear sector has been aggressively developing reactor fuels that are more robust and have improved performance during normal operation and in accident conditions (accident tolerant fuels). Several fuel vendors are developing such fuels. The first test assemblies using advanced fuel cladding materials have already been loaded into the US commercial reactors. Advancements in reactor and fuel cycle technology are not only aimed at addressing economic, safety, security, non-proliferation and waste concerns, but also at increasing the efficiency of uranium resource use. The introduction and use of advanced reactor designs would also permit the use of other types of nuclear fuels (e.g. fuels based on high assay low enriched uranium or other fuel compositions such as uranium-238 and thorium), thereby expanding the available uranium resource base. Fast-neutron reactors are being developed to make more efficient use of the energy contained in uranium.

Box 2.2. **Advancing High-Assay Low-Enriched Uranium (HALEU) supply**

Many companies around the world are developing advanced reactors with smaller and more flexible designs. However, most of these reactors will require high-assay low-enriched uranium (HALEU) fuels that are not yet available at the commercial scale.

The current nuclear reactors use uranium fuel that is enriched up to 5% with uranium-235, the main fissile isotope that produces energy during a chain reaction. HALEU is enriched between 5% and 20% and is required for many advanced reactors in order to optimise their systems for longer life cores, increased efficiencies and better fuel utilisation. Potential recovery methods include:

- down-blending of government-owned highly enriched uranium (HEU) stocks;
- or enrichment process to produce a higher percentage of uranium-235.

As an example, the United States is working on two chemical methods to provide small amounts of HALEU to reactor developers in the near term to support demonstration projects, including: i) electrometallurgical process and ii) hybrid zirconium extraction process known as ZIRCEX (see US Office of Nuclear Energy, 2020). Both processes involve the recycling of used nuclear fuel from research reactors to recover HEU (greater than 20%) that can then be down-blended to make HALEU fuel. Nevertheless, the transition to a HALEU fuel supply chain would need a robust market for companies to investing and requires infrastructure and regulation updates.

Many national and several major international programmes are working to develop advanced technologies. For example, the Generation IV International Forum (GIF) and the IAEA International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO).

GIF brings together 13 countries and Euratom. Australia became the 14th GIF member in 2016. Since its launch in 2000, GIF has been working to carry out the research and development needed to establish the feasibility and performance capabilities of the next generation (Gen IV) reactor designs. These designs have stated objectives of safety, economics, sustainability and non-proliferation. In 2002, GIF reviewed 130 proposals and selected six nuclear energy system concepts to be the focus of continued collaborative research and development. These concepts include the sodium-cooled fast reactor, the very-high-temperature reactor, the supercritical-water-cooled reactor, the lead-cooled fast reactor, the gas-cooled fast reactor and the molten salt reactor. In 2016, the GIF Technology Roadmap was updated, taking into account plans to accelerate the development of some technologies by deploying prototypes and demonstrators within the next decade. Many of the Gen IV concepts also have the potential to provide heat in addition to electricity, and therefore target other energy market sectors (such as hydrogen production).

Established in 2000, the objective of INPRO is to help to ensure that nuclear energy is available to contribute, in a sustainable manner, to energy needs in the 21st century. Many member states along with the European Commission are engaged in this project. Holders and users of nuclear technology are being brought together to consider international and national actions that would produce the innovations required in nuclear reactors, fuel cycles or institutional approaches. INPRO assists member states in building national long-range nuclear energy strategies and making informed decisions on nuclear energy development and deployment.

In the long-term future, new reactor designs may bring fundamental changes to the nuclear fuel landscape.

Conclusion

As documented in this volume, sufficient uranium resources exist to support continued use of nuclear power and significant growth in nuclear capacity for electricity generation and other uses in the long term. Identified recoverable resources,[3] including reasonably assured resources and inferred resources, are sufficient for over 135 years, considering uranium requirements of about 59 200 tU (data as of 1 January 2019). Exploitation of the entire conventional resource[4] base would increase this to well over 250 years. Nevertheless, the rapid growth of nuclear power in the coming decades would significantly change this picture. Furthermore, uranium exploration and development, motivated by significantly increased demand and market prices, would be required to move these resources into more definitive categories.

The uranium resource base described in this document is more than adequate to meet projected growth requirements to 2040. Meeting projected low case requirements to 2040 would consume about 20% of the identified resources available at a cost of <USD 130/kgU and about 16% of identified resources available at a cost of <USD 260/kgU. Meeting high case growth requirements to 2040 would consume about 28% of identified resources available at a cost of <USD 130/kgU and about 22% of identified resources available at a cost of <USD 260/kgU. However, when considering lower cost resources, in the light of recent market prices, meeting projected requirements to 2040 would consume about 64% of the identified resources available at a cost of <USD 80/kgU (USD 30/lb U_3O_8) in the low case scenario and about 87% of identified resources in the high demand case. Given the limited maturity and geographical coverage of uranium exploration worldwide, there is considerable potential for the discovery of new

3. Identified resources include all cost categories of reasonably assured resources and inferred resources for a total of about 8 070 400 tU (see Table 1.2a).
4. Total conventional resources include all cost categories of reasonably assured, inferred, prognosticated and speculative resources for a total of about 15 290 700 tU (see Tables 1.3a, 1.4a and 1.13). This total does not include secondary sources or unconventional resources, e.g. uranium from phosphate rocks.

resources of economic interest. As clearly demonstrated in the last few years, with appropriate market signals, new uranium resources can be readily identified and mined.

As noted in this report, there are also considerable unconventional resources, including phosphate deposits and black schists/shales that could be used to significantly lengthen the time that nuclear energy could supply energy demand using current technologies. However, more research and innovation effort and investment would need to be devoted to better defining the extent of this potentially significant source of uranium and developing cost-effective extraction techniques.

Deployment of advanced reactor and fuel cycle technologies could also significantly add to world energy supply in the long term. Moving to advanced technology reactors and recycling fuel could increase the long-term availability of nuclear energy from hundreds to thousands of years. In addition, thorium, which is more abundant than uranium in the earth's crust, is also a potential source of nuclear fuel, if alternative fuel cycles are developed and successfully introduced in a cost-effective manner. Thorium-fuelled reactors have been demonstrated and operated commercially in the past.

Sufficient nuclear fuel resources exist to meet energy demands at current and increased demand well into the future. However, to reach their full potential, considerable exploration, innovative techniques and investment will be required in order to develop new mining projects in a timely manner and to facilitate the deployment of promising technologies.

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Chapter 3. **National reports on uranium exploration, resources, production, demand and the environment**

Introduction

This chapter presents the national submissions on uranium exploration, resources and production. These reports have been provided by official government organisations (see Appendix 1) responsible for the control of nuclear raw materials in their respective countries, although the details are the responsibility of the individual organisations concerned. In countries where commercial companies are engaged in exploration, mining and production of uranium, the information is first submitted by these companies to the government of the host country and may then be transmitted to the NEA or the IAEA at the discretion of the government concerned. In certain cases, where an official national report was not submitted, and where it was deemed helpful for the reader, the NEA/IAEA has provided additional comments or estimates to complete this report. In such cases, "NEA/IAEA estimates" are clearly indicated.

It should be noted that exploration activities may be currently ongoing in a number of other countries that are not included in this report. In addition, uranium resources may have been identified in some of these countries. It is believed, however, that the total of these resources would not significantly affect the overall conclusions of this report. Nevertheless, the NEA and IAEA encourage the governments of these countries to submit an official response to the questionnaire for the next edition of the Red Book.

Additional information on the world's uranium deposits is available in the IAEA online database *World Distribution of Uranium Deposits – UDEPO* (www-nfcis.iaea.org). UDEPO contains information on location, ranges of uranium tonnage and average grade, geological type, status, operating organisations (in case the deposit is being mined), and other technical and geological details about the deposits.

Thirty-one member countries submitted a response to the questionnaire and the NEA/IAEA drafted fourteen country reports. As a result, there are a total of 45 national reports in the following section.

Algeria

Uranium exploration and mine development

Historical review

Over the past 40 years, uranium exploration in Algeria, which began with the launching of the mineral prospecting programme in the Hoggar region, went through an initial phase (1969-1973) marked by a significant investment effort, which led to the discovery of the first uranium deposits in the Hoggar Precambrian crystalline basement (Timgaouine-Abankor-Tinef).

These results, obtained through ground radiometric surveys and geological mapping, quickly identified the uranium resource potential of the Hoggar region, which overall has favourable geological and metallogenic characteristics for mineral deposits.

An aeromagnetic-spectrographic survey of the entire national territory carried out in 1971 provided the initial incentive and direction for uranium exploration. The processing of the data collected from this survey identified potential regions for further uranium prospecting, including the Eglab, Ouggarta and Tin Serinine sedimentary basins (South Tassili; where the Tahaggart deposit was discovered), as well as individual areas in Tamart-n-Iblis and Timouzeline.

While these developments were taking place, uranium prospecting entered a new phase (1973-1981) primarily aimed and focused on the assessment of reserves and the exploitation of previously discovered deposits.

Despite a pronounced slowdown in prospecting activities in the phase that followed (1984-1997), work undertaken in the immediate vicinity of previously discovered deposits and in other promising areas revealed indications of uranium mineralisation and radiometric anomalies in the Amel and Tesnou zones situated in the north-west and north respectively of the Timgaouine region.

Surveys conducted in the Tin Seririne basin (Tassili south Hoggar) provided a basis on which undertake geologic mapping and revealed the distribution of uranium-bearing minerals in Palaeozoic sedimentary formations.

Recent and ongoing uranium exploration and mine development activities

In 2017 and 2018, preliminary prospecting work for undiscovered mineral resources (diamond, Au, PGE-Cr, Cu-Ni-PGE-Cr and Mo-Cu) of the Eglabs region including uranium resources related to granites, calcretes, alkaline rocks and carbonatites were carried out by the Agency of the Geological Service of Algeria in collaboration with the United States Geological Survey.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

Reasonably assured resources in Algeria are of two geological types: upper Proterozoic vein deposits in the western Hoggar, and a deposit linked to the Precambrian basement and its Palaeozoic sedimentary unconformity in the central Hoggar. The first type includes vein deposits linked to the faults traversing the Pan-African batholith in the Timgaouine region, represented by the Timgaouine, Abankor and Tinef deposits of the south-west Ahaggar.

The second type is unconformity-related represented by the Tahaggart deposit, which is associated with a weathering profile (regolith) developed at the interface between the Pre-Cambrian basement and the Palaeozoic cover, and to conglomerates at the base of the Palaeozoic sedimentary sequence in the Tin Seririne basin (south-east Hoggar).

It is worth noting that the uranium mineralisation discovered in the Ait Oklan-El Bema (north Hoggar) region has not been assessed in terms of uranium resources.

Undiscovered conventional resources (prognosticated and speculative resources)

Algeria does not report resources in any other category than reasonably assured resources.

Uranium production

Historical review

Algeria does not produce uranium.

Regulatory regime

The protection of the environment in relation to mining activities is covered by the following legislation:

- Law No. 14-05 of 24 February 2014 on mining activities;
- Law No. 03-10 of 19 July 2003 on the protection of the environment for sustainable development.

On 17 July 2019, a law on civil nuclear activities was adopted. This law aims to define the legislative and regulatory framework for activities related to the research, production and peaceful uses of nuclear energy, in compliance with Algeria's commitments under international conventions. Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

From a mining perspective, in a world market dominated in the short and medium term by a small number of producers, it is currently not economically feasible to exploit the uranium resources in Algeria.

Algeria's uranium resources can only be exploited in a sustainable manner as part of an integrated development of the nuclear sector and its main applications. The latter include, in particular, nuclear power generation and seawater desalination plants, together with applications in medicine, agriculture, water resources and industry.

With regard to the current situation in the global energy market, Algeria is working towards the integrated development of the uranium sector, ranging from exploration to production and encompassing research and development, training and long-term nuclear power generation prospects.

Gaining control over the uranium production cycle and its applications would require the acquisition of technical expertise that can only be gained through ambitious research, development and training programmes. Through its nuclear research centres, Algeria currently has the appropriate tools in place to start work in the future, either alone or through bilateral or multilateral co-operation on various research, development and training programmes.

It is in a spirit of openness and transparency that Algeria applied itself to the task of putting in place the most supportive and appropriate institutional and regulatory framework to provide a basis on which to pursue the energy development of the country, including a Mining Act, Electricity Act, an Oil and Gas Act and recently a civil nuclear activities Act.

To improve the mining sector and boost research, mining and exploration, the government amended Law 01-10 (from 3 July 2001) by the enactment of Law 14-05 on 24 February 2014.

This mining law aims to create better conditions for the revival of the sector through adequate funding for research and exploration of new economically exploitable mining deposits.

Uranium stocks

None.

Reasonably assured conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Proterozoic unconformity				2 000
Granite-related				24 000
Total				26 000

Reasonably assured conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Unspecified	0	0	0	26 000
Total	0	0	0	26 000

Reasonably assured conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Unspecified	0	0	0	26 000
Total	0	0	0	26 000

Installed nuclear generating capacity to 2035

(MWe net)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
0	0	0	0	NA	NA	NA	NA	NA	NA	NA	NA

Argentina

Uranium exploration and mine development

Historical review

Uranium exploration activities in Argentina were launched in 1951-1952 by the National Atomic Energy Commission (CNEA), leading to the discovery of the Papagayos, Huemul, Don Otto and Los Berthos uranium deposits. During the late 1950s and the early 1960s, airborne surveys also led to the discovery of the Los Adobes sandstone deposits in Patagonia.

During the 1960s, the Schlagintweit and La Estela vein deposits were discovered and subsequently mined. During the 1970s, follow-up exploration near the previously discovered uranium occurrences in Patagonia led to the discovery of two new sandstone deposits: Cerro Condor and Cerro Solo. At the end of the 1980s, a nationwide exploration programme was undertaken to evaluate geological units with uranium potential.

The CNEA selected the Cerro Solo sandstone-type uranium-molybdenum deposit to perform an assessment project in 1990, based on the deposit's promising grade. Mineralised layers are distributed in fluvial sandstone conglomerates belonging to the Cretaceous Chubut Group, at depths of 50 to 130 m.

An intensive exploration programme was developed to define the main morphological features of the orebodies and the mineralisation model, to update resource estimates, and to select preliminary mining-milling methods to carry out an economic assessment of the project.

From 1990 to 1997, exploration was conducted in the vicinity of the Cerro Solo deposit (Chubut Province), where more than 56 000 m was drilled to test the potential of favourable portions of the paleochannel structure. The results included the localisation and partial evaluation of specific mineralised bodies with a content of recoverable uranium resources estimated at 4 600 tU of reasonably assured and inferred resources.

These results allowed the CNEA to carry out a programme to complete a preliminary economic assessment of the Cerro Solo U-Mo deposit in 1997, including a revised geological model and ore resource estimate, mining and milling methods and their costs, cash flow and risk analysis, as well as the exploration and evaluation of the surrounding areas.

As a result of the policy to reactivate the nuclear programme announced in August 2006 by the national government, active exploration/evaluation on different areas of uranium interest have subsequently been undertaken.

From 2007 to 2016, a total of 45 672 m have been drilled (380 boreholes) into the main mineralised areas of the Cerro Solo district, including 7 701 m of core (58 boreholes) and 37 971 m of cutting sample (322 boreholes). A total of 44 246 m have been drilled (373 boreholes) at the Cerro Solo uranium deposit, including 6 276 m of core (51 boreholes), which were sampled as the focus of mineralogical and hydrometallurgical studies and triaxial strength tests; and 37 970 m of cutting samples (322 boreholes), which were sampled as the focus of stratigraphic correlation and metallogenic studies.

It is worth mentioning that all drill holes were logged using caliper, long and short resistivity, spontaneous potential and gamma ray. Some tests were also performed with a sonic probe and a gamma-ray spectrometry probe.

Other areas under study at Chubut Province are the Sierra Cuadrada Uranium District, located in the southeastern part of the province, where at least four uranium-mineralised areas were recognised. Three of them – Sierra Cuadrada, Sierra Cuadrada Sur and La Meseta – are defined as "statements of discovery" (SD), which means that there is a legal document certifying the discovery of these new mines or mining areas. The fourth one, which has not been defined as an "SD", is the Unión exploration area.

In the Sierra Cuadrada Uranium District, a regional geological survey was carried out in an area of 4 000 ha with geological-radiometric data collection within three semi-regional profiles. Subsequently, four holes were drilled at SD Sierra Cuadrada (two holes) and SD Sierra Cuadrada Sur (two holes), accounting for a total of 585 m.

Two hundred kilometres north of the Sierra Cuadrada District, a discovery was made at the SD Mirasol Chico and SD El Cruce, where uranium ore is related to fluvial and lacustrine deposits of Cretaceous age. In the SD El Cruce, radiometric prospecting was followed by four drill holes with core sample recovery, resulting in 647 m, and logged with downhole tools to obtain electric profiles. The core samples were used to obtain lithological, chemical and radiometric determinations. At SD Mirasol Chico, the geological-topographic map was updated, covering an area of 2 000 ha, providing a base map to plan the drilling programme of 507 m (3 holes) executed in 2015.

Regarding environmental preservation in the areas where exploration is conducted, monitoring networks are being implemented, adjusting the number of sampling points according to the knowledge and progress of the stage of the mining project.

In the south of Argentina (Santa Cruz province), exploration has primarily focused on shallow low-grade uranium anomalies in six areas of surficial deposits (calcrete-type), and within the Laguna Sirven area the focus is on defining the extension and continuity of uranium mineralisation to depths between 0.5 and 3 m. Mining properties are shared by FOMICRUZ S.E. and the CNEA.

At Laguna Sirven, laboratory hydrometallurgical tests have demonstrated that if the fine fraction can be separated (about 35% of the total volume) and concentrated by screening, the original grade could be doubled.

In the Urcal and Urcuschun deposits, located in La Rioja Province, uranium mineralisation is associated with limestone deposits from the Ordovician-aged San Juan Formation with chert and fault and fracture planes. It is also related to a sedimentary sequence from the Carbono-Permian Paganzo Group. Exploration activities included vertical and semi-regional detailed geological profile surveys, geological and topographic map updates, as well as re-examination of old mining activities. Samples from mineralised zones were the subject of metallogenic studies.

Following this work, activities were focused on geophysical exploration by means of standard geoelectrical methods and through the implementation of the dipole-dipole method. Those efforts were the foundation for the design of the drilling programme of 993 m (13 drilled holes) implemented in 2015.

In the SDs Alipán I, Velasco Range, La Rioja Province (defined as a granite-related uranium-type, perigranitic subtype deposit), systematic geochemical studies in new trenches were continued; two geological profile surveys with samples of water, rock and sediments were carried out, and geophysical exploration (audio-magnetotelluric and geoelectrical) to obtain structural and lithological information at depth was introduced. As a result, it was determined that the mineralised block occupies a "sloping" position towards the east over the oxidised sterile block.

Between 2010 and 2013, 14 drilling programmes were conducted for a total of 2 344 m. The other four planned programmes were not undertaken due to anti-mining actions by local authorities and non-governmental organisations since 2013.

Over the eastern side of Velasco Range, towards the north of SD Alipán I, a new area of exploration called Lucero is being studied, where results are encouraging and three zones with anomalies and evidence of surface uranium minerals were defined.

Gamma radiometric exploration airborne test surveys have been carried out with CNEA equipment on four sites within the Córdoba Ranges, reintroducing the application of an exploration technique that had been halted for decades.

In Vaquería Range, Salta Province, and San Buenaventura Range, Catamarca Province, a zone of over 100 000 ha, which corresponds to 12 exploration permit areas, was liberated because it did not have the frequency and concentration of uranium mineralisation associated with Cretaceous-aged sandstone deposits that was expected.

At the Mina Franca deposit, classified as a granite-related, perigranitic subtype uranium deposit, located in Fiambalá Range, Catamarca Province, surface systematic radiometric survey and geological-structural-metallogenic mapping have been undertaken, while mineralogical and geochemical analyses in the central and south sectors of Mina Franca have also been carried out. In 2017, surface geological reconnaissance activities were completed, which provided the structural geological base map used to plan a drill programme to define mineralisation at depth.

Simultaneously, a monitoring plan for water and sediment modules has been implemented as part of the baseline environmental survey. Moreover, communication programmes related to exploration activities in the Fiambalá Range and nuclear technology applications are being conducted in neighbouring populations and provincial offices.

With the aim of studying mineralisation behaviour in detail in the north and centre sectors of the Don Otto deposit, Salta Province, which has been classified as Cretaceous-aged sandstone-type uranium deposit, geophysical techniques (geoelectrical and magnetotelluric methods) were applied in order to collect subsoil data on the existing stratigraphic and structural sequence. Other activities conducted in the district included geomorphological studies, identification of depositional settings, lithological facies and ichnofacies. These efforts were complemented with a drilling programme of 8 drill holes totalling 1 734 m.

Evidence of uranium found in oil wells, and to a lesser extent, known from surface data, is under investigation in two exploration areas near Catriel, in the Río Negro Province. Mineralisation is related to sedimentary deposits within the Neuquén Basin, and therefore could be classified as a sandstone-type uranium deposit. Exploration undertaken during 2015 and 2016 involved the application of geophysical techniques including an audio-magnetotelluric (AMT) study and vertical electrical sounding (VES). These studies were complemented with geochemical exploration and geological radiometric reconnaissance programmes in semi-regional profiles. The studies seeked to obtain a wider knowledge about subsoil geology and identifying uranium anomalies. In order to detect uranium anomalies, a drilling programme of 1 910 m distributed in 10 drill holes was implemented. Similar activities were also carried out on four exploration properties within the area of Las Mahuidas.

Some semi-regional geological recognition activities, including geochemical surveys and geophysical studies (AMT and VES), were conducted in an exploration area in Gobernador Ayala, La Pampa Province. The results of the resistivity soundings had considerable correlation with oil well logs that show a radiometric anomaly at a depth of less than 200 m. Based on this information, a drilling programme was planned.

In the framework of an IAEA Coordinated Research Project on “Geochemical and Mineralogical Characterisation of Uranium and Thorium Deposits”, the interpretation of new studies on uranium mineralisation from several uranium sites of interest has improved the metallogenetic understanding of the granite-related deposits and the exploration guidelines.

In the early 2000s, six private uranium exploration companies undertook work in Argentina as reported by the *Cámara Argentina de Empresas de Uranio* (CADEU – Argentine Chamber of Uranium Companies): U3O8 Corp (Meseta Exploraciones S.A.- MEXSA); Sophia Energy S.A.; Blue Sky Uranium Corp (Minera Cielo Azul S.A.); Cauldron Minerals Ltd; Gaia Energy Argentina S.A. and UrAmerica Ltd. Of these, U3O8 Corp., Sophia Energy S.A., UrAmerica Ltd and Blue Sky Uranium Corp. The first of these two companies carried out uranium exploration in the south of Chubut Province and in the northern sector of Santa Cruz province, respectively, where exploration was focused on shallow low-grade uranium anomalies defined as a calcrete-type deposit.

The Laguna Salada uranium deposit (Chubut Province) operated by MEXSA (a subsidiary of U3O8 Corporation) is considered to be a surficial uranium-vanadium deposit, and includes the Guanaco and Lago Seco areas with 82% and 12% of the resources, respectively. Mineralisation occurs within 3 m from the surface in soft, unconsolidated gravel. Reasonably assured and inferred resources have been evaluated at 2 420 tU and 1 460 tU, respectively, at grades ranging between 55 and 72 ppm U (0.0055% and 0.0072% U), while vanadium identified resources have been assessed at 21 330 tV at grades ranging from 308 to 330 ppm V (0.0308% to 0.033% V). Test work shows that the removal of the pebbles and coarse sand from the gravel increases the uranium grade by 11 times from the in situ grade of the Guanaco gravels, and seven times those of the Lago Seco gravels. Vanadium grades in the residual fine material increase 3.7-3.8 times relative to the grade of the in situ gravel from Guanaco and Lago Seco, respectively. The fine material being fed to the hydrometallurgical plant would then have grades of 720-740 ppm U (0.072-0.074% U) on average. Fine material from the gravel would have an average grade of 1 310-1 330 ppm V (0.131-0.133% V). Uranium and vanadium would be extracted from the fine material by alkaline leach, in which the reagents are sodium carbonate (washing soda) and sodium bicarbonate (baking soda) at an optimal temperature of 80°C. In 2014, this project was put on care and maintenance status.

Sophia Energy S.A. carried out the exploration of its calcrete-type vanadium-uranium deposit at Laguna Sirven site in Santa Cruz Province. Geochemical and biogeochemical surveys and hyperspectral and thermal remote sensing studies were performed in order to spectrally characterise and determine mineralised areas of interest.

UrAmerica Ltd undertook an intensive underground exploration programme that included drilling 250 holes, for a total of approximately 24 000 m, on neighbouring areas of the Cerro Solo ore deposit, in Chubut Province. They report 7 350 tU as inferred resources for the Meseta-Central project. As reported by UrAmerica Ltd., about 75% of the uranium resources evaluated are in confined aquifers. Therefore, further geological and hydrological studies will be needed to determine its amenability to ISL mining. In 2013, this project was put on care and maintenance status.

Blue Sky Uranium Corp was actively exploring its Amarillo Grande Project in central Rio Negro Province. Defined mineralisation at Amarillo Grande is found in three target areas (Ivana, Anit, and Santa Barbara) along a 145 km long trend. Mineralisation in all three areas occurs at, or very near the surface, in unconsolidated to weakly cemented host rocks. Surface exploration, ground geophysics, pit sampling and more than 9 000 m of reverse circulation (RC) drilling were completed at the project since the beginning of the revitalised work programme in 2016.

Recent and ongoing uranium exploration and mine development activities

As of 2018, CNEA owned 50 exploration licences in Argentina, considering requested and conceded exploration permit areas (22), statements of discovery (18), and ore deposits (10). They are located within the provinces of Salta, Catamarca, La Rioja, San Juan, Mendoza, La Pampa, Río Negro, Chubut and Santa Cruz.

For the period 2017-2018, exploration activities carried out by the government have slowed and no drilling programmes have been carried out. In general, the activities have been focused on some field work for geological and radiometric reviews, sampling for geochemical analysis and environmental studies at different sites of interest.

Of those uranium deposits managed by the CNEA, the Cerro Solo deposit, which is part of the homonymous district in Chubut Province, is the primary focus of assessment/ exploration activities. Identified uranium resources of the Cerro Solo deposit totalled 9 230 tU, and to define the hydrometallurgical extraction baseline of uranium and molybdenum minerals, laboratory-scale sample testing has been completed, but further up-scale testing was postponed. Since 2018, only environmental monitoring has been carried out. From 2012 to 2018, one of the main activities at Cerro Solo ore deposit was related to environmental baseline surveying. In this regard, hydrological, palaeontological, socio-economic, air quality, flora and fauna and pedological studies have been completed. Others, such as archaeological and radiometric surveys, are being developed.

Sophia Energy S.A., UrAmerica Ltd and Blue Sky Uranium Corp reported exploration-related activities during the 2017-2019 period. Sophia Energy S.A. continued exploration of its mining properties at the Laguna Sirven deposit in Santa Cruz Province. In 2018, a radiometric airborne survey was carried out covering the whole project (600 km^2). The National Atomic Energy Commission was contracted for this work. All of these exploration efforts yielded encouraging results.

In January 2018, UrAmerica Ltd, Uranium One Group from Russia, UrAmerica Argentina and the Government of Argentina signed a memorandum of understanding whose purpose is to promote co-operation and the joint development of uranium exploration and production focused on ISL. Planned investment in this project amounts to USD 250 million. In 2019, Blue Sky Uranium Corp announced the first PEA for Ivana (Amarillo Grande project), as well as an updated resource estimate. The inferred resource estimate includes 8 730 tU at 0.031% U and 2 920 tV at 0.011% V. Exploration in 2019 continued to focus on delineating mineralisation proximal to the Ivana deposit. The first half of the year included additional pit and auger sampling, with a 6 km-long Induced Polarisation (IP) geophysical survey and up to 4 500 m of RC drilling planned for the second half of the year.

The information about private exploration expenditures must be taken as only partially complete since the industry is not required to report these expenditures to the government.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

From governmental studies, there are no changes in reasonably assured, inferred and prognosticated resources since the last edition (NEA, 2018). However, new inferred resources of 8 730 tU from the Ivana deposit (Amarillo Grande project) have been reported by the private sector.

As of 1 January 2019, the total identified resources of Argentina were 38 740 tU at the cost category <130 USD/kgU (see table below), belonging toto seven projects whose main characteristics are mentioned above. It should be noted that if the higher production cost category of <260 USD/kgU is considered, there is no substantial variation and identified resources account for 39 790 tU.

Identified uranium resources in Argentina

(as of 1 January 2019)

Deposit (ownership)	Province	Type	RAR tU ≤ USD 130/kgU	IR tU ≤ USD 130/kgU
Sierra Pintada (CNEA)	Mendoza	Volcanic-related	3 900	6 110
Cerro Solo (CNEA)	Chubut	Sandstone	4 420	3 760 (4 810)*
Don Otto (CNEA)	Salta	Sandstone	180	250
Laguna Colorada (CNEA)	Chubut	Volcanic-related	100	60
Laguna Salada (U3O8 Corp)	Chubut	Surficial	2 420	1 460
Meseta Central (UrAmericaLtd)	Chubut	Sandstone	-	7 350
Ivana/Amarillo Grande (Blue Sky Corp)	Río Negro	Sandstone (surficial)	-	8 730
Subtotal			11 020 tU	27 720 tU (28 770 tU)*
Total			38 740 tU (39 790 tU)*	

* tU for production cost category of <260 USD/kgU.

Undiscovered conventional resources (prognosticated and speculative resources)

Reported prognosticated resources of 13 810 tU correspond to five sandstone type deposits in the Cerro Solo uranium district of Chubut province (Cerro Solo, El Ganso, Puesto Alvear, El Molino and Arroyo Perdido).

To assess the uranium favourability and estimate the potential resources by the application of quantitative methods (i.e. the U.S. Geological Survey National Uranium Resource Evaluation method), the country was divided into 61 investigation units (IU). These IU, which cover 1 450 000 km^2, were delineated on the basis of the geotectonic setting as well as petrological, mineralogical and geochemical characteristics. Speculative uranium resources account for 79 450 tU according to this resource assessment, representing five IU with the greatest uranium potential (specifically: Salta Group Basin, Pampean Ranges, Paganzo Basin, San Rafael Basin and Chubut Group Basin). Sandstone, volcanic-related and granite-related were the uranium deposit types considered in this analysis.

In addition, qualitative methodologies, based on geospatial modelling and mineral systems concepts, were applied to determine uranium exploration targets.

Other potential resources studies have been conducted, notably related to uranium from phosphates (unconventional resources). As part of an IAEA Coordinated Research Project, preliminary studies are underway for the assessment of the uranium potential of phosphate rocks and testing uranium extraction from low-grade phosphate ores. The project involves studies in three sedimentary basins (Ordovician North-Western Basin, Upper Jurassic – Lower Cretaceous Neuquen Basin, and Paleocene – Miocene Patagonia Basin), where low-grade phosphate mineralisation and uranium anomalies (up to 135 ppm U; 0.0135% U) have been identified.

Uranium production

Historical review

Argentina produced uranium from the mid-1950s until 1999, with a total of seven commercial-scale production centres and a pilot plant that operated between 1953 and 1970. The closure of one of the last of these facilities in 1995 (Los Colorados) resulted in a change in the ownership structure of uranium production in Argentina, and since 1996, the uranium mining industry has been wholly owned by CNEA. The last facility that remained operative at that time, San Rafael, was placed on standby in 1997. No uranium has been produced since then, neither privately nor by state. Between the mid-1950s and 1997, cumulative uranium production totalled 2 582 tU.

Status of production facilities, production capability, recent and ongoing activities and other issues

Production projects

Argentina produced about 120 tU/year for about 20 years to provide raw material to fuel its nuclear power plants Atucha I and Embalse, with ore from different sites distributed throughout the national territory. However, in the late 1990s, the decline in the international price of uranium made domestic production no longer competitive, and the decision to shut down the remaining production plants and import uranium was taken. Nevertheless, changes in recent years have resulted in CNEA reviewing its plans and considering reopening production facilities. These changes include mainly uncertainties related to future external supply, and increases in domestic uranium requirements related to full capacity operation of the Atucha II reactor, which was reached in 2015. These uncertainties and increases are in part related to the Embalse plant, that was not producing power for two years due to refurbishing designed to extend its useful life for a term of 30 years, which included an increase in its power by an additional 35 MWe. With an approximate installed capacity of 1.7 GWe, natural uranium requirements are about 220 tU per year. The potential addition of one new pressurised water reactor, and the development of the CAREM-25 prototype and CAREM-120 commercial reactors, will further increase the domestic uranium requirement, which could reach approximately 500 tU/year by 2030.

The San Rafael Mining-Milling Complex (CMFSR) Remediation and Reactivation Project

Once CNEA evaluated the possibility of reopening the production facilities of the San Rafael mining-milling complex (Sierra Pintada mine), an environmental impact assessment (EIA-2004, according to provincial Act 5961) was presented to the authorities in the province of Mendoza and to the Nuclear Regulatory Authority. This study evaluated the potential impacts of uranium concentrate and dioxide production and the treatment of the former wastes simultaneously.

The EIA concluded that former operations had not affected the quality of underground and surface waters in the area, or any other environmental component in the surrounding area. Provincial authorities nonetheless rejected this proposal, arguing that CNEA must first remediate the open-pit water and the milling wastes stored in drums before restarting the production. In response, CNEA prepared and submitted a new EIA (2006) addressing only the treatment of wastes in temporary storage and pit water. This proposal received technical approval, but not final approval because it lacked the required statutory public hearing. A further complication that increased the difficulty of reopening the plant was the approval of Mendoza Provincial Act 7722 (2007) that prohibits the use of sulphuric acid, among other chemicals, in mining activities.

Currently, CNEA is building evaporation ponds and defining the basic engineering for the simultaneous treatment of open-pit water and milling wastes stored at the San Rafael complex. To date, three effluent evaporation ponds have been finished and one more is under construction. In 2018, an update to EIA 2006 (EIA, 2013), presented to the provincial control authorities, was received favourably, with technical opinion and a public hearing mandatory by law held in 2019 yielding positive outcomes. Consequently, the provincial authorities granted the EIA by Resolution N° 259/19.

CNEA secured sufficient funds for the rehabilitation of former uranium production facilities from the Bank for Investment Projects in the Ministry of Economy. An approved budget provided more time and resources could be devoted to addressing the remediation and rehabilitation. These activities involved the removal of obsolete facilities, construction of effluent ponds, purchase of equipment and facilities, and other associated work.

Before restarting uranium production in San Rafael, it was necessary to obtain both provincial approval and agreement to amend the provincial law that prevents the use of sulphuric acid, among other chemicals. Technical feasibility has been partially demonstrated by the fact that this deposit was previously in operation, using an acid heap-leaching mining method. Other alternatives have been considered for possible future production, including the use of alkaline leaching, bioleaching and vat leaching. Also, given the possibility of the reopening of the mining-milling complex, all available data have been processed to redefine the geological model and formulate a more suitable mining design.

The Cerro Solo Project

CNEA continues developing feasibility studies for the proposed mining of the Cerro Solo deposit (Chubut Province), and several laboratory-scale tests have been carried out to determine the most economic milling process. Since the deposit contains molybdenum in addition to uranium, identifying an appropriate and feasible process is not trivial. Molybdenum could be a valuable by-product, but its presence in the leachate could compromise the exchange resins, so another process, like liquid-liquid extraction, may be used. For this reason, all preliminary investigations have been critical steps in developing a profitable production plan. Recently, the conceptual engineering design has been developed.

In the mining sector, a conceptual study was advanced and improved using specific software for geological modelling. A pre-technical economic feasibility study was in development, beginning with prior validation of all information (tonnages, grade, geotechnical, geostructural and hydrogeological) and some surface works.

Currently, the project has been put on stand-by status, awaiting a governmental decision to move forward, which will take into consideration the basic engineering studies of both the mining operation and the processing plant.

Besides technical considerations, a Chubut provincial Law 5001/03 that prevents open-pit mining is still in effect, and mining projects need to wait for the Chubut provincial territory zoning provisions of this law, as well as the introduction of a regulatory framework for mining in this jurisdiction.

Ownership structure of the uranium industry

In Argentina, uranium production cycle activities have been carried out by the government. Private sector participation exists only in the exploration phase, although legislation provides for the participation of both state and private sectors in uranium exploration and production activities.

Uranium production centre technical details

(as of 1 January 2019)

	Centre #1	Centre #2
Name of production centre	San Rafael Mining-Milling Complex	Cerro Solo Deposit
Production centre classification	Planned (reopening)	Planned
Date of first production	1976	NA
Source of ore:		
Deposit name(s)	Sierra Pintada	Cerro Solo
Deposit type(s)	Volcanic-related, synsedimentary	Sandstone, paleochannel
Recoverable resources (tU)	6 000	NA
Grade (% U)	0.107	NA
Mining operation:		
Type (OP/UG/ISL)	OP	OP-UG
Size (tonnes ore/day)	550	NA
Average mining recovery (%)	90	NA
Processing plant:		
Acid/alkaline	Acid	Acid
Type (IX/SX)	IX	SX
Average process recovery (%)	78	NA
Nominal production capacity (tU/year)	150	200
Plans for expansion	Yes	NA
Other remarks	Yellowcake production ceased in 1997. Remediation activities are underway	Preliminary stage

Employment in the uranium industry

In connection with the uranium production industry, currently most of the employees are working on development, maintenance and remediation of the San Rafael mining-milling complex.

Future production centres

The development of a new production centre in the Chubut Province, in the area of the Cerro Solo deposit, would be the most suitable option for the future. However, the project is on stand-by status and construction commitments have not yet been made.

Production and/or use of mixed oxide fuels

Argentina neither produces MOX fuel nor uses it in its nuclear power plants.

Production and/or use of re-enriched tails

The mock-up facility for uranium enrichment, located in Pilcaniyeu Technological Complex (Bariloche), is a pilot plant that was already operating in the 1980s and early 1990s, until it was deactivated in 1995. The project was relaunched in 2006, restarting its activities in 2007.

The start-up of the operations took place in March 2014, enabling Argentina to produce enriched uranium by gaseous diffusion technology. CNEA aims to use this technology for supplying currently operating and planned/projected NPPs. Furthermore, CNEA is currently developing other technologies, such as ultra-centrifuge and laser.

Environmental activities and socio-cultural issues

Environmental impact assessments

In Argentina, production permits are subject to both national and provincial legislation. Currently, environmental studies are being undertaken on three major uranium production projects.

The San Rafael Mining-Milling Complex Remediation Project (Mendoza Province)

As stated in the 2018 edition of the Red Book, an update of the 2006 EIA (MGIA-2013) had been presented to the authorities of the Mendoza Province. This study addressed only the treatment of solid wastes, currently in temporary storage, and open-pit mine water. The proposal received technical approval (2013 EIA), which was endorsed after the implementation of the statutory public hearing held in 2019. In the meantime, CNEA has continued with some improvements to preserve the environment along with establishing the following additional security measures:

- Effluent pond "DN 8-9"

The construction of an evaporation pond (5 hectares) with a double liner waterproof high-density polyethylene (HDPE) geo-membrane with a leakage detection system has been completed, and hydraulic tests have been successfully accomplished. It is currently being used to manage open-pit water.

- Effluent pond "DN 5"

Civil works for ground stabilisation have been completed. The design of this precipitation facility complex aims to treat open-pit water. Engineering details have been submitted to the local authorities to determine the corresponding allowance and to continue with the works. These ponds will have a total operational capacity of approximately 12 000 m^3 and will have security drainage systems and double waterproofing HDPE geo-membrane to control leaks. These ponds are designed for providing the necessary conditions (residence time) to generate As and Ra precipitates before they are conducted to the effluent pond "DN 8-9" for final disposal.

- Other remediation activities

Other activities related to waste management are being carried out, such as building cisterns, waterproofing, design of wastewater treatment systems, repairing facilities and the installation of pipes for pumping effluents between the quarries and the processing and treatment facilities.

Cerro Solo ore deposit (Chubut Province)

As requested by the provincial authorities, environmental baseline studies are being developed by CNEA through contracts with universities and institutes. Some aspects of these studies (archaeological, palaeontological and socio-economic impacts) have already been completed and presented to the provincial authorities. In addition, CNEA continues with communication activities, offering information on mining activities to the neighbourhoods located near the proposed mining projects and areas of exploration.

The Los Gigantes former Mining-Milling Complex Remediation Project (Córdoba Province)

In November 2018, detailed engineering of the environmental restitution project for this site was presented to the provincial authorities. CNEA is awaiting the response before conducting a public hearing and obtaining an environmental impact statement.

Monitoring

The San Rafael Mining-Milling Complex Remediation Project (Mendoza Province)

CNEA currently has an intense monitoring programme, which includes:

- Surface water: systematic sampling of surface water and run-off, both upstream and downstream of the facilities, are being undertaken in order to follow the evolution of possible pollutants concentration (U, As, Ra, among others) inside and outside CNEA's influence area.
- Groundwater: systematic sampling of groundwater within a redesigned well network inside the complex is being carried out.
- Air pollution: particulate matter and radon emissions are periodically sampled within key locations of the complex.
- Open-pit water: systematic sampling of open-pit water is being carried out in every pit.
- Sediments: systematic sampling of sediments is being carried out within the complex.

Cerro Solo ore deposit (Chubut Province)

The sampling work includes water samples from exploration wells, water samples from domestic wells (owned by inhabitants of the area), surface run-off and sediment from streams and springs in the watershed (analysing for U, Ra, As, F, among others). Air pollution samples include particulate matter and radon emissions measurements.

Effluent management

The San Rafael Mining-Milling Complex Remediation Project (Mendoza Province)

The construction of the "DN 8-9" evaporation pond and the "DN 5" open-pit water treatment facility, aims to reduce pollutants and meet provincial water quality standards. Moreover, the design and implementation of a domestic wastewater treatment system is under study.

Site rehabilitation

The San Rafael Mining-Milling Complex Remediation Project (Mendoza Province)

In general, CNEA is submitting technical proposals to rehabilitate those areas of the complex that will not be used for uranium production in the future. Topics of these projects include the former tailings dump, open-pits rehabilitation and waste rock management, among others.

Uranium Mining Environmental Restoration Programme

CNEA is currently undertaking the Uranium Mining Environmental Restoration Programme (PRAMU). The aim of this programme is to restore the environment, as much as possible, in every area where uranium mining and milling activities have taken place.

In Córdoba Province, the Córdoba and Los Gigantes sites have advanced detailed engineering projects underway. In Mendoza Province, at the Malargüe site, environmental restoration work was completed in June 2017. A recreation space for the community was built and environmental and radiological conditions have been monitored since closure. Also in the Mendoza Province, at the Huemul site, as well as at the Pichiñán site in Chubut Province, the Tonco site in Salta Province, the La Estela site in San Luis Province, and the Los Colorados site in La Rioja Province, partial environmental baseline studies are being carried out.

All these sites are the subject of periodic radiological and environmental monitoring. PRAMU seeks to improve the current conditions of the tailings deposits and mines, and to ensure the long-term protection of people and the environment.

The CNEA is required to comply with all legislation that is in force and is under the control of various national, provincial and local state institutions.

Regulatory activities

Argentina's provinces have legislation limiting certain aspects of mining activities (use of certain substances, open-pit mining, etc.). The local regulations co-exist with national legislation related to mining activities and environmental protection.

National regulations

- Law No. 25675: "General Environmental Law" establishes minimum standards for achieving sustainable management of the environment, the preservation and protection of biodiversity and the implementation of sustainable development.
- Law No. 1919: "National Mining Code", which in Title Eleventh (Articles 205 to 212) refers to nuclear minerals (U and Th).
- Law No. 24585: Obligation of submitting an environmental impact assessment (EIA) prior to each stage of development of a mining project. It sets the maximum acceptable limits of various effluent parameters in water, air and soil.

Mendoza provincial regulations

- Law No. 3790, created the Mining General Direction and states that their specific functions are the administration, control and promotion of the mining industry in all its phases and throughout the territory of the province.
- Law No. 7722 prohibits on the territory of the Mendoza Province, the use of chemicals such as cyanide, mercury, sulphuric acid, and other similar toxic substances in metalliferous mining, including prospecting, exploration, exploitation and industrialisation of metal ores obtained by any extraction method.
- Resolution No. 778/96 of the General Department of Irrigation (DGI) regulates all activities that may affect the quality of surface water and groundwater in the territory of the Province of Mendoza.

Chubut provincial regulations

- Law XVII-No. 68 prohibits open-pit methods for metal mining activity in the province of Chubut, as well as the use of cyanide in mining production processes. It also mentions the need of zoning in the territory of the province for the exploitation of mineral resources with an approved production model for each case.

Uranium requirements

The uranium requirements listed below correspond to an estimation made in the Strategic Nuclear Energy Planning 2010-2030 and the reactivation of the Argentine Nuclear Energy Plan launched in 2006. As of the end of 2018, the nuclear plan status is as follows:

- Extending the life of Embalse NPP: achieved.
- Extending the life of Atucha I NPP: planned.
- Construction of the 4^{th} and 5^{th} NPPs: at present only construction of one is planned.
- Development and construction of a small modular nuclear power reactor (CAREM): in progress.

- Reactivation of uranium enrichment: in progress.
- Reactivation of uranium mining industry: in stand-by status.

The most important update in Argentine nuclear production was the start-up of Atucha II (745 MWe), reaching first criticality at the end of 2014.

Also proposed is the expansion of the nuclear energy network, which would be covered by the construction of the 4th NPP consisting of a PWR-type reactor (1 150 MWe by 2035).

In addition, CNEA is currently carrying out the construction of the CAREM (27 MWe) by 2023, a small modular reactor prototype, and is planning to build another larger unit, CAREM-120 (120 MWe) by 2030.

Embalse has been off-line not generating electricity for two years due to refurbishing and upgrades designed to extend its useful life for a term of 30 years, as well as also increasing in its electricity output by an additional 35 MWe. Within the 2023-2024 period, Atucha I will be off-line for facility refurbishing and upgrades to extend operational life to 2046.

Supply and procurement strategy

In 1992, due to the low prices in the international market, the import of uranium concentrates from South Africa began, a situation that gradually led to the closure of local production in 1997. Since then, there has been no production of uranium in the country and uranium needs from operating nuclear power plants have been met with raw materials imports from abroad (i.e. from Uzbekistan, Czech Republic, Kazakhstan and Canada).

At present, both government and industry are carrying out exploration projects with the intention of restarting domestic uranium production in order to achieve self-sufficiency in uranium supply.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

The Nuclear Activity Law of 1997 establishes the respective roles of CNEA and the Nuclear Regulatory Authority. It also provides for the participation of both public and private sectors in uranium exploration and development activities.

The National Mining Code of 1994 states that the government has the first option to purchase all uranium produced in Argentina and that export of uranium is dependent upon first guaranteeing domestic supply. It also regulates development activities to ensure the use of environmental practices that comply with international standards.

Uranium stocks

CNEA does not have the responsibility of ensuring the uranium concentrate stock. The uranium dioxide producing company Dioxitek S.A., and the NPPs operator Nucleoeléctrica Argentina S.A./NA-SA, have the responsibility of guaranteeing a uranium stock for at least two years of operation for Argentina's nuclear power plants.

Current uranium stock accounts for 65 tU in the form of uranium oxide concentrate (UOC).

Uranium prices

There is no uranium market in Argentina.

Uranium exploration and development expenditures and drilling effort – domestic
(in Argentine pesos [ARS])

	2016	2017	2018	2019 (preliminary)
Industry* exploration expenditures	2 640 000	36 200 000	39 000 000	24 500 000
Government exploration expenditures	60 200 000	47 000 000	26 900 000	30 300 000
Total expenditures	62 840 000	83 200 000	65 900 000	54 800 000
Industry* exploration drilling (m)	0	7 159	2 378	610
Industry* exploration holes drilled	0	467	236	81
Government exploration drilling (m)	1 114	0	0	0
Government exploration holes drilled	6	0	0	0
Total drilling (m)	1 114	7 159	2 378	610
Total number of holes drilled	6	467	236	81

* Non-governmental.

Reasonably assured conventional resources by production method
(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	0	180	180	72
Open-pit mining (OP)*	0	5 130	10 840	10 840*	70-72
Total	0	5 130	11 020	11 020	

* 78% of the total has a recovery factor of 72% and 22% of total a recovery factor of 70%.

Reasonably assured conventional resources by processing method
(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Heap leaching* from UG	0	0	180	180	72
Heap leaching* from OP	0	5 130	8 420	8 420	72
Unspecified	0	0	2 420	2 420	70
Total	0	5 130	11 020	11 020	

* A subset of open-pit and underground mining, since it is used in conjunction with them.

Reasonably assured conventional resources by deposit type
(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Sandstone	0	2 890	4 600	4 600	72
Volcanic-related	0	2 240	4 000	4 000	72
Surficial	0	0	2 420	2 420	70
Total	0	5 130	11 020	11 020	

Inferred conventional resources by production method
(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	2 430	12 730	20 120	21 170*	72-78
Underground mining (UG)	0	0	250	250	72
Unspecified	0	0	7 350	7 350	72
Total	2 430	12 730	27 720	28 770	

* 59% of the total with a recovery factor of 72% and 41% of the total with a recovery factor of 78%.

Inferred conventional resources by processing method
(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from OP	2 430	12 730	18 660	19 710*	72-78
Heap leaching from OP	0	0	1 460	1 460	70
Heap leaching from UG	0	0	250	250	72
Unspecified	0	0	7 350	7 350	72
Total	2 430	12 730	27 720	28 770	72

* 58% of the total with a recovery factor of 72% and 42% of the total with a recovery factor of 78%.

Inferred conventional resources by deposit type
(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Sandstone	1 950	10 930	20 090	21 140*	72-78
Volcanic-related	480	1 800	6 170	6 170	72
Surficial	0	0	1 460	1 460	70
Total	2 430	12 730	27 720	28 770	

* 59% of the total has a recovery factor of 72% and 41% of the total with a recovery factor of 78%.

Prognosticated conventional resources
(tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
NA	13 810	13 810

Speculative conventional resources
(tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
NA	79 450*	NA

* Estimated over five investigation units.

Historical uranium production by production method

(tonnes U in concentrate)

Production method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Open-pit mining[1]	1 858.7	0	0	0	1 858.7	0
Underground mining[1]	723.0	0	0	0	723.0	0
Total	2 581.7	0	0	0	2 581.7	0

1. Pre-2015 totals may include uranium recovered by heap and in-place leaching.

Historical uranium production by processing method

(tonnes U in concentrate)

Processing method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Conventional	752.7	0	0	0	752.7	0
Heap leaching	1 829.0	0	0	0	1 829.0	0
Total	2 581.7	0	0	0	2 581.7	0

Historical uranium production by deposit type

(tonnes U in concentrate)

Deposit type	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Volcanic-related	1 600.0	0	0	0	1 600.0	0
Sandstone	729.2	0	0	0	729.2	0
Granite-related	252.5	0	0	0	252.5	0
Total	2 581.7	0	0	0	2 581.7	0

Uranium industry employment at existing production centres

(person-years)

	2016	2017	2018	2019 (expected)
Total employment related to existing production centres	65	58	50	45*
Employment directly related to uranium production	0	0	0	0

* Center in standby. Remediation activities are underway.

Short-term production capability

(tonnes U/year)

2017				2020				2025			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
0	0	0	0	0	0	0	0	0	0	NA	NA

2030				2035			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
NA	NA	NA	NA	NA	NA	NA	NA

Net nuclear electricity generation

	2017	2018	2019
Nuclear electricity generated (TWh net)	5.72	6.45	8.70 (estimated)

Installed nuclear generating capacity to 2040

(MWe gross capacity)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
1 755	1 755	1 790	1 790	1 822	1 822	3 092	3 092	4 242	4 722	4 722	6 352

Annual reactor-related uranium requirements to 2040 (excluding MOX)

(tonnes U)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
101	114	218	218	230	230	486	486	698	874	874	1 262

Armenia

Uranium exploration

Historical review

On 23 April 2007, the Director-General of Rosatom (a state corporation of Russia) and the Armenian Minister of Ecology Protection signed a protocol on conducting uranium exploration work in Armenia.

Based on this protocol, an Armenian-Russian joint venture, CJ-SC Armenian-Russian Mining Company (ARMC), was established in April 2008 for the purpose of geological exploration, mining and processing of uranium. The founders of ARMC are the Armenian government and Atomredmetzoloto of Russia.

Within this framework, the collection and analysis of archival material relevant to uranium mining was completed, and a document, "Geologic Exploration Activity for 2009-2010", specifically regarding uranium ore exploration in Armenia, was published and approved.

In the Spring of 2009, field work related to uranium ore exploration started in the province of Syunik. Geological prospecting work was carried out on the first Voghchi zone of the Pkhrut-Lernadzor licensed area in 2011. Geologic prospecting identified some anomalies. All plans for geologic prospecting in 2011 were fulfilled by January 2012. In 2012, legislated works were implemented.

Exploration of the block 1st Voghchi zone of the Pkhrut deposit identified a very small occurrence below 1 000 tU inferred resources (category C2 in Russian classification) and indicated that the deposit is prospective.

In 2013, the Armenian-Russian joint venture was suspended due to unfavourable uranium market prices.

Uranium production

Armenia does not produce uranium.

Uranium requirements

There have been no changes to Armenia's nuclear energy programme during the past two years. The country's short-term uranium requirements remain the same and are based on the operation of one VVER-440 unit (Armenian-2). A detailed forecast for uranium requirements was carried out, taking into account the designed lifetime for this reactor, which has an installed capacity of about 407.5 MWe.

The Ministry of Energy Infrastructures and Natural Resources released the "Armenia New Nuclear Unit Environmental Report" in April 2011. According to the Armenian energy sector development plan, a high-level forecast envisions the construction of a new nuclear unit by 2025.

Long-term requirements depend on the country's policy in the nuclear energy sector. On 23 October 2013, the President of the Republic of Armenia signed an executive order on the Approval of the Concept of Ensuring the Energy Security of Armenia. On 31 July 2014, the Armenian government adopted the Action Plan on Implementation of the Energy Security Measures. Long-term development of the Armenian energy sector (i.e. up to 2036) was approved by the government on 10 December 2015. According to this document, there is a need for a new nuclear power plant with a capacity of up to 600 MWe to ensure the necessary level of energy security and energy independence by 2027.

Supply and procurement strategy

Nuclear fuel for the Armenian NPP is supplied by Russia. Armenia's nuclear fuel requirements have remained unchanged for the past two years. The fuel procurement strategy has also remained unchanged and continues to be based on fuel sourced from Russia. The requirements for the proposed new unit will depend on the reactor type.

In 2007, the Armenian government decided it would enter into an agreement with the governments of Kazakhstan and Russia to establish an international uranium enrichment centre (IUEC) at the Angarsk electrolytic chemical combine in Russia. Armenia completed the legal registration of accession and in 2010 joined the IUEC.

Net nuclear electricity generation

	2017	2018
Nuclear electricity generated (TWh net)	2.62	2.08

Installed nuclear generating capacity to 2040

(MW(e) net)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
375	375	375	375	375	375	600	600	600	600	NA	NA

Annual reactor-related uranium requirements to 2040 (excluding MOX)

(tonnes U)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
64	64	64	64	64	64	129	129	129	129	NA	NA

Australia

Uranium exploration

Historical review

Australia has maintained involvement in the uranium industry since its inception and remains one of the world's largest producers and exporters of uranium. The majority of Australia's significant uranium deposits were discovered between 1969 and 1980 when exploration expenditures for the commodity were relatively high. Uranium exploration budgets have generally declined since the greenfields discovery of the Kintyre deposit in Western Australia by Conzinc Rio Tinto of Australia (CRA) in 1985. Despite the lack of major recent greenfields discoveries, the resource base has grown through significant brownfields extensions to known resources, and some new occurrences delineated proximal to these with similar geology.

Discovered by Western Mining in 1975, and owned/operated by BHP Billiton (BHP) since 2005, the Olympic Dam mine in South Australia is the world's largest single uranium resource. Continuous production has been maintained since 1988. Australia's uranium has usually been produced from a small number of mines (often only three), though production has shifted localities over time. Mining has occurred at Mary Kathleen and Westmoreland in Queensland; Radium Hill, Mount Painter, Honeymoon, Four Mile, and Beverley in South Australia; along with Ranger, Narbalek and Rum Jungle in the Northern Territory.

Most of Australia's uranium resources occur in two main types of deposits: breccia complex deposits, such as Olympic Dam, or unconformity-related deposits, such as Ranger or Kintyre. Other categories include sandstone uranium deposits, for example, Honeymoon; surficial (calcrete) deposits such as Yeelirrie or Centipede; and metasomatite, metamorphic, volcanic, or intrusive deposits. Australia has no significant deposits of the quartz-pebble conglomerate-type, vein-type, and collapse breccia-pipe-type.

Recent and ongoing uranium exploration and mine development activities

Mineral exploration in Australia is undertaken exclusively by commercial entities. However, quality geoscientific databases and information systems are maintained and made available by the Federal Government and relevant state or territory governments, augmenting Australia's favourable geological settings.

Exploration expenditures for uranium decreased in 2018 to AUD 12.3 million from AUD 19.8 million in 2017.

Western Australia

- Mulga Rock

The sandstone-type Mulga Rock resource is wholly owned by Vimy Resources Ltd. It is located 240 kilometres east of Kalgoorlie in Western Australia and consists of four deposits: Ambassador, Emperor, Princess, and Shogun. The Mulga Rock Uranium project was granted development approval in Western Australia and then secured Federal Government approval in March 2017.

The project involves shallow open-pit mining of four polymetallic deposits with commercial grades of uranium situated in sandstone-hosted carbonaceous material. It has a 15-year mine life and is anticipated to produce 1 346 tU annually. In January 2018, Vimy Resources released a definitive feasibility study for the Mulga Rock project.

- Yeelirrie

The surficial calcrete-hosted Yeelirrie uranium deposit is wholly owned by Cameco Australia. It is located about 420 km north of Kalgoorlie and 70 km south-west of Wiluna in Western Australia, and is one of the world's largest surficial uranium deposits.

The Yeelirrie deposit is suited to open-cut mining as the resource is close to the surface and most of the ore will not require drilling or blasting. Cameco acquired the Yeelirrie project from BHP in 2012. The Yeelirrie Uranium Project received environmental approval from the Western Australia Government in January 2017 and the Commonwealth Government in April 2019.

As of 2019, no work is planned at Yeelirrie, with future development of the project awaiting better market conditions. It is estimated that average production from the Yeelirrie project would be nearly 3 300 tU per annum over 19 years, utilising open-cut mining and alkaline leach technology.

- Kintyre

The unconformity-related Kintyre uranium deposit is wholly owned by Cameco Australia, who in 2018 acquired the 30% interest that was held by Mitsubishi Development Pty Ltd. Kintyre is located in the East Pilbara region of Western Australia, approximately 260 km north-east of Newman at the western edge of the Great Sandy Desert. The Kintyre resource is suited to open-pit mining. The uppermost parts of the resource are 50 m below surface, though there is no outcrop.

Cameco Australia secured environmental approval for the Kintyre project in 2015 from the Commonwealth and Western Australian governments. As of 2019, no work is planned at Kintyre with the future development of the project awaiting better market conditions. It is estimated that the likely production from the Kintyre project is around 2 290 tU per annum, with an estimated mine life of 15 years.

- Wiluna Uranium Project

Toro Energy Ltd is the single owner of the Wiluna Uranium Project, which is a surficial calcrete-hosted regional resource consisting of six deposits: Centipede, Lake Way, Millipede, Lake Maitland, Dawson Hinkler, and Nowathanna.

The Centipede, Millipede, Lake Maitland, and Lake Way deposits collectively make up the Wiluna Uranium Project, while the Dawson Hinkler and Nowathanna deposits are regarded as advanced exploration prospects.

Mining of the Centipede and Lake Way uranium deposits, including the construction of a processing facility at Centipede, received environmental approval from the Western Australian Government in 2012 and the Commonwealth Government in 2013. Toro expanded the Wiluna project proposal, which encompasses the Lake Maitland and Millipede resources, and received environmental approval from the Western Australian Government in January 2017 and the Commonwealth in July 2017.

Mining at Wiluna is planned as shallow strip excavation to a maximum depth of 15 metres. It is proposed to use alkaline agitated leaching in tanks at elevated temperatures to process the ore. Production is estimated to be approximately 577 tU per year.

South Australia

South Australia has five approved uranium mines: Olympic Dam, Honeymoon, Beverley, Beverley North, and Four Mile. With only Olympic Dam and Four Mile producing uranium in 2018.

- Olympic Dam

BHP's breccia complex-hosted Olympic Dam is Australia's largest mine, contributing around two-thirds of Australia's uranium production. Plans for a large expansion at Olympic Dam have been scaled back although BHP plans to steadily increase production capacity under its existing approvals, and in 2018, underground operations commenced in the "Southern Mining Area" of the resource. Approval applications have been lodged with the South Australian and Commonwealth governments for expanded production in the future. While production is planned to remain stable in the near term, it is anticipated output may increase through debottlenecking of investments, plant upgrades and modernisation of infrastructure.Beverley, Beverley North and Four Mile.

The Beverley, Beverley North and Four Mile mines use in situ recovery (ISR) to extract uranium from sandstone deposits. The mines are located around 550 km north of Adelaide. The Beverley and Beverley North mines have been in care and maintenance since 2012 and 2018, respectively, but retain approval to operate. Production is currently focused on the nearby Four Mile mine, from which leach solution is processed at the Beverley processing plant.

- Honeymoon

Operated by Boss Resources Ltd, the sandstone-type Honeymoon deposit is currently in care and maintenance. However, it remains approved for mining, and exploration and metallurgical test work continues. Additional resources were identified at the nearby Jason's deposit resulting in a total published resource of over 20 732 tU. The company completed a programme of field leach trials in 2018 that successfully demonstrated the application of the ion-exchange process.

Northern Territory

- Ranger

The Ranger mine, operated by Energy Resources of Australia (ERA – majority owner Rio Tinto), is the only operating uranium mine in the Northern Territory. Ranger occurs in the Pine Creek Inlier and is classified as an unconformity-related deposit type. Continuous production and export of uranium oxide concentrate have been maintained from Ranger since operations commenced in 1980. In 2012, Pit 3 mining operations ceased with production from 2013 being maintained through stockpiled ore material. The mine is a significant employer of indigenous people, who hold a range of positions at the operation.

Uranium mining at Ranger will cease in January 2021. Activities ceased at Ranger Open Pit 1 in 1994, and as a part of the closure, the pit was filled with tailings and waste rock with a laterite clay cap being placed on the pit surface in 2016. Mining of Open Pit 3 ended in 2012 and ERA's mine closure and rehabilitation plan commenced soon afterward. This involves placing all tailings in the mined-out pit, as well as low-grade mineralised rock and waste rock. Final rehabilitation is to be completed by January 2026.

- Queensland

Queensland hosts more than 80 known sites that contain valuable amounts of uranium, mainly in the remote northwestern area of the state. In March 2015, the incoming Queensland government announced that it intended to reinstate a ban on uranium mining. The ban had been repealed in 2012 by the previous government following a period of over 30 years during which no uranium mining had been undertaken in the state. Currently, Queensland allows uranium exploration but not mining.

New South Wales

Uranium exploration was prohibited in New South Wales for 26 years until the then state government overturned the ban in 2012. The ban on uranium mining and the construction or operation of nuclear reactors for the production of electricity remains in place.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

On 1 January 2019, Australia's total identified resources of uranium recoverable at a cost of <USD 130/kgU amounted to 1 183 861 tU of reasonably assured conventional resources and 508 807 tU of inferred conventional resources.

Estimated mining and processing losses were deducted from commercial uranium resource reports for individual deposits submitted under the Australian Joint Ore Reserves Committee (JORC) Code. For deposits where this information is not available, an overall, mining and milling recovery factor was applied as recommended in the 2019 Red Book Questionnaire. Overall recovery factors range from 58% to 95%.

Notable differences between Australia's previous country report (2018) include an overall decline of RAR and lower cost IR, as well as an increase in high-cost IR. These changes can be accounted for by (1) new and reassessed uranium recoverability information, (2) the shifting of some resources to higher cost categories, and (3) the depletion of the Ranger stockpile.

Although there are more than 35 deposits with identified resources recoverable at costs of <USD 130/kgU, the vast majority of Australia's resources are within the following five individual deposits: Olympic Dam in South Australia, Ranger and Jabiluka in the Alligator Rivers Region of the Northern Territory, and Mulga Rock and Yeelirrie in Western Australia.

At the Olympic Dam mine, uranium is a co-product of copper mining, with gold and silver also recovered. At the proposed Carrapateena mine, uranium would not be recovered, and the metal would largely report to tailings.

Undiscovered conventional resources (prognosticated and speculative resources)

Geoscience Australia does not make estimates of Australia's undiscovered uranium resources.

Unconventional resources and other materials

Geoscience Australia does not make estimates of Australia's unconventional uranium resources.

Uranium production

Historical review

The current phase of Australian uranium production commenced in 1976. Current exports are approximately 6 400 (tU) per annum (averaged over ten years), or around 12% of the global market. Uranium produced in Australia is exported to countries in North America, Asia, and Europe and is used as fuel in nuclear power stations to generate electricity.

A review of the history of uranium exploration, development and production in Australia is provided in *Australia's Uranium Resources, Geology and Development of Deposits,* available at: www.ga.gov.au/webtemp/image_cache/GA9508.pdf.

Status of production capability and recent and ongoing activities

On 1 January 2019, Australia had three operating uranium mines: Ranger (Northern Territory), Olympic Dam and Four Mile (South Australia), with the latter operation's pregnant solution being processed at the Beverley plant.

Five uranium projects in Australia are awaiting better market conditions before proceeding with development: Honeymoon (Boss Resources Ltd) in South Australia, Kintyre and Yeelirrie (Cameco Australia Pty Ltd), Wiluna (Toro Energy Ltd), and Mulga Rock (Vimy Resources Ltd), all in Western Australia.

Total uranium mine production for 2018 from the three operating mines, Olympic Dam, Ranger, and Four Mile amounted to 6 526 tU.

Olympic Dam

Olympic Dam's production of payable metal in concentrate for 2018 was 3 168 tU, an increase of nearly 790 tonnes from 2017. Based on a reserve life of 47 years and more than one million tonnes of uranium resources, Olympic Dam is the largest single uranium deposit in the world. It is also the only known breccia complex deposit that has significant economic resources of uranium. Olympic Dam produces copper cathode, refined gold and silver bullion, along with uranium oxide. The BHP-owned underground mine utilises long-hole open stoping technology and cemented aggregate fill, with integrated metallurgical processing.

BHP's plans for a large single-step expansion of Olympic Dam have been scaled back. While production is planned to remain stable in the near term, it is anticipated output may increase through debottlenecking of investments, plant upgrades and modernisation of infrastructure.

BHP has completed laboratory trials of heap leach technology, which was aimed at evaluating less capital-intensive processing technologies. This work has delivered positive outcomes that may be considered for longer-term processing and investment decisions.

Ranger

ERA has produced uranium at Ranger since 1981, with more than 128 000 tonnes of uranium oxide concentrate (108 544 tU) produced to date. The Ranger uranium mine produced 1 695 tU in 2018, a 13% decrease from the 1 945 tU produced in 2017. Mining at Ranger Pit 3 concluded in December 2012. Although mining has now ceased, stockpiled ore continued to be processed at the main metallurgical plant and the laterite treatment plant.

Ranger 3 Deeps was discovered in 2009 and is estimated to contain over 34 000 tonnes of uranium oxide (28 830 tU). ERA invested around AUD 120 million into an exploration decline, which was commenced in 2012 and completed in 2014, providing access to the resource for further analysis and assessment. ERA's majority owner (68.4%) Rio Tinto announced in 2015 that after careful consideration the company did not support further study or the future development of Ranger 3 Deeps due to economic challenges facing the project.

The Gundjeihmi Aboriginal Corporation advised ERA in 2016 that the Mirarr Traditional Owners do not support the creation of a new Ranger Authority, which would provide the regulatory mechanism to enable mining after 2021. The existing Ranger Authority allows for mining and processing activities until 8 January 2021 and access for rehabilitation activities until January 2026.

Beverley/Beverley North

The sandstone-type Beverley resources, located east of the Flinders Ranges in South Australia, commenced operations in 1990. Production from Beverley, operated by Heathgate Resources Pty Ltd, started in late 2000, making it Australia's first operating ISR mine. The Beverley and Beverley North mines have been in care and maintenance since early 2012 and 2018, respectively, but retain approval to operate. Production is currently focused on the nearby Four Mile mine, from which leach solution is processed at the main Beverley processing plant. Government approvals for Beverley and Beverley North remain and, should commercial conditions change, the company may recommence production from known resources

Four Mile

The Four Mile resource comprises two significant sandstone uranium deposits, Four Mile East and Four Mile West, operated by Heathgate Resources on behalf of Quasar Resources Pty Ltd. The initial phase of operations consisted of pumping uranium-bearing solutions to the nearby satellite ion-exchange plant at the Pannikan deposit. The resin produced was initially trucked to the Beverley processing plant for elution, but as of October 2019, it is pumped via trunk lines for precipitation and drying of the uranium concentrates.

Honeymoon

Operated by Boss Resources, who acquired it in 2015 from Uranium One (Rosatom – the Russian state-owned nuclear industry operator), Honeymoon remains in care and maintenance. Uranium One's production from the Honeymoon project ceased in November 2013. However, all government approvals remain in place, and exploration and metallurgical test work continues.

Mineral exploration continued by Boss Resources in the Yarramba and Billeroo palaeochannels with new resources identified at Goulds Dam and Jason's deposit, resulting in a total published resource of over 20 732 tU. In 2017, Boss Resources completed a prefeasibility study for Honeymoon and announced the commencement of a definitive feasibility study, which is expected for completion in the December 2019 quarter. The investment by Boss Resources in research to improve the use of resin and ion-exchange technology at Honeymoon, along with consideration of a larger processing plant, aims to improve future economic outcomes with the objective of the resumption of production.

Uranium production centre technical details

(as of 1 January 2019)

	Centre #1	Centre #2	Centre #3	Centre #4
Name of production centre	Ranger	Olympic Dam	Four Mile	Honeymoon
Production centre classification	Existing	Existing	Existing	Planned
Date of first production	1981	1988	2014	2011
Source of ore:				
Deposit name(s)	Ranger	Olympic Dam	Four Mile	Honeymoon, Goulds Dam Jason's
Deposit type(s)	Proterozoic unconformity	Polymetallic Fe-oxide breccia complex	Sandstone	Sandstone
Recoverable resources (tU)	31 278	1 304 168	22 561	20 732
Grade (% U)	0.24	0.041	0.29	0.15
Mining operation:				
Type (OP/UG/ISR)	OP (stockpiled) & UG	UG & OP	ISR	ISR
Size (Mt ore/year)	4.5	12	NA	NA
Average mining recovery (%)	85	85	NA	NA
Processing plant:				
Acid/alkaline	Acid	Acid	Acid	Acid
Type (IX/SX)	SX	FLOT, SX	IX	SX & IX
Size (Mt ore/year); for ISR (litre/hour)	2.5	12	NA	NA
Average process recovery (%)	87	68	NA	NA
Mining and processing recovery factor (%)	-	-	85	85
Nominal production capacity (tU/year)	2 100	3 250	1 700	769
Plans for expansion	No	Yes	No	No
Other remarks	(a)	(b)	(c)	

(a) The Ranger mine will close in January 2021.

(b) BHP has completed trials of heap leach technology, which should assist the company in assessing less capital-intensive mineral processing technology for ore mined underground. The company has announced efforts to improve production by removing bottlenecks, through plant upgrades and modernisation of infrastructure.

(c) The Four Mile resource comprises Four Mile East and Four Mile West. Uranium-bearing resin from Four Mile is now pumped to the Beverley processing plant for elution, precipitation and drying as uranium concentrate.

Uranium production centre technical details *(cont'd)*

(as of 1 January 2019)

	Centre #6	Centre #7	Centre #8	Centre #9
Name of production centre	Mulga Rock	Yeelirrie	Wiluna	Kintyre
Production centre classification	Planned	Planned	Planned	Planned
Date of first production	Not known	Not known	Not known	Not known
Source of ore:				
Deposit name(s)	Princess, Shogun, Ambassador, Emperor	Yeelirrie	Centipede, Lake Way, Millipede, Lake Maitland	Kintyre
Deposit type(s)	Sandstone	Surficial (Calcrete)	Surficial (Calcrete)	Proterozoic unconformity
Recoverable resources (tU)	28 836	39 409	16 653	18 253
Grade (% U)	0.08	0.13	0.09	0.53
Mining operation:				
Type (OP/UG/ISR)	OP	OP	OP	OP
Size (Mt ore/year)	NA	NA	NA	NA
Average mining recovery (%)	95	NA	NA	NA
Processing plant:				
Acid/alkaline	Acid	Alkaline	Alkaline	Alkaline
Type (IX/SX)		(d)	IX	NA
Size (t ore/year); for ISR (litre/hour)	NA	NA	NA	1 700
Average process recovery (%)	87.3	NA	NA	NA
Mining and processing recovery factor (%)	-	80	80	80
Nominal production capacity (tU/year)	1 346	3 265	577	2 290
Plans for expansion	No	No	Yes	No
Other remarks				(d)

(d) Cameco is investigating several options for processing the ores including tank leaching with ion exchange and heap leaching with ion exchange.

Ownership of uranium production

Australia's uranium mines are owned and operated by a range of domestic and international companies:

- The Ranger uranium mine is owned by Energy Resources of Australia Ltd (ASX: ERA); Rio Tinto currently holds 68.4% of ERA shares with the remaining capital held publicly.
- The Olympic Dam mine is fully owned by BHP Ltd, listed on the Australian Stock Exchange (ASX: BHP).
- The Four Mile mine is fully owned by Quasar Resources Pty Ltd, a subsidiary of Heathgate Resources Pty Ltd which is in turn, owned by General Atomics (United States).

Secondary sources of uranium

Australia does not produce or use mixed oxide fuels, re-enriched tails, or reprocessed uranium.

Environmental activities and socio-cultural issues

Environmental approvals

Australia's Commonwealth and relevant state or territory legislative framework require proponents of uranium mines to undertake rigorous and comprehensive environmental impact assessment processes that incorporate public comments on the proposal. A Commonwealth assessment is conducted under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). An EPBC Act assessment is usually undertaken bilaterally with relevant state and territory authorities. An assessment is required for modifications to existing projects along with new proposals, ensuring that strict requirements for environmental, heritage and nuclear safeguards are maintained.

Social factors are also considered in the approvals processes. In particular, Aboriginal Land Rights and Native Title legislation ensures that the concerns and cultural needs of Aboriginal people are respected.

Recent environmental assessments include:

- BHP received approval in February 2015 from South Australia to raise the wall height of Tailings Storage Facility 4, from 30 m to 40 m. Commonwealth approval was not required. Also in 2012, BHP obtained approval to develop an open-pit mine. However, BHP has postponed this proposal indefinitely and in 2016, BHP announced plans to increase production through an underground expansion into the higher-grade Southern Mining Area at Olympic Dam.
- Cameco Australia's Kintyre project obtained Western Australian state environmental approval in March 2015 and Commonwealth environmental approval in April 2015.
- Vimy Resources' Mulga Rock project obtained Western Australian state environmental approval in December 2016 and Commonwealth environmental approval in March 2017.
- Toro Energy Ltd's Wiluna Extension project, encompassing the Lake Maitland and Millipede resources obtained Western Australian state environmental approval in January 2017 and Commonwealth environmental approval in July 2017.
- Cameco Australia's Yeelirrie Uranium Project obtained Western Australian state environmental approval in January 2017 and Commonwealth environmental approval in April 2019.

Site rehabilitation

In 2015, Energy Resources Australia (ERA) announced that the Ranger 3 Deeps underground mining project would not proceed to final feasibility and it remains on care and maintenance. ERA will continue to process stockpiled ore until late January 2021. Ranger Mine rehabilitation is scheduled to be completed by January 2026.

Industry/government collaboration activities

The Uranium Council (UC), formerly the Uranium Industry Framework (UIF), was established by the Australian government in 2009 to develop a sustainable Australian uranium mining sector in line with world's best practice in environmental and safety standards. Membership of the UC comprises representatives of the Commonwealth, state and territory government agencies, industry, and industry associations.

The UC made a submission to the 2015 South Australian Royal Commission into the nuclear fuel cycle. The UC's submission reviewed its (and the UIF's) work undertaken in three key areas: health and safety, regulation and environment protection, and community engagement. The submission also provided the following publications developed in response to UC (or UIF) initiatives:

- *Safe and Effective Transport of Uranium* (2007);
- *Review of Regulatory Efficiency in Uranium Mining (2008);*

- *Consolidated Indigenous Engagement Factsheets;*
- *Australia's In Situ Recovery Uranium Mining Best Practice Guide: Groundwaters, Residues and Radiation Protection (2010);*
- *Environmental Protection: Development of an Australian Approach for Assessing Effects of Ionising Radiation on Non-Human Species (2010);*
- *Guide to Safe Transport of Uranium Oxide Concentrate (2012);*
- *Uranium Oxide Concentrate (UOC) Transport Strategy 2014.*

Further information on the UC can be found at www.industry.gov.au/about-us/what-we-do/uranium-council.

National Energy Resources Australia (NERA) is one of six growth centres established by the Australian government under the Industry Growth Centres Initiative. Through a national focus, NERA's roles are to grow collaboration and innovation to assist the energy resources industry (petroleum, coal, and uranium) manage cost structures and productivity, direct research to industry needs, deliver the future work skills required and promote fit for purpose regulation. To do this, key strategies include:

- supporting collaborative and innovative research;
- building a resilient and agile supply chain through small and medium-sized enterprises and research sector collaboration;
- promoting industry sustainability through developing a greater understanding of social, environmental, economic and operational consequences of industry activity;
- promoting fit for purpose regulation.

To date, NERA has developed a Sector Competitiveness Plan and in association with Accenture, undertaken the Australian Uranium Industry Competitiveness Assessment. These reports have outlined several challenges facing the Australian uranium industry, but also have identified several opportunities to assist the industry in becoming more globally competitive. Further information on NERA can be found at: www.nera.org.au.

Regulatory activities

Radiological protection matters arising from uranium mining in Australia are principally the responsibility of the states and territories where mining occurs. The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) is responsible for developing Australia's national radiological protection framework as laid out in the Radiation Protection Series (RPS), which are implemented through jurisdictional legislation and licence conditions.

ARPANSA's RPS includes a pivotal background document, RPS F-1 *Fundamentals for Protection Against Ionising Radiation* (2014), and several codes and guides relating to uranium mining and associated processes:

- *RPS 9 Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (2005);RPS 15 Safety Guide for the Management of Naturally Occurring Radioactive Material (NORM) (2008);*
- *RPS 16 Safety Guide for the Predisposal Management of Radioactive Waste (2008);*
- *RPS 20 Safety Guide for Classification of Radioactive Waste (2010);*
- *RPS 9.1 Safety Guide for Monitoring, Assessing and Recording Occupational Radiation Doses in Mining and Mineral Processing (2011);*
- *RPS C-2 Code for the Safe Transport of Radioactive Material (2014);*
- *RPS G-1 Guide for Radiation Protection of the Environment (2015);*
- *RPS C-1 Code for Radiation Protection in Planned Exposure Situations (2016).*

ARPANSA continues to develop frameworks that guide radiological protection best practice and works closely with industry representative bodies through relevant consultative processes. ARPANSA also administers the Australian National Radiation Dose Register (ANRDR) for the storage and maintenance of dose records of workers occupationally exposed to ionising radiation. Since 2013, ANRDR has complete coverage of the uranium mining and milling industry in Australia with all operations submitting relevant dose records.

A Radon Progeny Technical Coordination Group was established with representation from the uranium mining industry, state regulators, and ARPANSA to develop a national approach to radon progeny dose assessment to address proposed changes in international recommendations. This included a programme of measurements in Australian uranium mines. This work has been published as an Advisory Note on the ARPANSA website: *New dose coefficients for radon progeny: Impact on workers and the public*, and is available at: www.arpansa.gov.au/understanding-radiation/sources-radiation/radon/new-dose-coefficients-radon-progeny-impact-workers.

The Australian government released the 2016 edition of the *Leading Practice Sustainable Development Program for the Mining Industry (LPSDP)* in November 2016. The latest edition consists of a 17-book series with several updated handbooks and two new handbooks – *Community Health and Safety and Energy Management in Mining*. Further information on the Leading Practice handbooks can be found at www.industry.gov.au/data-and-publications/leading-practice-handbooks-for-sustainable-mining.

Uranium requirements

Australia has no commercial nuclear power plants and has very limited domestic uranium requirements. An Open Pool Australian Lightwater (OPAL) research reactor is operated by the Australian Nuclear Science and Technology Organisation (ANSTO) at Lucas Heights south of Sydney, New South Wales. The OPAL reactor was opened in 2007, with the capacity to produce commercial quantities of radioisotopes utilising low-enriched uranium (LEU) fuel.

Uranium policies, uranium stocks and uranium prices

National policies

Australian policy states Australian uranium can only be sold to countries with which Australia has a nuclear co-operation agreement, to ensure that countries are committed to peaceful uses of nuclear energy. They must also have safeguards agreements with the International Atomic Energy Agency (IAEA), including an Additional Protocol. Australia's network of safeguards agreements now totals 43.

The Australian government supports the development of a sustainable Australian uranium mining sector in line with world's best practice environmental and safety standards. Uranium exploration and mining are currently permissible in South Australia, the Northern Territory, and Western Australia. New South Wales overturned legislation prohibiting uranium exploration in 2012, however uranium mining remains prohibited. In March 2015, Queensland stated it planned to reinstate the ban on uranium mining, which had been overturned in October 2012 by the previous state government, but uranium exploration is permitted. Victoria currently prohibits uranium exploration and mining. In March 2017, the incoming Western Australian government restated its commitment to place a ban on future uranium activities except for mines that had been approved by the previous government, which will be able to proceed.

Australia currently has no plans to have a domestic nuclear power industry, but interest at the state level led to the South Australian Nuclear Fuel Cycle Royal Commission in 2015. In addition, more recently, the New South Wales, Uranium Mining and Nuclear Facilities (Prohibitions) repeal Bill 2019 and the Victorian Inquiry into Nuclear Energy Prohibition (2019).

At the Commonwealth level, on 6 August 2019, an Inquiry into the Prerequisites for Nuclear Energy in Australia commenced. The Inquiry is being undertaken by the House of Representatives Standing Committee on the Environment and Energy.

Further, Regulation 9 of *Australia's Customs (Prohibited Exports) Regulations 1958*, provides that the export of goods listed in Schedule 7 of the Regulations is prohibited unless permission is obtained from the Commonwealth Minister for Industry, Innovation and Science or an authorised person. Goods listed in Schedule 7 include minerals, ores and concentrates containing more than 500 parts per million (ppm) of uranium and thorium combined.

Uranium stocks

For reasons of confidentiality, information on producer stocks is not available.

Uranium prices

The average price of uranium exported from Australia in 2018 was USD 24.59/lb U_3O_8 (USD 63.93/kgU), with exports governed by a combination of contract specifications. Average export prices for the last five years are listed in the table below.

Average export prices for Australian uranium oxide 2013-2018

Average export value	2013	2014	2015	2016	2017	2018
AUD/lb U_3O_8	43.82	40.37	51.31	43.03	36.36	40.11
USD/lb U_3O_8	38.17	33.21	36.46	25.64	21.66	24.59

Uranium exploration and development expenditures and drilling effort – domestic

(AUD millions)

	2015	2016	2017	2018
Industry* exploration expenditures	44.0	23.4	19.8	12.3
Government exploration expenditures	0	0	0	0
Industry* development expenditures	NA	NA	NA	NA
Government development expenditures	0	0	0	0
Total expenditures	44.0	23.4	19.8	12.3
Industry* exploration drilling (m)	NA	NA	NA	NA
Industry* exploration holes drilled	NA	NA	NA	NA
Industry* exploration trenches (m)	NA	NA	NA	NA
Industry* exploration trenches	NA	NA	NA	NA
Government exploration drilling (m)	0	0	0	0
Government exploration holes drilled	0	0	0	0
Government exploration trenches (m)	0	0	0	0
Government exploration trenches	0	0	0	0
Industry* development drilling (m)	NA	NA	NA	NA
Industry* development holes drilled	NA	NA	NA	NA
Government development drilling (m)	0	0	0	0
Government development holes drilled	0	0	0	0
Subtotal exploration drilling (m)	NA	NA	NA	NA
Subtotal exploration holes drilled	NA	NA	NA	NA
Subtotal development drilling (m)	NA	NA	NA	NA
Subtotal development holes drilled	NA	NA	NA	NA
Total drilling (m)	NA	NA	NA	NA
Total number of holes drilled	NA	NA	NA	NA

* Non-government.

Source: Australian Bureau of Statistics 8412.0.

Reasonably assured conventional resources by production method
(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Underground mining (UG)	NA	NA	96 570	104 343
Open-pit mining (OP)	NA	NA	164 373	181 006
In situ recovery (ISR)	NA	NA	32 988	40 722
Co-product and by-product	NA	NA	889 930	958 774
Total	NA	NA	1 183 861	1 284 845

Reasonably assured conventional resources by processing method
(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Conventional from UG	NA	NA	986 500	1 063 117
Conventional from OP	NA	NA	164 373	181 006
In situ recovery (ISR)	NA	NA	32 988	40 722
Total	NA	NA	1 183 861	1 284 845

Reasonably assured conventional resources by deposit type
(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Proterozoic unconformity	NA	NA	110 249	114 044
Sandstone	NA	NA	63 893	72 776
Polymetallic Fe-oxide breccia complex	NA	NA	898 546	967 737
Granite-related	NA	NA	322	322
Intrusive	NA	NA	13 439	18 761
Volcanic-related	NA	NA	2 731	5 125
Metasomatite	NA	NA	29 136	34 448
Surficial	NA	NA	65 545	71 632
Total	NA	NA	1 183 861	1 284 845

Inferred conventional resources by production method
(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Underground mining (UG)	NA	NA	35 632	48 076
Open-pit mining (OP)	NA	NA	16 414	122 245
In situ recovery (ISR)	NA	NA	28 255	62 127
Co-product and by-product	NA	NA	428 506	532 127
Total	NA	NA	508 807	764 575

Inferred conventional resources by processing method
(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Conventional from UG	NA	NA	464 138	580 203
Conventional from OP	NA	NA	16 414	122 245
In situ recovery (ISR)	NA	NA	28 255	62 127
Total	NA	NA	508 807	764 575

Inferred conventional resources by deposit type
(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Proterozoic unconformity	NA	NA	37 491	55 320
Sandstone	NA	NA	42 542	105 375
Polymetallic Fe-oxide breccia complex	NA	NA	428 506	532 127
Granite related	NA	NA	0	28
Intrusive	NA	NA	0	10 785
Volcanic-related	NA	NA	0	1 089
Metasomatite	NA	NA	0	11 515
Surficial	NA	NA	268	48 336
Total	NA	NA	508 807	764 575

Prognosticated conventional resources
(tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
NA	NA	NA

Speculative conventional resources
(tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
NA	NA	NA

Historical uranium production by production method
(tonnes U in concentrates)

Production method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Open-pit mining	124 051	1 993	1 945	1 695	129 684	1 485
Underground mining	838	0	0	0	838	0
In situ recovery (ISR)	9 030	1 088	1 556	1 663	13 337	1 764
Co-product/by-product	66 388	3 232	2 381	3 168	75 169	3 364
Total	200 307	6 313	5 882	6 526	219 028	6 613

Historical uranium production by processing method
(tonnes U in concentrates)

Processing method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Conventional	191 277	5 225	4 326	4 863	205 691	4 849
In situ recovery (ISR)	9 030	1 088	1 556	1 663	13 337	1 764
Total	200 307	6 313	5 882	6 526	219 028	6 613

Historical uranium production by deposit type

(tonnes U in concentrates)

Deposit type	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Proterozoic unconformity	116 637	1 993	1 945	1 695	122 270	1 485
Sandstone	9 030	1 088	1 556	1 663	13 337	1 764
Polymetallic Fe-oxide breccia complex	66 388	3 232	2 381	3 168	75 169	3 364
Metamorphite	7 531	0	0	0	7 531	0
Intrusive	721	0	0	0	721	0
Total	200 307	6 313	5 882	6 526	219 028	6 613

Ownership of uranium production in 2018*

Domestic		Foreign		Totals	
private		Government/private			
(tU)	(%)	(tU)	(%)	(tU)	(%)
3 707	56.8	2 819	43.2	6 526	100

* These figures are estimated based on public ownership information. For reasons of confidentiality, government vs private ownership information is not available; there is no Australian government production ownership. Estimated by proportioning domestic private ownership and foreign private ownership for each uranium mining company by its production for 2018.

Uranium industry employment at existing production centres

(person-years)

	2016	2017	2018	2019
Total employment related to existing production centres	3 630	4 488	4 559	3 198
Employment directly related to uranium production	2 499	3 135	3 163	2 220

Short-term production capability

(tonnes U/year)

2020				2025				2030				2035			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
NA	NA	7 200	7 200	NA	NA	5 800	5 965	NA	NA	3 623	6 009	NA	NA	3 540	10 566

Total uranium stocks

(tonnes natural U-equivalent)

Holder	Natural uranium stocks in concentrate	Enriched uranium stocks	Depleted uranium stocks	Reprocessed uranium stocks	Total
Government	0	0	0	0	0
Producer	NA	0	0	0	NA
Utility	0	0	0	0	0
Total	0	0	0	0	0

Botswana*

Uranium exploration and mine development

Historical review

The surge in the uranium price in the 1970s led to exploration activities in Botswana by various foreign and local companies. Large airborne radiometric surveys were followed by ground surveys, soil sampling, trenching and drilling. However, the thick sand cover in many parts of the country hindered exploration activities. Exploration work effectively ceased in the early 1980s with the slump in uranium prices. No deposits of economic interest were discovered in this early phase of exploration, but significant mineralisation was identified in the Karoo sandstones and surficial calcretes, particularly in the east-central part of the country.

Rising uranium prices in 2005 renewed interest in uranium exploration by junior Australian companies, and by 2011, there were 168 uranium prospecting licences registered in Botswana.

A-Cap Resources has been exploring in Botswana since 2004, following up on mineralisation discovered by Falconbridge in the 1970s in the Serowe area and further discovering significant mineralisation at the Letlhakane project. Intensive drilling resulted in A-Cap reporting Botswana's first JORC compliant uranium resource in 2008 of just over 100 000 tU at an average grade of 129 ppm U (0.0129% U).

At the end of 2012, A-Cap's prospecting licences for uranium totalled 5 000 km^2 while Impact Minerals Ltd controlled 26 000 km^2. The two companies drilled a total of 12 462 m in 95 reverse circulation holes during 2011 but no drilling was reported in 2012. Both companies completed regional ground gravity surveys and Impact Minerals Ltd completed a soil geochemical survey over an area of 250 km^2 at the Ikongwe prospect.

Impact Minerals Ltd, another Australian junior company, acquired permits around A-Cap's areas in early 2008. Exploration activities in 2009 began with airborne radiometric surveys, followed by field reconnaissance, mapping and drilling, leading to the discovery of four prospects in Karoo siltstones and sandstones. In addition to sandstone-hosted mineralisation, uranium-bearing alaskitic rocks, similar to those found at Rossing in Namibia, and mineralisation related to Proterozoic sedimentary and basement rocks with similarities to the unconformity-related deposits in Canada and Australia, were discovered. Further work is needed to assess the validity of the model and the potential of this unconformity style of mineralisation.

Along strike from Letlhakane, Impact Minerals was exploring some prospective deposits in eastern Botswana including Lekobolo, with uranium mineralisation down to 45 m. Further south, it had the Shoshong and Ikongwe prospects in calcrete. In May 2013 Impact announced the sale of four prospecting licences to a local company Sechaba Natural Resources, but this was not completed due to licensing delays, and in 2014, Impact put its uranium exploration on hold, and the majority of Impact's prospecting licences within the Botswana uranium project licences were not renewed.

Recent and ongoing uranium exploration and mine development activities

The Letlhakane uranium deposit has been the focus of detailed technical work for A-Cap since 2010, resulting in the February 2013 release of a positive scoping study. A thorough examination of all aspects of the resource has led to a greater understanding of the framework and grade

* Report prepared by the NEA/IAEA, based on previous Red Books and company reports.

distribution of uranium mineralisation and the use of appropriate mining techniques to maximise the economics of the deposit.

The uranium mineralisation, hosted predominantly in carbonaceous mudstones and siltstones, occurs in relatively thin (0.5-5 m), laterally extensive lenses with lower-grade material separating higher-grade ore horizons. The nature of the ore combined with shallow, flat-lying and soft strata lends itself well to open-pit extraction methods. This information has resulted in a resource determination that is less than previously reported, but with higher grades.

A drilling programme was completed in September 2014 focusing on shallow high-grade zones where initial optimisation runs delineated possible early pits. This drilling was designed to test the continuity and mine scale variability of mineralisation in three main project areas (Kraken, Gorgon and Serule West), and to provide data for further resource modelling and mine planning. This drilling yielded excellent results and confirmed the presence and continuity of high-grade mineralisation within these areas.

A drill optimisation study has also been completed. The drill study focused on the Kraken area where infill drilling had previously been completed. Holes were then excluded to make pre-infill drilling grids. These were completed at 400 m spacing and 200 m spacing and also 100 x 100 m and 50 x 100 m. At the 400 m and 200 m spacing alternate offset grids were also used to evaluate consistency. The results from the Kraken area concluded that the drilling defines the resource at 200 m spacing and only small variations in grade and contained metal occur when the infill drilling is conducted. This gives A-Cap an excellent guide to defining mineralisation on the project as a whole.

An infill drilling programme that was a follow-up to a major reverse circulation and diamond drilling programme, completed in June 2014, was commenced in October 2014 to further define potential early pilot pits. This programme was successfully completed in November. Resource evaluation, using uniform conditioning (UC) and localised uniform conditioning (LUC) techniques, were conducted. In September 2015, A-Cap announced an upgrade of Letlhakane resources utilising LUC method. The resources for all deposits, in compliance with the JORC 2012 code are presented in the table below.

Resources reported by A-Cap, compliant with the JORC 2012 code (September 2015)

Cut-off (U ppm)	Total indicated			Total inferred			Total		
	Mt	U (ppm)	Contained U (tU)	Mt	U (ppm)	Contained (tU)	Mt	U (ppm)	Contained U (tU)
85	197.1	167	32 885	625	172	107 730	822.1	171	140 615
170	59.2	274	16 230	209.7	272	57 000	268.9	272	73 230
255	22.2	393	8 730	81.6	378	30 885	103.8	382	39 615

In August 2015, a mining licence application was submitted to the Botswana Department of Mines. The application was based on the results of a technical study and financial modelling, assuming open-pit mining and heap leaching processing, to produce 1 440 tU/yr over a mine life of 18 years.

A detailed programme of acid column leaching, solvent extraction and ion exchange was completed. Uranium recoveries varied from 60.5 to 77.7% depending on the mineralisation type.

In 2017, A-Cap completed in-house processing studies with the objective of reducing acid consumption and increasing recovery. Acid soluble uranium analysis was performed on 296 samples. Results showed spatial and mineralogical relationships with high acid consumption within the Kraken and Gorgon South areas, exhibiting an increase in acid consumption with depth. A-Cap continued to assess the LUC resources in terms of mining optimisation, and in 2018, A-Cap continued to attend to the requirements of the Letlhakane Uranium Project's mining licence, including meeting reporting requirements, maintenance of the mining licence boundary, radiation inspectorate, compliance and engaging with the community to update them on the Project's status. The Department of Mines confirmed that the mining licence and all prospecting licences continue to be in good standing.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

In September 2015, A-Cap Resources upgraded the global JORC Resource of the Letlhakane Uranium Project. Letlhakane hosts a global resource of 822.1 million tonnes at 171 ppm uranium (0.017% U) for an in situ resource totalling 140 615 tU, based on an 85 ppm U cut-off grade. Within this resource, A-Cap has defined a higher-grade resource of 268.9 million tonnes at 272 ppm uranium (0.027% U) for 73 230 tU, based on 170 ppm U cut-off grade. Using a total recovery factor of 62% (mining and processing), the total reasonably assured and inferred recoverable resource is 87 180 tU in the <USD 260/kg U category.

Undiscovered conventional resources (prognosticated and speculative resources)

The key feature for uranium mineralisation in Botswana is the presence of highly radiogenic granitoid suites, most relating to the Pan-African (~500 Ma) magmatic event, which introduced uranium-rich source material into the upper crust. The uranium mineralisation is highly mobile and through leaching, uranium-bearing solutions became concentrated in reduced environments in sandstones, mudstones and carbonaceous materials in the overlying lower Karoo system.

Most calcareous sediments in the Gojwane and the Foley area, which lies on top of the Karoo and the Karoo-aged sediments are presumed to host widespread and continuous uranium mineralisation. These areas are considered to have the same geology as the Letlhakane area, which host one of the biggest undeveloped uranium deposits in Botswana.

Impact Minerals Ltd reports "target conceptual" undiscovered resources of less than 2 000 tU, however, the uncertainty of this term, and small amount reported, do not warrant inclusion as undiscovered resources at this time. Although undiscovered resources no doubt exist, further work is required to develop the estimates.

Uranium production centre technical details

(as of 1 January 2019)

	Centre #1
Name of production centre	Letlhakane
Production centre classification	Prospective
Date of first production	NA
Source of ore:	
Deposit name(s)	Gojwane/Serule
Deposit type(s)	Secondary/calcrete
Recoverable resources (tU)	87 180
Grade (% U)	0.017
Mining operation:	
Type (OP/UG/ISR)	OP
Size (Mt ore/year)	24 000
Average mining recovery (%)	90
Processing plant:	
Acid/alkaline	Acid
Type (IX/SX)	Heap leaching
Size (Mt ore/year); for ISR (litre/hour)	
Average process recovery (%)	69
Mining and processing recovery factor (%)	1 440
Nominal production capacity (tU/year)	Letlhakane

Uranium production

From 2013-2015, A-Cap conducted feasibility studies required for the application of a mining licence for the Letlhakane uranium project.

Physical test work on expected lithology mixes was done to evaluate productivity and mining costs using surface miners. Metallurgical test work was completed to optimise the process design and provide geotechnical, geochemical and hydrological data for studies on heaps and waste products. Process test work was based on heap leach processing using acid leaching for the primary, oxide and secondary mudstone ore, and alkaline leaching for the secondary calcrete ore. The uranium recoveries varied from 60.5% to 77.7% depending on mineralisation type.

On completion of the feasibility study, a mining licence application was submitted to the Botswana Department of Mines in August 2015. The mining licence was granted by the Minister of Minerals, Energy and Water Resources on 12 September 2016, and is valid for 22 years.

A-Cap Resources anticipated starting production at its uranium mine by 2018, with a production capacity of 1 440 tU/yr, at an average operating cost of USD 34.9/lb (USD 76.94/kg) in the first five years and USD 40.70/lb (USD 89.72/kg) during the life of the mine.

On 23 April 2019, A-Cap met with the Botswana Department of Mines and submitted a letter requesting an amendment to the commencement of the pre-construction and construction period for the Letlhakane Uranium Project for a further two years. On 20 August 2019, A-Cap received confirmation from the Botswana Minister of Mineral Resources, Green Technology and Energy Security, that the amendment was approved. The amended date for the commencement of the pre-construction and construction period is now 30 October 2021.

Environmental activities and socio-cultural issues

A-Cap has established a Safety, Health, Radiation, Environment and Community Group aimed at informing, educating and involving local communities with regard to their activities. Meetings are held on a regular basis. The company submitted an environmental and social impact assessment study of the Letlhakane project to the Botswana government in 2011. The scoping study indicates potential for a mine life in excess of 20 years, subject to world market prices for uranium.

A detailed water exploration programme by A-Cap has confirmed that a well field located 30 km west of Letlhakane could supply water of sufficient quality and quantity to meet the project's requirements. A-Cap submitted water rights applications which were subsequently granted by Botswana's Water Apportionment Board in 2012.

In 2014, an environmental and social impact assessment (ESIA) consistent with the Botswana government's requirements was completed and submitted in May 2015 to the Department of Environmental Affairs (DEA). Studies determined that with appropriate mitigation all environmental and social aspects during the construction and planned operations could be addressed. Presentations of the ESIA findings were presented to the Serule and Gojwane Kgoltas, the Mmadindare and Paje subland Boards, and the Tonata council.

Following a comprehensive review by the DEA, A-Cap was advised in March 2016 that it had adequately identified and assessed impacts associated with the project. A four-week public review was completed, following which the environmental and social impact assessment was approved on 13 May 2016.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

National policies regarding uranium exploitation and production are under development and no regulations for uranium mining and milling are currently in place. However, the government is committed to encouraging private investment in exploration and new mine development. The fiscal, legal and policy framework for mineral exploration, mining and mineral processing in Botswana is continuously being reviewed to make it more competitive. Amendments made to the Mines and Minerals Act in 1999 and the Income Tax Act in 2006 streamlined licensing, enhanced security of tenure and reduced royalty payments and tax rates.

Reasonably assured conventional resources by production method

(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	0	0	20 388	20 388	62
Total	0	0	20 388	20 388	62

Reasonably assured conventional resources by processing method

(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Heap leaching* from OP	0	0	20 388	20 388	62
Total	0	0	20 388	20 388	62

* A subset of open-pit and underground mining, since it is used in conjunction with them.

Reasonably assured conventional resources by deposit type

(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	20 388	20 388
Total	0	0	20 388	20 388

Inferred conventional resources by production method

(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	0	0	66 792	66 792	62
Total	0	0	66 792	66 792	62

Inferred conventional resources by processing method

(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Heap leaching* from OP	0	0	66 792	66 792	62
Total	0	0	66 792	66 792	62

* A subset of open-pit and underground mining, since it is used in conjunction with them.

Inferred conventional resources by deposit type

(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	66 792	66 792
Total	0	0	66 792	66 792

Brazil

Uranium exploration and mine development

Historical review

Systematic prospecting for radioactive minerals by the Brazilian National Research Council began in 1952. These efforts led to the discovery of the first uranium occurrences at Poços de Caldas (State of Minas Gerais) and Jacobina (State of Bahia). In 1955, a technical co-operation agreement was signed with the United States to assess the uranium potential of Brazil. After the creation of the National Nuclear Energy Commission (CNEN), a mineral exploration department was organised with the support of the French Alternative Energies and Atomic Energy Commission (CEA) in 1962.

In the 1970s, CNEN exploration for radioactive minerals accelerated with the addition of financial resources. Further incentive for exploration was provided in 1974 when the government opened NUCLEBRAS, an organisation with the exclusive purpose of uranium exploration and production. One of the early achievements of the government organisations was the discovery and development of the Osamu Utsumi deposit on the Poços de Caldas plateau.

In late 1975, Brazil and Germany signed a co-operation agreement for the peaceful use of nuclear energy. It was the beginning of an ambitious nuclear development programme that required NUCLEBRAS to increase its exploration activities. This led to the discovery of eight areas hosting uranium resources, including the Poços de Caldas plateau, Figueira, the Quadrilátero Ferrífero, Amorinópolis, Rio Preto/Campos Belos, Itataia, Lagoa Real and Espinharas (discovered and evaluated by Nuclam, a Brazilian-German joint venture).

As a result of the Brazilian nuclear development programme reorganisation of 1988, Industrias Núcleares do Brasil S.A. (INB) discontinued uranium exploration activities in 1991. Since then, limited exploration work has been done to further define resources in Lagoa Real province.

Recent and ongoing uranium exploration and mine development activities

During 2017, exploration efforts were focused on favourable albititic areas in the north part of the Lagoa Real province on LR 35 and LR 36 deposits. Expenditures totalled BRL 1.9 million (Brazilian reals) and 5 600 m of exploration drilling done. No exploration work was done in 2018.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

Brazil's conventional identified uranium resources are hosted in the following deposits:

- Poços de Caldas (Osamu Utsumi mine) with the orebodies A, B, E and Agostinho (collapse breccia-type);
- Figueira and Amorinópolis (sandstone);
- Itataia, including the adjoining deposits of Alcantil and Serrotes Baixos (phosphate);
- Lagoa Real, Espinharas (metasomatic);
- Campos Belos (metamorphite);

- Others including the Quadrilátero Ferrífero with the Gandarela and Serra des Gaivotas deposits (paleo-quartz-pebble conglomerate).

No additional resources were identified during the 2017-2018 period.

Undiscovered conventional resources (prognosticated and speculative resources)

Based on exploration activities in the Rio Cristalino (Proterozoic unconformity) area and additional resources at the Pitinga site (granite-related), in situ prognosticated resources are estimated to amount to 300 000 tU.

Speculative uranium resources account to some 500 000 tU according to a preliminary resource assessment that has been completed in geological environments with high uranium potential. Different geological types of uranium deposits were included in this estimate.

Uranium production

Historical review

The Poços de Caldas uranium production facility, which started production in 1982 with a design capacity of 425 tU/year, was operated by the state-owned company NUCLEBRAS until 1988. At that time, Brazil's nuclear activities were restructured. NUCLEBRAS was succeeded by INB and its mineral assets transferred to Urânio do Brasil S.A. With the dissolution of Urânio do Brasil in 1994, ownership of uranium production is 100% controlled by INB, a state-owned company.

Between 1990 and 1992, the production centre at Poços de Caldas was on standby because of increasing production costs and reduced demand. Production was restarted in late 1993 and continued until October 1995. After two years on standby, the Poços de Caldas production centre was shut down in 1997 and a decommissioning programme started in 1998. This industrial facility was used to produce rare earth compounds from monazite treatment until 2006, but closed the next year for market reasons. The Caetité unit (Lagoa Real) is currently the only uranium production facility in operation in Brazil.

Status of production facilities, production capability, recent and ongoing activities and other issues

The open-pit part of the Cachoeira deposit was entirely mined out in 2014. The licensing process for underground mining of the remainder of the deposit is under way and production is expected to start in 2026.

The expansion of Lagoa Real, Caetité unit to 670 tU/year is progressing but the operation has been delayed to around 2026. The expansion involves replacement of the current heap leaching (HL) process by conventional agitated leaching. The overall investment in this expansion is estimated to amount to USD 90 million. There was no production at the Caetité site in 2017 and 2018.

Since 2014, INB has been working on the development of the Engenho deposit with the first production scheduled for 2019. Engenho was initially planned as an additional ore source for increased production at the Caetité plant, but it is currently the only ore source for the plant due to the delay in commissioning the Cachoeira underground mine.

Ownership structure of the uranium industry

The Brazilian uranium industry is 100% government-owned through INB.

Employment in the uranium industry

Employment at existing production centres slightly decreased in 2018 from 2016-2017, with a very small increase expected for 2019 (see table below).

Future production centres

The phosphate/uranium project of Santa Quitéria, an INB-Brazilian fertiliser producer partnership agreement, remains under development. In 2012, the project operators applied for a construction licence, but it was denied in 2018. INB and its partner are now working on a new model for the project. The operation is scheduled to begin in 2026.

The Engenho deposit, located 2 km from the mined Cachoeira deposit, is under development and is expected to feed the Caetité mill after 2019.

Uranium production centre technical details

(as of 1 January 2019)

	Centre #1	Centre #2	Centre #3
Name of production centre	Caetité	Santa Quitéria	Caetité
Production centre classification	Planned	Planned	Existing
Date of first production	2026	2026	2020
Source of ore:			
Deposit name(s)	Cachoeira	Santa Quitéria	Engenho
Deposit type(s)	Metasomatic	Phosphate	Metasomatic
Recoverable resources (tU)	10 100	76 100	5 000*
Grade (% U)	0.3	0.08	0.2
Mining operation:			
Type (OP/UG/ISL)	UG	OP	OP
Size (tonnes ore/day)	1 000	6 000	1 000
Average mining recovery (%)	90	90	90
Processing plant:			
Acid/alkaline	Acid	Acid	Acid
Type (IX/SX)	SX	SX	HL/SX
Size (tonnes ore/day)			
Average process recovery (%)	90	70	70
Nominal production capacity (tU/year)	340	970	300
Plans for expansion (yes/no)	No	Yes	Yes
Other remarks	OP operation from 1999 to 2014	By-product phosphoric acid	To be sent to Caetité mill

* Expected production at Engenho mine.

Environmental activities and socio-cultural issues

Licences in Brazil are issued by the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA) and by CNEN.

The closure of Poços de Caldas in 1997 ended the exploitation of this low-grade ore deposit that produced vast amounts of waste rock. Several studies have been carried out to characterise geochemical and hydrochemical aspects of the waste rock and tailings dam to better establish the impact they may have had on the environment and to develop the necessary mitigation measures. A remediation/restoration plan, considering several alternatives, was submitted to the regulatory body at the end of 2012. Depending on the option adopted, the costs of implementing the remediation/restoration plan could reach USD 300 million. In the meantime, some measures have been taken to reduce environmental impacts, such as uranium recovery from acid drainage (resin), heavy metal precipitation (ozone), and surface drainage optimisation. INB, regulators and the central government, are involved in the consolidation of a work plan for the remediation.

The licensing of Santa Quitéria Uranium/Phosphate Project is split into a non-nuclear part, involving milling and phosphate production, and a nuclear part, involving uranium concentrate production. INB has applied for local construction licences under the guidelines established by IBAMA and CNEN.

Regulatory regime

Licences are issued by IBAMA, according to Brazilian environment law and CNEN regulations.

Government policies and regulations established by CNEN include basic radiation protection directives (NE-3.01 – *Diretrizes Básicas de Radioproteção*), standards for licensing of uranium mines and mills (NE-1.13 – *Licenciamento de Minas e Usinas de Beneficiamento de Minérios de Urânio ou Tório*) and decommissioning of tailings ponds (NE-1.10 – *Segurança de Sistema de Barragem de Rejeito Contendo Radionuclídeos*), as well as standards for conventional U and Th mining and milling (NORM and TENORM NM 4.01 – *Requisitos de Segurança e Proteção Radiológica para Instalações Mínero-Industriais*). In the absence of specific norms, the International Commission on Radiological Protection (ICRP) and IAEA recommendations are used.

CNEN is in charge of nuclear research and regulation, but due to the potential future growth of the Brazilian nuclear programme, the creation of a separate independent nuclear regulatory agency is under study by the federal government.

Uranium requirements

Brazil's present uranium requirements for the Angra 1 nuclear power plant, a 630 MWe pressurised water reactor (PWR), are about 150 tU/yr. The Angra 2 nuclear power plant, a 1 245 MWe PWR, requires 220 tU/yr. The start-up of the Angra 3 nuclear power plant (a similar design to Angra 2), scheduled initially for 2016, halted construction in 2015 and is currently scheduled to be operating in 2026. Once in operation, this will add another 220 tU/yr to annual domestic demand.

A new (2020) version of the national energy plan, "*Plano Nacional de Energía 2050*" (PNE 2050), is a fundamental study of long-term planning for the country's energy sector. It assesses trends in production and use of energy and evaluates alternative strategies for expanding energy supply in the coming decades. PNE 2050 also establishes guidelines for the role of nuclear power in the national strategy, including post-Fukushima risk perception and increasing costs, mastery of the complete nuclear fuel production cycle, and the possibility of exporting such products, taking into consideration the scale of production and competitiveness.

Supply and procurement strategy

All domestic production is designated for internal requirements. The shortfall between demand and production is met through market purchases. In the 2017-2018 period, INB acquired a total of 635 tU.

The planned uranium production increases are designed to meet all reactor requirements, including the Angra 3 unit and all units foreseen in the long-term planned expansion of nuclear energy for electricity generation.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

INB, a 100% government-owned company, is in charge of fuel cycle activities, which are conducted under state monopoly. INB is currently working on increasing uranium concentrate production and towards full implementation of fuel cycle activities to meet domestic demand.

Uranium stocks

The Brazilian government does not maintain stocks of uranium concentrate or enriched uranium product.

Uranium exploration and development expenditures and drilling effort – domestic

(in BRL [Brazilian real])

	2012	2013	2014	2015	2016	2017	2018	2019
Industry* exploration expenditures	0	0	0	0	0	0	0	0
Government exploration expenditures	2 500 000	3 500 000	0	700 000	4 500 000	1 900 000	0	0
Total expenditures	2 500 000	3 500 000	0	700 000	4 500 000	1 900 000	0	0
Government exploration drilling (m)	5 200	7 500	0	2 300	14 500	5 600	0	0
Government exploration holes drilled	41	45	0	32	117	45	0	0
Total drilling (m)	5 200	7 500	0	2 300	14 500	5 600	0	0
Total number of holes drilled	41	45	0	32	117	45	0	0

* Non-government.

Reasonably assured conventional resources by production method*

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	72 900	72 900	72 900	72 900	90 (mine); 90 (process)
Open-pit mining (OP)	9 900	9 900	9 900	9 900	90 (mine); 90 (process)
Co-product and by-product	101 500	126 900	126 900	126 900	70 (process)
Total	184 300	209 700	209 700	209 700	

* No changes in resources in the period 2017/18 due to absence of mining activities.

Reasonably assured conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	72 900	72 900	72 900	72 900	90 (mine); 90 (process)
Conventional from OP	4 900	8 100	8 100	8 100	90 (mine); 90 (process)
Heap leaching* from OP	1 800	1 800	1 800	1 800	90 (mine); 70 (process)
Unspecified	101 500	126 900	126 900	126 900	70 (process)
Total	184 300	209 700	209 700	209 700	

* A subset of open-pit and underground mining, since it is used in conjunction with them.

Reasonably assured conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Granite-related	25 400	50 800	50 880	50 880
Collapse breccia-type	500	500	500	500
Metasomatic	82 300*	82 300	82 300	82 300
Phosphate	76 100**	76 100	76 100	76 100
Total	184 300	209 700	209 700	209 700

* Associated with the Lagoa Real site. Recovery cost will be further evaluated.

** Associated with the Santa Quiteria site. Operating expenditures for uranium recovery is considered (incremental cost for uranium extraction).

Inferred conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	0	3 400	3 400	3 400	90 (mine); 80 (process)
Co-product and by-product	0	44 600	112 300	112 300	70 (process)
Unspecified	0	56 900	56 900	56 900	70 (average)
Total	0	104 900	172 600	172 600	

Inferred conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from OP	0	3 400	3 400	3 400	90 (mine); 80 (process)
Unspecified	0	101 500	169 200	169 200	70 (average)
Total	0	104 900	172 600	172 600	

Inferred conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Sandstone	0	13 000	13 000	13 000	90 (mine); 80 (process)
Paleo-quartz-pebble conglomerate	0	15 000	15 000	15 000	90 (mine); 80 (process)
Granite-related	0	0	67 700	67 700	70 process
Metamorphite	0	1 000	1 000	1 000	90 (mine); 80 (process)
Collapse breccia-type	0	26 400	26 400	26 400	90 (mine); 80 (process)
Metasomatic	0	5 000	5 000	5 000	90 (mine); 80 (process)
Phosphate	0	44 500	44 500	44 500	70 process
Total	0	104 900	172 600	172 600	

Prognosticated conventional resources
(tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
300 000	300 000	300 000

Speculative conventional resources
(tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
NA	NA	500 000

Historical uranium production by production method
(tonnes U in concentrates)

Production method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Open-pit mining*	4 216	0	0	0	4 216	0
Total	4 216	0	0	0	4 216	0

* Pre-2015 totals may include uranium recovered by heap and in-place leaching.

Historical uranium production by processing method
(tonnes U in concentrates)

Processing method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Conventional	1 097	0	0	0	1 097	0
Heap Leaching*	3 119	0	0	0	3 119	0
Total	4 216	0	0	0	4 216	0

* A subset of open-pit and underground mining, since it is used in conjunction with them.

Historical uranium production by deposit type
(tonnes U in concentrates)

Deposit type	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Collapse breccia-type	1 097	0	0	0	1 097	0
Metasomatic	3 119	0	0	0	3 119	0
Total	4 216	0	0	0	4 216	0

Ownership of uranium production in 2018

Domestic				Foreign				Totals	
Government		Private		Government		Private			
(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)
0	100	0	0	0	0	0	0	0	100

Uranium industry employment at existing production centres

(person-years)

	2016	2017	2018	2019 (expected)
Total employment related to existing production centres	680	680	500	550
Employment directly related to uranium production	310	310	310	310

Short-term production capability (tonnes U/year)

2020				2025			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
340	340	340	340	300	300	300	300

2030				2035				2040			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
300	1 600	300	1 600	NA	1 600	NA	1 600	NA	1 600	NA	1 600

Net nuclear electricity generation

	2017	2018
Nuclear electricity generated (TWh net)	15.74	15.67

Installed nuclear generating capacity to 2040

(MWe net)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
1 875	1 875	1 875	1 875	1 875	1 875	1 875	3120	3 120	NA	3 120	NA

Annual reactor-related uranium requirements to 2040 (excluding MOX)

(tonnes U)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
400	400	400	400	400	400	400	550	550	NA	550	NA

Canada

Uranium exploration

Historical review

Uranium exploration in Canada began in 1942, with the focus of activity first in the Northwest Territories where pitchblende ore had been mined since the 1930s to extract radium. Exploration soon expanded to other areas of Canada, resulting in the development of mines in northern Saskatchewan and in the Elliot Lake and Bancroft regions of Ontario during the 1950s. In the late 1960s, exploration returned to northern Saskatchewan where large high-grade deposits were discovered in the Athabasca Basin and later developed (the first was Rabbit Lake deposit, discovered in 1968, and brought into production in 1975). Saskatchewan is now the sole producer of uranium in Canada.

Recent and ongoing uranium exploration and mine development activities

During 2017 and 2018, exploration efforts continued to focus on areas favourable for the occurrence of deposits associated with Proterozoic unconformities in the Athabasca Basin of Saskatchewan. Very little exploration activity occurred in other areas of Canada in 2017 and 2018.

Surface drilling, as well as geophysical and geochemical surveys, continued to be the main tools used to identify new uranium occurrences, define extensions of known mineralised zones and to reassess previously discovered deposits.

Exploration activity has led to new uranium discoveries in the Athabasca Basin. Notable recently discovered large high-grade uranium deposits include Phoenix/Gryphon, Triple R, Arrow and Fox Lake.

Domestic uranium exploration expenditures were CAD 137 million in 2017, down 16% from 2016 exploration expenditures of CAD 164 million. Domestic exploration expenditures increased to CAD 170 million in 2018, primarily due to deposit appraisal work on recent discoveries. In 2017 and 2018, overall Canadian uranium exploration and development expenditures amounted to CAD 332 million and CAD 264 million, respectively.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

As of 1 January 2019, Canada's total identified conventional uranium resources recoverable at a cost of <USD 80/kgU amounted to 269 500 tU, a decrease of 13.2% from the 2017 estimate of 310 400 tU, primarily due to mining depletion. Canada's total identified uranium resources recoverable at a cost of <USD 130/kgU were 565 000 tU as of 1 January 2019, an increase of 9.8% compared to the 2017 estimate of 514 400 tU. These increases are primarily due to new resources being identified as a result of recent exploration activity. Most of Canada's identified uranium resources are re-evaluated annually by the uranium mining companies.

The bulk of Canada's identified conventional uranium resources occur in Proterozoic unconformity-related deposits in the Athabasca Basin of Saskatchewan and the Thelon Basin of Nunavut. These deposits host their mineralisation near the unconformity boundary (below, above, and across) in either monometallic or polymetallic mineral assemblages. Pitchblende prevails in the monometallic deposits, whereas uranium-nickel-cobalt assemblages prevail in the polymetallic assemblages. The average grade varies from 1% U to over 15% U. None of the uranium resources referred to or quantified herein are a co-product or by-product output of any other mineral of economic importance. Mining losses (~10%) and ore processing losses (~3%) were used to calculate known conventional resources if not provided by the company.

The percentage of identified conventional uranium resources in existing or committed production centres that are recoverable at <USD 40/kgU, <USD 80/kgU, <USD 130/kgU and <USD 260/kgU are 100%, 100%, 61.2% and 53.0%, respectively. All of the resources in existing or committed production centres are updated annually by the mining companies.

Undiscovered conventional resources (prognosticated and speculated resources)

Prognosticated and speculated resources have not been a part of recent resource assessments; hence there are no changes to report in these categories since 1 January 2001.

Uranium production

Historical review

Canada's uranium industry began in the Northwest Territories with the 1930 discovery of the Port Radium pitchblende deposit. Exploited from 1933 to 1940 for radium, the deposit was reopened in 1942 in response to uranium demand for the Manhattan Project. A ban on private exploration and development was lifted in 1947, and by the late 1950s some 20 uranium production centres had started up in Ontario, Saskatchewan and the Northwest Territories. Production peaked in 1959 at 12 200 tU. No further defence contracts were signed after 1959 and production began to decline. Despite government stockpiling programmes, output fell rapidly to less than 3 000 tU in 1966, by which time only four producers remained. While the first commercial sales to electric utilities were signed in 1966, it was not until the mid-1970s that prices and demand had increased sufficiently to promote expansions in exploration and development activity. By the late 1970s, with the industry firmly re-established, several new facilities were under development in Saskatchewan and Ontario. Annual output grew steadily throughout the 1980s, as Canada's focus of uranium production shifted increasingly to Saskatchewan. The last remaining Ontario uranium mine closed in mid-1996.

Status of production capability and recent and ongoing activities

All active uranium production centres are located in northern Saskatchewan and operated by Cameco Corporation (Cameco) and Orano Canada Limited (Orano; formerly Areva). Current Canadian uranium production is well below the full licensed production capacity of the uranium mills. Production in 2018 was 6 996 tU, 47% below 2017 production of 13 130 tU, due to suspension of operations at the McArthur River mine and Key Lake mill in response to low uranium market prices. Canadian uranium production is forecast to remain at 6 900 tU per year until operations at McArthur River and Key Lake resume.

Cameco is the operator of the McArthur River mine, a Cameco (70%), Orano (30%) joint venture, which was the world's second largest uranium mine in terms of annual production in 2017 and is the world's largest high-grade uranium deposit. Production was suspended indefinitely in January 2018 in response to low uranium demand; however the mine is expected to restart when markets improve. At the mine, ground freezing is used to reduce water inflow from the overlying rock formation and the high-grade ore (>5% U) is extracted using raise bore mining. A high-grade ore slurry is produced by underground crushing, grinding and mixing, which is then pumped to the surface and loaded on specially designed containers that are shipped 80 km southward by road to the Key Lake mill. Remaining identified resources for McArthur River mine are currently 153 700 tU with an average grade of 5.5% U.

The Key Lake mill is a Cameco (83%) and Orano (17%) joint venture operated by Cameco. In 2017, the mill produced 6 183 tU from McArthur River ore, 27 tU from stockpiled Key Lake special waste rock that is blended with the McArthur River ore to reduce the mill feed grade of about 5% U, as well as 21 tU from processing Cameco's uranium refinery wastes that were shipped from Ontario for disposal. In 2018, 61 tU were recovered by cleaning out the mill circuits before operations were suspended in late January.

The McClean Lake production centre, operated by Orano, is a joint venture between Orano (70%), Denison Mines Corp. (22.5%) and Overseas Uranium Resources Development (Canada) Co. Ltd, a subsidiary of Overseas Uranium Resources Development Corporation of Japan (7.5%). Open-pit mining was completed in 2008 and ore containing 2 500 tU was stockpiled to provide mill feed. Production in 2009 and 2010 amounted to 2 045 tU and was obtained from processing the higher-grade ore from the stockpile. The 500 tU of ore remaining in the stockpile was not economic to process so the mill was placed into care and maintenance in July 2010. Production from the McClean Lake JEB mill resumed in 2014 to process low-grade ore from the stockpile and high-grade ore from the Cigar Lake mine. Production from Cigar Lake ore was 6 925 tU in 2017 and 6 935 tU in 2018, placing McClean Lake as the world's largest uranium mill in terms of production.

Production from the Rabbit Lake production centre, wholly owned and operated by Cameco, has been suspended since mid-2016 due to low uranium prices. Production could resume when uranium prices recover. Exploratory drilling at the Eagle Point mine during the last several years has increased identified resources to 27 000 tU at an average grade of 0.63% U. An environmental assessment is under way on a proposal to expand tailings storage capacity to allow additional ore to be processed, should operations resume in the future.

Cigar Lake, with identified resources of 115 100 tU at an average grade of 11% U, is the world's third-largest high-grade uranium deposit. The mine began operation in March 2014 and is a Cameco (50.025%), Orano (37.1%), Idemitsu (7.875%) and Tokyo Electric Power Company (5%) joint venture operated by Cameco and was the world's largest producing uranium mine in 2017 and 2018. Ground freezing is used to reduce groundwater inflow and ore is extracted using an innovative jet bore mining method. The high-grade ore slurry is then shipped by road to the McClean Lake (JEB) mill for processing. The McClean Lake mill produced 6 925 tU and 6 935 tU from Cigar Lake ore in 2017 and 2018, respectively.

Ownership structure of the uranium industry

Cameco Corporation (Cameco) and Orano Canada Limited (Orano) are the operators of the current uranium production centres in Canada. Cameco is the owner and operator of the Rabbit Lake production centre, which includes the Eagle Point mine and the Rabbit Lake mill. Cameco is also the operator of the McArthur River mine and the Key Lake mill, which are joint ventures with Orano. Cameco is the majority owner and operator of the Cigar Lake mine, in which Orano, Idemitsu and the Tokyo Electric Power Company have minority ownership. Orano is the majority owner and operator of the McClean Lake production centre in which Denison Mines Corp. and Overseas Uranium Resources Development (Canada) Co. Ltd. have minority ownership.

Uranium production centre technical details

(as of 1 January 2019)

	Centre #1	Centre #2	Centre #3	Centre #4	Centre #5
Name of production centre	McArthur River /Key Lake	McClean Lake	Rabbit Lake	Cigar Lake	Midwest
Production centre classification	Suspended	Existing	Suspended	Existing	Planned
Date of first production	1999/1983	1999	1975	2014	NA
Source of ore:					
Deposit name(s)	P2N et al.	JEB, McClean, Sue A-E, Caribou	Eagle Point	Cigar Lake	Midwest
Deposit type(s)	Unconformity	Unconformity	Unconformity	Unconformity	Unconformity
Recoverable resources (tU)	153 700 tU	12 100 tU	27 000 tU	115 100 tU	19 000 tU
Grade (% U)	5.5	1.1	0.63	11.0	1.52
Mining operation:					
Type (OP/UG/ISR)	UG	UG/OP	UG	UG	OP
Size (tonnes ore/day)	~200	NA	NA	~200	NA
Average mining recovery (%)	NA	NA	NA	NA	NA
Processing plant:					
Acid/alkaline	Acid	Acid	Acid	Processed at McClean Lake	To be processed at McClean Lake
Type (IX/SX)	SX	SX	SX		
Size (tonnes ore/day)	864	300	2 880		
Average process recovery (%)	98	97	97		
Nominal production capacity (tU/year)	9 600	9 200	6 500	6 900	2 300
Plans for expansion		Expansion of tailings capacity	Expansion of tailings capacity		

Employment in the uranium industry

Direct employment at Canada's uranium mines and mills industry totalled 1 029 in 2017 and 529 in 2018. Total employment, including contract employees, was 1 418 in 2017 and 652 in 2018. The reduction in employment in 2018 is primarily the result of suspension of operations at the McArthur River mine and Key Lake mill in response to continuing low uranium prices.

Future production centres

Two uranium mining projects in Saskatchewan that would feed existing mills, could enter into production within the next decade should uranium prices increase. Ore from Orano's proposed Midwest mine, which has received environmental approval, would provide additional feed for the McClean Lake mill. Ore from Cameco's proposed Millennium mine would be processed at the Key Lake mill. Cameco has also identified other deposits (Fox Lake, Tamarack) that could feed existing mills.

There are several other exploration projects in the Athabasca Basin, which have recently identified large high-grade uranium deposits that have potential for development. In the western Athabasca Basin, the Arrow Deposit (NexGen Energy Ltd.) is the world's second largest high-grade uranium deposit (130 900 tU) and a project to develop an underground mine and a mill is currently undergoing an environmental assessment. The nearby Triple R deposit (Fission Uranium Corp.), is a high-grade uranium deposit (49 900 tU), which also has indicated and inferred gold resources totalling 67 000 ounces and has recently undergone a Pre-Feasibility Assessment for the development of an underground mine. In the eastern Athabasca Basin, Denison Mines Corp.'s Phoenix deposit (26 900 tU) is undergoing an environmental assessment process for a proposal to develop an ISL mining operation, should tests indicate the method is feasible. Denison Mines Corp.'s nearby Gryphon deposit (24 000 tU) has potential to be mined by conventional underground methods in the future.

There is also a possibility of mines being developed outside of Saskatchewan, however uranium prices would have to increase substantially. Orano has proposed to develop the Kiggavik and Sissons deposits in Nunavut, should market conditions improve and mining becomes economic.

Secondary sources of uranium

Canada does not use secondary sources of uranium. Canada does not produce or use mixed oxide fuels nor use re-enriched tails.

Environmental activities and socio-cultural issues

Environmental impact assessments

As indicated above, environmental assessments are currently underway for proposals to develop the Arrow deposit in the western Athabasca Basin and the Phoenix deposit in the eastern Athabasca Basin.

Effluent management

Water treatment and minor engineering works continued to be the main activities at the closed Elliot Lake area uranium mine and mill sites in 2017 and 2018. Water quality within the Serpent River Watershed has improved since the closure and decommissioning of the mines and currently meets Ontario Drinking Water Standards.

Site rehabilitation

The Cluff Lake mine, located in the western Athabasca Basin of Saskatchewan, ceased mining and milling operations in May 2002. A two-year decommissioning programme was initiated in 2004, following a five-year comprehensive environmental assessment study. Decommissioning was essentially completed by 2006, followed by revegetation. The remaining buildings were demolished in 2013 and access to the site is no longer restricted. Orano conducts monitoring of the site on a quarterly basis.

In northern Saskatchewan, several mines (principally the Gunnar and Lorado mines) were operated from the late 1950s to early 1960s by private sector companies that no longer exist. When the sites were closed, there were no regulatory requirements in place to appropriately contain and treat the waste, which has led to environmental impacts on local soils and lakes. The responsibility for these sites is now held by the government of Saskatchewan and a project is currently under way to remediate these sites.

Uranium requirements

In 2018, nuclear energy provided about 15% of Canada’s total electricity needs (including approximately 60% in Ontario and 33% in New Brunswick) and should continue to play an important role in supplying Canada with electricity in the future. Canada has a fleet of 22 CANDU pressurised heavy water reactors, of which 18 are currently in full commercial operation (17 in Ontario and 1 in New Brunswick). One reactor in Ontario (Darlington-2) was taken out of service in October 2016 for refurbishment and will return to service in 2020. Two reactors in Ontario (Pickering 2 & 3) and one reactor in Quebec (Gentilly-2) have been shut down permanently for decommissioning.

In Canada, the responsibility for deciding on energy supply mix and investments in electricity generation capacity, including the planning, construction and operation of nuclear power plants, resides with the provinces and their provincial power utilities.

Canada’s CANDU nuclear reactors are designed to provide electricity generation for about 25-30 years. Through “refurbishment” (replacement of key reactor and station components) continued operation of the reactors can be extended for approximately 30 additional years.

Refurbishment projects in New Brunswick (Point Lepreau) and Ontario (Bruce A units 1 and 2) have been successfully completed and the reactors returned to service in the fall of 2012. Furthermore, as laid out in Ontario's 2013 Long-term Energy Plan), Ontario is proceeding with plans to refurbish four reactors at Darlington Nuclear Generating Station and six reactors at Bruce Nuclear Generating Station (two at Bruce A and four at Bruce B). Refurbishment of the first Darlington unit began in October 2016 and is expected to be completed by June 2020, four months behind schedule. Refurbishment of the second Darlington unit will begin in early 2020 with all four Darlington units expected to be refurbished by 2026 as planned and within budget. Similarly, the first Bruce unit refurbishment is expected to commence in 2020 and all six Bruce units are to be refurbished by 2033.

The Pickering Nuclear Generating Station, Ontario's first commercial-scale nuclear power plant, will not be refurbished once it reaches the end of its safe operating life. In 2018, approval was given for continued operation of Pickering up to 2024. Two of the six operating Pickering units will be shut down in 2022, with the remaining four units shut down in 2024.

In 2012, Canada's nuclear regulator, the Canadian Nuclear Safety Commission (CNSC), granted a site preparation licence for nuclear new build at Darlington following approval of the environmental assessment. However, due to lower expected growth in demand for electricity, Ontario has deferred a decision on construction of new nuclear reactors.

Supply and procurement strategy

Approximately 1 700 tU of Canada's uranium production is used domestically to generate nuclear power. The nuclear utilities fill uranium requirements through long-term contracts and periodic spot market purchases.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

The Nuclear Fuel Waste Act (NFWA), which came into force on 15 November 2002, requires nuclear energy corporations to establish a Nuclear Waste Management Organization (NWMO) to safely and securely manage nuclear fuel waste over the long term.

Adaptive phased management (APM) was chosen as Canada's approach for safely managing nuclear fuel waste over the long term. The APM involves the containment and isolation of nuclear fuel waste in a deep geological repository. The APM approach recognises that people benefiting from nuclear energy produced today must take steps to ensure that the wastes are dealt with responsibly and without unduly burdening future generations. At the same time, it is sufficiently flexible to adapt to changing social and technological developments. The APM is implemented by the NWMO, using funds provided by the owners of nuclear fuel waste.

The NWMO has developed a siting process to identify an informed willing host community with a safe, secure and suitable site for a deep geological repository. This nine-step siting process was collaboratively designed, refined and finalised through an iterative two-year public engagement and consultation process. In May 2010, the NWMO initiated the siting process with an invitation to communities to learn more about the APM project and the plan to safely manage the waste. By the end of 2014, the NWMO had actively engaged with 21 communities in Ontario and Saskatchewan, including First Nations and Métis communities that had expressed an interest in hosting the waste management facility. The ultimate success of the project depends upon community engagement and lasting partnerships.

In November 2019, the NWMO selection process was narrowed down to two potential siting areas: the Township of Ignace (northwestern Ontario), and the Township of Huron-Kinloss/ Municipality of South Bruce (southern Ontario). Detailed field work to address the scientific and technical aspects, as well as the social dimensions of site selection, will proceed over the next several years. Field studies, borehole drilling, airborne surveys, environmental mapping, socio-economic studies and other assessments will be carried out to determine the suitability of sites and the willingness of communities. The NWMO will continue to build and strengthen its working relationships with participating communities as this process advances.

The Nuclear Liability and Compensation Act (NLCA), which entered into force on 1 January 2017, replacing the Nuclear Liability Act of 1976, strengthens Canada's nuclear liability regime. It establishes the compensation and civil liability regime to address damages in the extremely unlikely event of a nuclear incident at a Canadian nuclear installation. It also permits Canada to implement the IAEA Convention on Supplementary Compensation for Nuclear Damage.

The NLCA embodies the principles of absolute and exclusive liability of the operator, mandatory insurance and limitations on the operator's liability in both time and amount. Under the act, operators of nuclear installations are absolutely and exclusively liable for civil nuclear damage to a limit of CAD 1 billion, an amount phased in from CAD 650 million in 2017, to CAD 1 billion in 2020. All suppliers or contractors providing parts or services to the nuclear installation are thereby indemnified.

The act also contains a mechanism for periodic updating of the operator's liability; expanded categories of compensable damage to address environmental damage, economic loss, and costs related to preventive measures; and a longer limitation period for submitting compensation claims for bodily injury.

Uranium stocks

The Canadian government does not maintain any stocks of natural uranium and data for producers and utilities are not available. Since Canada has no enrichment or reprocessing facilities, there are no stocks of enriched or reprocessed material in Canada. Although Canadian reactors use natural uranium fuel, small amounts of enriched uranium are used for experimental purposes and in booster rods in certain CANDU reactors.

Uranium prices

In 2002, Natural Resources Canada suspended the publication of the average price of deliveries under export contracts for uranium.

Uranium exploration and development expenditures and drilling effort – domestic

(CAD millions)

	2016	2017	2018	2019 (expected)
Industry* exploration expenditures	164	137	170	196
Industry* development expenditures	253	195	94	NA
Total expenditures	417	332	264	NA
Industry* exploration drilling (m)	367 885	329 302	260 640	NA
Industry* exploration holes drilled	NA	NA	NA	NA
Industry* development drilling (m)	45 426	59 205	52 734	NA
Industry* development holes drilled	NA	NA	NA	NA
Subtotal exploration drilling (m)	367 885	329 302	260 640	NA
Subtotal exploration holes drilled	NA	NA	NA	NA
Subtotal development drilling (m)	45 426	59 205	52 734	NA
Subtotal development holes drilled	NA	NA	NA	NA
Total drilling (m)	413 311	388 507	313 374	NA
Total number of holes drilled	NA	NA	NA	NA

* Non-government.

Reasonably assured conventional resources by production method

(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	258 270	258 270	441 274	589 729	NA**
Open-pit mining (OP)	270	270	20 358	54 098	NA
In-place leaching*				8 347	
Total	258 540	258 540	461 632	652 174	

* Also known as stope leaching or block leaching. ** Mining losses (~10%) and ore processing losses (~3%) were used to calculate recoverable resources if recovery factors were not provided by companies.

Reasonably assured conventional resources by processing method

(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Conventional from UG	258 270	258 270	441 274	589 729
Conventional from OP	270	270	20 358	54 098
In-place leaching*				5 426
Heap leaching** from UG				2 921
Total	258 540	258 540	461 632	652 174

* Also known as stope leaching or block leaching. ** A subset of open-pit and underground mining, since it is used in conjunction with them.

Reasonably assured conventional resources by deposit type

(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Proterozoic unconformity	258 540	258 540	455 632	605 234
Sandstone			6 000	6 000
Paleo-quartz-pebble conglomerate				8 347
Metasomatite				32 593
Total	258 540	258 540	461 632	652 174

Inferred conventional resources by production method

(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	1 925	10 945	90 549	181 533	NA*
Open-pit mining (OP)			12 764	39 315	NA
Total	1 925	10 945	103 313	220 848	

* Mining losses (~10%) and ore processing losses (~3%) were used to calculate recoverable resources if recovery factors were not provided by companies.

Inferred conventional resources by processing method

(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Conventional from UG	1 925	10 945	90 549	167 642
Conventional from OP			12 764	39 315
In-place leaching*				9 029
Heap leaching** from UG				4 862
Total	1 925	10 945	103 313	220 848

* Also known as stope leaching or block leaching.

** A subset of open-pit and underground mining, since it is used in conjunction with them.

Inferred conventional resources by deposit type

(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Proterozoic unconformity	1 925	10 945	97 269	171 163
Sandstone			6 044	22 032
Paleo-quartz-pebble conglomerate				13 891
Intrusive				2 543
Metasomatite				11 219
Total	1 925	10 945	103 313	220 848

Prognosticated conventional resources

(tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
50 000	150 000	150 000

Speculative conventional resources

(tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
700 000	700 000	0

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Open-pit mining*	119 566	0	0	0	119 566	0
Underground mining*	378 194	14 039	13 130	6 996	412 359	7 000
Total	497 760	14 039	13 130	6 996	531 925	7 000

* Pre-2015 totals may include uranium recovered by heap and in-place leaching. Post-2013 underground mining totals includes uranium recovered at Key Lake mill from recycling uranium refinery wastes.

Historical uranium production by processing method

(tonnes U in concentrates)

Processing method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Conventional	496 760	14 039	13 130	6 996	530 925	6 900
In-place leaching*	1 000	0	0	0	1 000	0
Total	497 760	14 039	13 130	6 996	531 925	6 900

* Also known as stope leaching or block leaching.

Historical uranium production by deposit type

(tonnes U in concentrates)

Deposit type	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Proterozoic unconformity	321 891	14 022	13 109	6 996	356 018	7 000
Paleo-quartz-pebble conglomerate	144 182	0	0	0	144 182	0
Granite-related	7 539	0	0	0	7 539	0
Intrusive	5 636	0	0	0	5 636	0
Metasomatite	18 489	0	0	0	18 489	0
Other/unspecified*	23	17	21	0	61	0
Total	497 760	14 039	13 130	6 996	531 925	7 000

* Uranium recovered at Key Lake mill from recycling uranium refinery wastes.

Ownership of uranium production in 2018

Domestic				Foreign				Totals	
Government		Private		Government		Private			
(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)
0	0	3 512	50	2 591	37	893	13	6 996	100

Uranium industry employment at existing production centres

(person-years)

	2016	2017	2018	2019 (expected)
Total employment related to existing production centres	2 246	1 418	652	650
Employment directly related to uranium production	1 616	1 029	529	530

Net nuclear electricity generation

	2017	2018
Nuclear electricity generated (TWh net)	95.6	89.1

Short-term production capability

(tonnes U/year)

2020				2025				2030			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
9 200	9 200	9 200	9 200	18 700	18 700	18 700	18 700	12 330	18 850	12 330	18 850

2035				2040			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
12 330	18 850	12 330	18 850	12 330	18 850	12 330	18 850

Installed nuclear generating capacity to 2040

(MWe net)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
13 340	13 340	12 510	12 510	8 450	8 450	10 250	10 250	11 110	11 110	11 110	11 110

Annual reactor-related uranium requirements to 2040 (excluding MOX)

(tonnes U)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
1 770	1 650	1 570	1 570	1 140	1 140	1 480	1 480	1 640	1 640	1 640	1 640

* Uranium requirements calculated assuming 18.5 tU per TWh (net) electrical generation.

Total uranium stocks

(tonnes natural U-equivalent)

Holder	Natural uranium stocks in concentrates	Enriched uranium stocks	Enrichment tails	LWR reprocessed uranium stocks	Total
Government	0	0	0	0	0
Producer	NA	0	0	0	NA
Utility	NA	0	0	0	NA
Total	NA	0	0	0	NA

Chile*

Uranium exploration and mine development

Historical review

Uranium exploration was initiated in the 1950s with a review of uranium potential in mining districts with Cu, Co, Mo, Ag mineralisation conducted by the US Atomic Energy Commission. Following a delay of about ten years, activities were renewed in 1970 by the Spanish Nuclear Energy Organisation, focusing for four years on Region IV of the Tambillos mining district.

Between 1976 and 1990, regional prospecting encompassing an area of 150 000 km^2 was conducted in co-operation with the IAEA using geochemical drainage surveys, aerial radiometry, ground-based geology and radiometry. This work led to the detection of 1 800 aerial anomalies, 2 000 geochemical and radiometric anomalies and the definition of 120 sectors of interest. Subsequent investigation of 84 of these sectors of interest led to the identification of 80 uranium occurrences, stimulating further study of the 12 most promising prospects, preliminary exploration of these prospects, and eventually the evaluation of uranium resources as a by-product of copper and phosphate mining.

From 1980 to 1984, Cía Minera Pudahuel (the Pudahuel Mining Company), in co-operation with the Chilean Nuclear Energy Commission (CCHEN), conducted drilling of the Sagasca Cu-U deposit, Region I (Tarapacá), leading to a technical and economic evaluation of the Huinquintipa copper deposit, Region I. The Production Development Corporation (Corporación de Fomento de la Producción – CORFO) and CCHEN conducted exploration and technical economic evaluation of the Bahía Inglesa phosphorite deposit, Region III (Atacama) in 1986 and 1987.

Between 1990 and 1996, CCHEN undertook geological and metallogenic uranium research, mainly in the north of the country. From 1996 to 1999, CCHEN and the National Mining Company of Chile (ENAMI) investigated REE in relation to radioactive minerals in the Atacama and Coquimbo regions. Dozens of primary occurrences were studied, with the "Diego de Almagro" Anomaly-2 chosen as a priority. The study of this 180 km^2 sector found disseminations and veins of davidite, ilmenite, magnetite, sphene, rutile and anatase, with 3.5 to 4.0 kg/t of REE oxides (REO), 0.3 to 0.4 kg/t of U and 20 to 80 kg/t of Ti. The geological resources of the ore contained in this prospect were estimated at 12 000 000 t. The metallurgical recovery of REO from these minerals was also investigated with a purpose of investigating mining resources with economic potential in the medium term.

In 1998 and 1999, CCHEN created the National Uranium Potential Evaluation Project, encompassing the activities of uranium metallogeny research and development of a geological database. The aim of this project was to set up a portfolio of research projects to improve the evaluation of national uranium ore potential. Between 2000 and 2002, a preliminary geological evaluation for uranium and REO of the Cerro Carmen prospect (2000-2002), located in Region III (Atacama), was completed as part of the specific co-operation agreement between CCHEN and ENAMI. Geophysical exploration work was undertaken (magnetometry, resistivity and chargeability), defining targets with metallic sulphur minerals with uranium and associated REE.

In 2001, a project portfolio document was developed that updated the metallogeny and geological favourability for uranium in Chile. A total of 166 research projects were proposed, ranging from regional activities to detailed scientific studies, to be undertaken sequentially in accordance with CCHEN capacities. In the extractive metallurgy area, work has been ongoing

* Report prepared by the NEA/IAEA, based on previous Red Books, government data and company reports.

since 1996, through a co-operation agreement between CCHEN and ENAMI, to develop processes to produce commercial concentrates of rare earths. High-purity concentrates of light REE, as well as yttrium have been obtained.

In 2003, regional reconnaissance was undertaken for uranium and REE in Region I of the country, after which the CCHEN-ENAMI co-operation agreement was terminated. Through 2004, database work was continued by CCHEN and commercial services were provided to the mining industry through 2010.

From 2008 to 2012, CCHEN completed a broad scope co-operation agreement with the National Copper Corporation (CODELCO Norte) for geological and metallurgical investigation of natural radioactive material occurrences. From 2009 to 2012, CCHEN and CODELCO Norte completed an agreement on activities to investigate recovery of uranium and molybdenum from copper ore leaching solutions.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

No new uranium resources have been identified since the 2011 edition of the Red Book. Using a recovery factor of 75% (as applied to in situ RAR + IR of 68 tU from surficial, 1 762.8 tU from metasomatic, and 100 tU from volcanic-related deposits, totalling 1 930.8 tU), total identified RAR + IR recoverable resources are 1 448 tU in the <USD 260 kg/U cost category.

Uranium resources by deposit type

(in situ tonnes U)

Deposits, areas and other resources	RAR + IR	PR + SR	SR*
Surficial deposits	68.0	123.5	
Metasomatic deposits	1 762.8	4 060.0	
Volcanic-related deposits	100.0	500.0	
Unconventional deposits and resources	1 798.0	5 458.0	1 000
Deposit areas:			
1 – Surface deposits, Cenozoic	--	--	500
2 – Metasomatic deposits, Cretaceous	--	--	500
3 – Magmatic deposits, Cenozoic			250
4 – Polymetallic deposits, Cretaceous	--	--	100
Favourable areas:			
A – Acid volcanism, Tertiary	--	--	500
B – Intrusives, Jurassic-Cretaceous	--	--	500
C – Volcanic acid-sedimentary, Cretaceous	--	--	200
D – Main Cordillera, Palaeozoic magmatism	--	--	50
E – Sedimentary-volcanic, Middle Cretaceous	--	--	100
F – Nahuelbuta, Palaeozoic plutonism	--	--	300
G – Clastic sedimentary, Cretaceous-Tertiary	--	--	300
Total	3 728.8	10 141.5	4 300

* Undiscovered resources are expected to exist remotely from the known occurrences, either in the aforementioned uranium deposit areas or in favourable areas. In the case of unconventional resources, the figures correspond to uranium that could be recovered from the copper leaching plant solutions of the country's medium and large-scale mining activities. The latter could be several orders of magnitude greater, considering that large-scale national mining, both state-owned and private, produces large reserves of minerals in projects lasting up to 20 years. CCHEN has not updated its studies on this subject.

Surficial deposits

(in situ tonnes U)

Surface deposits	RAR	IR	PR	SR	% U_3O_8	Minerals
Boca Negra		3.0			0.02-0.600	Silica, yellow minerals
Manuel Jesús		2.5			0.10-0.190	Silica, yellow minerals
Casualidad					0.018	Silica, yellow minerals
San Agustín					0.20-0.250	Silica, yellow minerals
Poconchile					0.028	Silica, yellow minerals
Quebrada Vítor					0.028	Autunite
Pampa Chaca		2.0			0.028	Autunite
Pampa Camarones		3.5	3.5		0.030	Autunite, shronquingierite
Salar Grande	28.0		100.0		0.023	Carnotite
Quebrada Amarga		2.0			0.117	Carnotite
Quillagua		22.0			0.165	Carnotite
Chiu Chiu		5.0	5.0	15.0	0.04-0.140	Yellow minerals
Total	28.0	40.0	108.5	15.0		

Metasomatic deposits

(in situ tonnes U)

Metasomatic and hydrothermal deposits	RAR	IR	PR	SR	% U_3O_8	Minerals
Anomaly-2, Diego de Almagro (Cerro Carmen prospect)	595.3	796.5	1 400.0	1 500.0	0.03-0.10	Davidite, sphene, Ilmenite, anatase
Agua del Sol	15.0			50.0	0.02-0.06	Davidite
Sierra Indiana			15.0	15.0	0.02-0.08	Davidite
Estación Romero						
Carmen	20.0	10.0		50.0	0.01-0.12	Davidite
Producer	60.0	236.0	300.0	500.0	0.01-0.28	Autunite, torbernite
Tambillos	10.0			100.0	0.01-0.20	Uraninite, pitchblende
Pejerreyes – Los Mantos	20.0			130.0	0.01-0.05	Davidite, aut., torbernite
Total	720.3	1 042.5	1 715.0	2 345.0		

Volcanic-related deposits

(in situ tonnes U)

Volcanogenic deposits	RAR	IR	PR	SR	% U_3O_8	Minerals
Acid and intermediate volcanism, regions I to III						Not investigated
El Laco sector, Region II		100	500			Aut., torbernite, REE
El Perro sector, Region III						Not investigated
Total		100	500			

Unconventional resources and other materials*

(in situ tonnes U)

Mines, prospects, materials	RAR	IR	PR	SR	% U_3O_8	Minerals
Copper-uranium paleochannels						
Sagasca – Cascada[1]	164				0.0046	Crisocola, U
Huinquintipa[2]	46				0.0030	Crisocola, U
Chuquicamata Sur[3]	950				0.0007	Crisocola, U
Quebrada Ichuno[4]				25	0.0060	Crisocola, U
El Tesoro[5]				50	0.0070	Crisocola, U
North Chuquicamata (oxides zone)[6]				1 000	0.0008	Oxides Cu, U
Gravel from Chuquicamata oxides plant[7]				2 000	0.0008	Oxides Cu, U
Seams of high-temperature copper						
Algarrobo – El Roble[8]			513		0.0400	Sulph., Cu, U
Carrizal Alto[8]				500	0.0250	Sulph., Cu, U
Tourmaline breccias[8]						
Campanani[8]						
Sierra Gorda[8]				60	0.0020	Sulph., Cu, U
Los Azules[8]			5			
Cabeza de Vaca[8]				5		
Uranium-bearing phosphorites						
Mejillones			1 300		0.0026	Colophane – U
Bahía Inglesa[9]	638				0.0062	Colophane – U
Total	1 798		1 818	3 640		

* Note: The figures shown in this table represent historical data and are not current. Studies need to be done to validate or eliminate these figures.

1. The Sagasca deposit is exhausted, the Cascada deposit (continuation of the mineralised body) is practically exhausted; however, new explorations in the area have found new mineralised bodies, so the figure could vary substantially.
2. Huinquintipa currently forms part of the Collahuasi Project, a contractual mining company belonging to Anglo American Plc and Xstrata Copper, a division of the Swiss mining company Xstrata Plc, each of which has a 44% stake. The remaining 12% belongs to JCR, a consortium of Japanese companies led by Mitsui & Co., Ltd. The oxidised mineral reserves amount to 53 million tonnes, for which copper extraction and production began in 2000 and will last for 20 years. The figures shown in the foregoing table could rise by a factor of between 10 and 20.
3. Chuqui Sur: Although this deposit is not exhausted, the surcharge makes it expensive to operate, so the uranium resources contributed to the Chuquicamata Division oxides plant could be zero. Accordingly, the figures indicated above could decrease significantly.
4. Quebrada Ichuno, has not been studied and there are only preliminary works, so the figure mentioned above is maintained.
5. The uranium resources assigned to the El Tesoro mine correspond to preliminary geological reconnaissance data obtained in 1983. This deposit is currently a nationally important mining centre, 70% owned by Antofagasta Minerals S.A., which belongs to Antofagasta Plc, and 30% owned by the Marubeni Corporation of Japan. Its mineral reserves amount to 186 million tonnes, with a useful life of 21 years. Preliminary samples suggest uranium contents of between 5 and 200 ppm, with an average of between 15 and 20 ppm. Investigating this uranium source could change the figure indicated above substantially.
6. The "Chuquicamata Norte" prospect currently corresponds to the Radomiro Tomic mining centre, with reserves of 970 million tonnes of minerals that could be leached from copper and a useful life of 22 years. A programme of activities is currently being developed to recover uranium and molybdenum.
7. Estimations performed in the 1970s assigned a potential of 1 000 tU that could be recovered from copper leaching solutions obtained from the gravels of the old oxides plant of the Chuquicamata copper mine. This project began its activities in 1998 and will be active for 12 years. By the end of the period it will produce 467 000 t of fine copper. Recovery of uranium from these leaching solutions has not been researched.

   In addition to the uranium resources present in the leaching solutions from the aforementioned mines, there are other large copper deposits in the large-scale mining sector, whose leaching solutions have not been researched. An example is El Abra. This deposit, owned by Phelps Dodge Mining Co (51%) and CODELCO Chile (49%), started production of 800 million tonnes of is copper minerals for a 17-year period.
8. These figures have historical value only and as geological background data. The low copper content of these districts and the small volume of their reserves makes it difficult to recover their uranium content.
9. No experiments have been done to recover uranium from the uranium content in marine phosphorites. The only deposit currently being exploited is Bahía Inglesa, in Region III (Atacama), which produces a solid phosphate concentrate of direct use as fertiliser. In 2001, Compañía Minera de Fosfatos Naturales Ltda., (BIFOX LTDA.), which operates the aforementioned mine, began producing phosphoric acid, which would make it possible to recover uranium from the mother solutions.

Unconventional resources and other materials

(in situ tonnes U)

Deposit	RAR	IR	PR	SR	% U	Mineral
Unconventional	1 798	0	1 818	3 640	0.0008-0.1	Leaching solution 7 to 15 g/m^3 Oxide plants gravel Cu silicate and oxides, 20-70 ppm Sulphur oxide veins of 500-1 000 ppm
Total	1 798	0	1 818	3 640		

The uranium present in copper oxide ores could be recovered from the leaching solutions. A pilot-level trial was conducted in the Chuquicamata Division between 1976 and 1979, obtaining 0.5 t of yellow cake from copper-rich solutions containing 10 to 15 ppm U (0.001 to 0.0015% U), which was sent for purification at the CCHEN metallurgy pilot plant at the Lo Aguirre nuclear centre. The production of copper oxide minerals has quadrupled in Chile over the last decade.

The copper mining industry, particularly large-scale mining, has strategic (sub-economic) uranium potential in the large volumes of copper oxide leaching solutions. These resources are assigned a potential of 1 000 tU in mining centres not included in the previous table. However, no background studies have been performed to confirm these figures, either as mining resources or in terms of the volumes of solutions treated annually, so the information should be treated as unverified. Over the last decade, private firms, both domestic and foreign, have explored 12 "exotic copper" deposits in Chile, which correspond to paleochannels filled with gravel, mineralised with copper silicates, oxides and sulphates as a result of the natural leaching of porphyry copper deposits or other contribution areas. These mineralised bodies contain variable uranium contents ranging between 7 to 116 ppm (0.007 to 0.016% U). The leaching solutions in the plants that treat these copper oxide minerals display uranium levels of up to 10 ppm. This uranium content is technically recoverable using ion-exchange resins, at a likely production cost of over USD 80/kgU.

There has been no experience in recovering uranium from phosphorites in Chile. The only deposit currently being worked is Bahía Inglesa in Region III (Atacama), which produces a solid phosphate concentrate used directly as fertiliser. In 2001, Compañía Minera de Fosfatos Naturales Ltda. (Bifox Ltda.) began producing phosphoric acid from this deposit, opening the potential of recovering uranium from the acid.

Speculative resources in uranium geological favourable areas

Growing knowledge of the distribution of uranium mineralisation in Chile has made it possible to define four areas of uranium occurrence and seven favourable areas, five of which have occurrences of uranium, collectively accounting for ~3 300 tU.

Areas of uranium occurrences, accounting for ~1 350 tU:

1. Upper Cenozoic surface deposits – potential in SR: 500 tU.
2. Upper Cretaceous metasomatic deposits – potential in SR: 500 tU.
3. Upper Cenozoic magmatic and hydrothermal deposits – potential in SR: 250 tU.
4. Upper Cretaceous polymetallic and uranium deposits – potential in SR: 100 tU.
5. Tertiary volcanogenic deposits – potential not investigated.

Areas favourable for uranium occurrences, accounting for 1 950 tU (only minimum potential is indicated owing to a lack of research):

A. Acid volcanism and tertiary-quaternary alluvial deposits, Main Cordillera, Regions I and II – potential: 500 tU.

B. Intrusive Jurassic and Cretaceous rocks, Coastal Range, regions I and II – potential: 500 tU.

C. Acid volcanism and upper Cretaceous clastic sedimentary rocks; Central Valley, regions II and III – potential: 200 tU.

D. Paleozoic magmatism, Main Cordillera, Region IV – potential: 50 tU.

E. Sedimentary-volcanic rocks of the Middle Cretaceous period, neogenic intrusives, Main Cordillera, regions VI, VII and Metropolitan Region – potential: 100 tU.

F. Nahuelbuta Range, Paleozoic plutonism, regions VIII and IX – potential: 300 tU.

G. Acid and intermediate sedimentary clastic volcanism, Tertiary, Main Cordillera, regions VII, VIII and IX – potential: 300 tU.

Uranium production

Other than the trial production mentioned above, no uranium has been produced in Chile.

Environmental activities and socio-cultural issues

The CCHEN runs a permanent programme to disseminate information on peaceful uses of nuclear energy, attached to the Office of Dissemination and Public Relations (Oficina de Difusión y Relaciones Públicas).

Uranium requirements

Chile has achieved significant technological development in the manufacture of MTR-type (materials test reactor) combustible elements, based on U_3Si_2 (uranium silicide). In March 1998, the manufacture of 47 combustible elements began at the CCHEN combustible elements plant, ending in 2004. For this work, 60 kg of metallic uranium was purchased from Russia, enriched to 19.75% in ^{235}U, covering uranium requirements up to the indicated date. At the present time, 47 combustible elements have been manufactured, 16 of which are operating in the RECH-1 reactor, and another was sent to the Petten Research Centre in the Netherlands, to be classified under radiation in the high-flow reactor, which ended in November 2004.

Supply and procurement strategy

Should other loads of combustible elements be required, consideration will be given to purchasing enriched metallic uranium.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

There have been no changes in legislation relating to uranium in Chile.

Uranium stocks

There are no uranium stocks.

Undiscovered conventional resources (prognosticated and speculative resources)

Deposit	Type	Prognosticated tonnes U	Speculative tonnes U	Grade % U	Rocks hosting age
Diatomite, volcanic ash with organic material[1]	Surficial	108.5	15.0		Pliocene – Pleistocene
Intrusive, volcanic and metasomatic rocks[2]	Metasomatic	1 715	2 345	0.025-0.17	Upper Cretaceous
Tuffs with high magnetite and haematite content. Mineralisation of secondary REE minerals observed[3]	Volcanic-related	500	0*	0.085-0.15%	Oligocene – Pleistocene
Total		2 323.5	2 360*		

* 2 360 tU represents the speculative resources as tabulated and summed across the Surficial deposits, Metasomatic deposits, and Volcanic-related deposits tables. However, it does not take into account an additional 940 tU of speculative resources (for a total of 3 300 tU) indicated elsewhere in the report (see section "Speculative resources in uranium geological favourable areas" and table "Uranium resources by deposit type").

1. Salar Grande (100 tU), Pampa Camarones (3.5 tU), Chiu Chiu (20 tU).

   No new uranium prospecting has been done in the area of Cenozoic surface deposits.

2. Diego de Almagro Anomaly-2 (1 400 tU); Diego de Almagro Alignment (1 500 tU); Agua del Sol (50 tU), Sierra Indiana (30 tU), Sector Estación Romero: Carmen prospect (50 tU) and Productora Prospect (800 tU), Tambillos district (100 tU), Sector Pejerreyes – Los Mantos (130 tU).

   In 1999-2000, at the Diego de Almagro Anomaly-2 (Cerro Carmen prospect), 1 400 tU was assigned as prognosticated and speculative undiscovered resources. The regional alignment that controls the mineralisation of this prospect extends 60 km to the north-west. This structure, visible in satellite images, involves other mining districts for which a potential of 1 500 tU of speculative resources is assigned.

3. In 1999-2000, data held by CCHEN was reviewed as part of the National Uranium Potential Evaluation Project. It was concluded that the acidic and intermediate volcanism present in a broad area of the Main Cordillera stretching from regions I to III constituted an inclined plane dipping towards the west, ending in a lagoon environment situated in a central depression, with a similar conditions occurring to the east. This volcanism covered the pre-volcanic landscape, preserving the surface drainage courses (now paleochannels). The leaching of these volcanic rocks contributed large amounts of uranium into the lagoon systems, paleochannels and other structures in which solutions circulate. This process is represented by extensive layers of calcilutites, diatomites (Pampa Camarones), layers of salt (Salar Grande), argillites, limestones, limolites and volcanic ash (Quillagua, Prosperidad, Quebrada Amarga, Chiu Chiu), with uranium contents ranging between 100 and 1 000 ppm. These uranium occurrences and mineralisations have been classified historically as "surface deposits". There are also paleochannels with copper and associated uranium (the Sagasca, Cascada, Huinquintipa, Quebrada Ichuno, Chuqui Sur, El Tesoro deposits and others). Within the volcanic area, uranium mineralisation (torbernite and autunite) has been discovered in volcanic structures containing iron (El Laco and El Perro). This environment is considered to have great potential and requires further research. In structures associated with the U mineralisation indicated above, 500 tU is assigned as EAR-II (now prognosticated).

Identified conventional resources (reasonably assured and inferred resources)

(in situ tonnes U)

Deposit	Type	RAR	IR	Grade % U_3O_8	Rocks, hosting age
Cenozoic surficial deposits[1]	Surficial	28	40	0.023	Diatomite, volcanic ash with organic material (Pliocene – Pleistocene)
Cretaceous metasomatic[2]	Metasomatic	720	1 043	0.028-0.20	Intrusive, volcanic and metasomatic rocks (upper Cretaceous)
Cenozoic volcanic-related[3]	Volcanic-related	0	100	0.01-0.18	Magnetite and haematite tuffs. Secondary U-REE mineralisation (Oligocene Pleistocene)
Total		748	1 183		

Surface deposits:

1. Salar Grande (28 tU), Mina Neverman (?), Boca Negra (3 tU), Manuel Jesús (2.5 tU), Mina Casualidad (?), Mina San Agustín (?), Quebrada Vítor (?), Pampa Chaca (2 tU), Pampa Camarones (3.5 tU), Quebrada Amarga (2 tU), Quillagua (22 tU), Prosperidad (?), Chiu Chiu (5 tU).

Metasomatic deposits:

2. Estación Romero 326 tU (Carmen and Productora prospects), Cerro Carmen prospect (1 391.8 tU), Agua del Sol (15 tU), Sector Pejerreyes – Los Mantos (20 tU), Tambillos district (10 tU). The following estimates were produced at the prospect of the Diego de Almagro Anomaly-2 (Cerro Carmen prospect) in 1999-2000, as a result of detailed geological and radiometry work, together with magnetometry, excavation and sampling of exploration trenches, undertaken as part of the activities of the co-operation agreement between ENAMI and CCHEN: Calculations indicate that the deposit hosts a total of 595.3 tU as indicated resources, 796.5 tU as inferred resources, making a total in situ of 1 391.8 tU as identified resources (RAR + inferred). The cost of extracting these resources was not estimated, therefore not included in the identified resources tables.

Volcanogenic deposits:

3. In the El Laco iron ore deposit, produced during Cenozoic volcanism on the "altiplano" of Region II (Antofagasta), a total of 100 tU (in situ) was identified as inferred.

Reasonably assured conventional resources by production method

(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified	0	0	0	561	75
Total	0	0	0	561	75

Reasonably assured conventional resources by processing method

(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified	0	0	0	561	75
Total	0	0	0	561	75

Reasonably assured conventional resources by deposit type

(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Metasomatic	0	0	0	540
Surficial	0	0	0	21
Total	0	0	0	561

Inferred conventional resources by production method

(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified	0	0	0	887	75
Total	0	0	0	887	75

Inferred conventional resources by processing method

(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified	0	0	0	887	75
Total	0	0	0	887	75

Inferred conventional resources by deposit type

(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Volcanic-related	0	0	0	75
Metasomatic	0	0	0	782
Surficial	0	0	0	30
Total	0	0	0	887

Prognosticated conventional resources
(tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
0	0	2 324

Speculative conventional resources
(tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
0	0	2 360

Reasonably assured unconventional resources by deposit type
(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Intrusive (porphyry copper)	0	0	0	754
Phosphate	0	0	0	415
Total	0	0	0	1 169

Reasonably assured unconventional resources by mining method
(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified	0	0	0	1 169	65
Total	0	0	0	1 169	65

Reasonably assured unconventional resources by processing method
(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Co-product/by-product	0	0	0	1 169	65
Total	0	0	0	1 169	65

Prognosticated unconventional resources
(tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
0	0	1 818

Speculative unconventional resources
(tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
0	0	3 640

China (People's Republic of)

Uranium exploration and mine development

Historical review

Uranium exploration and mining in China started in the mid-1950s. Before the 1990s, uranium exploration mostly focused on granite-related or volcanic-related hydrothermal deposits in Jiangxi, Hunan, Guangdong, and Guangxi in South China. Over four decades, exploration by the Bureau of Geology (BOG), a subsidiary of China National Nuclear Corporation (CNNC), resulted in the identification of the majority of the ore fields (deposits), such as Xiangshan, Xiazhuang, Zhuguang, Ujing, and Miaoershan. Except for a few large deposits, most are relatively small and typically mid- to low-grade. Additionally, the deposits are mostly located in remote mountain areas, so mining costs are high.

At the beginning of the 1990s, when China initiated its nuclear energy programme, the demand for uranium increased very little due to the small number of NPPs. Given that there was an oversupply of natural uranium in the international market during that period, China slowed its uranium exploration activities and drastically cut its uranium exploration expenditures.

In the late 1990s, as NPP construction accelerated, demand for uranium steadily increased. Since then, the year-over-year national expenditures for uranium exploration gradually increased, and the targets shifted from conventional hard-rock mining in Southern China to in situ leaching (ISL) sandstone-type deposits in Meso-Cenozoic sedimentary basins in Northern China, such as in the Yili, Turpan-Hami, Junggar, Erlian, Erdos, and Songliao Basins. From 2000 to 2006, annual drilling gradually increased from 40 000 m to 250 000 m. Since 2006, investment in uranium exploration increased, with drilling peaking at 900 000 m in 2012.

Beside CNNC, which has been the major organisation involved in uranium exploration in China, the China National Petroleum Corporation (CNPC) also carried out uranium exploration in Tongliao, Inner Mongolia, in the late 1990s. Since 2008, Uranium Resources Co. Ltd, a subsidiary of China General Nuclear Power Corporation (CGN), has also been active in domestic uranium exploration and carried out related activities along the northern margin of Tarim Basin, Xinjiang, and in Guangdong Province.

Recent and ongoing uranium exploration and mine development activities

Domestic uranium exploration continued in 2017 and 2018 with positive results. The exploration focused on sandstone-type uranium deposits in north China, where resources were expanded in the Erdos, Yili, and Songliao Basins. Uranium mineralisation was discovered in new areas in the Songliao, Junggar, and Erlian Basins. Preliminary exploration indicates that these areas have high potential. Progress has also been made in the exploration of the deeper parts and periphery of the known uranium ore fields in south China.

Exploration, including regional uranium potential assessment and further work on previously discovered mineralisation and deposits in Northern China, has principally been focused on medium to large sedimentary basins, including the Yili, Turpan-Hami, Junggar and Tarim Basins in the Xinjiang Autonomous Region; the Erdos, Erlian, Songliao, Badanjili and Bayingebi Basins in Inner Mongolia; the Caidamu Basin in Qinghai Province and the Jiuquan Basin in Gansu Province. Geologic surveys, radiometric surveys, and electromagnetic surveys were combined with a moderate amount of drilling and shallow seismic methods to delineate prospects for further investigations. Further drilling was carried out in mineralised areas to identify ISL sandstone-type deposits, as well as sandstone/mudstone-type deposits with low permeability to be exploited by conventional mining.

The exploration work in Southern China is mainly directed at identifying metallogenic belts relating to volcanic-related and granite-related deposit types, mostly distributed in the Xiangshan uranium ore field in Jiangxi Province, the Xiazhuang and Zhuguang uranium ore fields in Guangdong Province, and the Miaoershan uranium ore field in the Guangxi Autonomous Region.

The total drilling completed in the last two years amounted to 1 190 000 m (about 610 000 m in 2017 and 580 000 m in 2018). As a result, uranium resources from the sedimentary basins in Northern China, such as the Yili, Erdos, Erlian, and Songliao Basins, have increased. In Southern China, there have been small increases of uranium resources in the deeper parts and on the periphery of the Xiangshan, Miaoershan, Zhuguangnanbu, and Xiazhuang uranium ore fields.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

As of 1 January 2019, the identified uranium resources categorised as reasonably assured resources (RAR) and inferred resources (IR) in China totalled 344 000 tU (in situ), distributed over 21 uranium ore fields in 13 provinces or autonomous regions, as listed in the following table. Compared to the end of 2016, the identified uranium resources decreased by approximately 7% due to the mining and re-evaluation of uranium resources.

No.	Location (province + place/name)		tU
1	Jiangxi	Xiangshan	26 200
		Ganzhou	28 900
		Taoshan	8 000
2	Guangdong	Xiazhuang	11 600
		Zhuguangnanbu	19 700
		Heyuan	2 300
3	Hunan	Xiangcaodawan	7 600
4	Guangxi	Ziyuan	9 500
5	Xinjiang	Yili	42 700
		Tuha	10 100
6	Inner Mongolia	Erdos	80 100
		Erlian	52 100
		Tongliao	16 500
		Bayingebi	7 500
7	Hebei	Qinglong	6 700
8	Yunnan	Tengchong	4 300
9	Shaanxi	Lantian	1 200
10	Gansu	Longshoushan	1 450
11	Zhejiang	Dazhou	2 100
12	Liaoning	Benxi	350
13	Sichuan	Ruoergai	5 100
Total (in situ)			344 000

Undiscovered conventional resources (prognosticated and speculative resources)

China has conducted systematic nationwide uranium resource prediction and evaluation with prognosticated resources estimated to be around 2 million tU. Favourable target areas for uranium mineralisation include the Erlian, Erdos, Tarim, Junggar, and Songliao Basins in northeast China, and the depth and periphery of the known uranium deposits in Southern China. With further exploration in uranium metallogenetic prospective areas, more uranium resources are expected to be discovered.

Unconventional resources and other materials

There are unconventional uranium resources associated with phosphate rocks in China, mainly distributed in Hunan, Guizhou, and Sichuan Provinces. The grade is relatively low. Systematic appraisal of unconventional uranium resources has not yet been conducted.

Uranium production

Historical review

The nearly 60-year history of China's natural uranium production includes both a boom in the first two decades and a decline from the late 1980s to the 1990s. In the early 2000s, there was a surge in activities, driven principally by the ambitious new NPP construction programme announced by the Chinese government and the increase in uranium spot price. As a result, uranium production was reinvigorated.

Uranium production centre technical details

(as of 1 January 2019)

	Centre #1	Centre #2	Centre #3	Centre #4	Centre #5	Centre #6	Centre #7
Name of production centre	Fuzhou	Chongyi	Yining	Lantian	Qinglong	Shaoguan	Tongliao
Production centre classification	Existing	Suspension	Existing	Suspension	Suspension	Existing	Existing
Date of first production	1966	1979	1993	1993	2007	1967	2015
Source of ore:							
Deposit name(s)				Lantian	Qinglong		
Deposit type(s)	Volcanic	Granite	Sandstone	Granite	Volcanic	Granite	Sandstone
Resources (tU)	NA	NA	NA	NA	NA	NA	NA
Grade (% U)	NA	NA	NA	NA	NA	NA	NA
Mining operation:							
Type (OP/UG/ISL)	UG	UG	ISL	UG	UG	UG	ISL
Size (tonnes ore/day)	1 000	600	NA	300	200	650	NA
Average mining recovery (%)	92	90	NA	80	85	90	NA
Processing plant:							
Acid/alkaline	Acid	Acid	Acid	Acid	Acid	Acid	CO_2+O_2**
Type (IX/SX)	IX	IX	IX	IX	SX	IX	IX
Size (tonnes ore/day); for ISL (l/day or l/h)	1 000	600	NA	NA	NA	NA	NA
Average process recovery (%)	90	84	NA	90	92	90	NA
Nominal production capacity (tU/year)	350	0	850	0	0	200	200
Plans for expansion	NA	NA	NA	NA	NA	NA	NA
Other remarks	NA	NA	NA	NA	NA	NA	NA

* Capacity prior to suspension. ** Considered a form of alkaline in situ leaching by some countries, as CO2+O2 ISL is alkaline at the beginning of the process, then neutral or slightly acidic at the end.

As uranium demand for NPPs is projected to increase rapidly in the coming decade, China responded by accelerating the pace of domestic uranium mining to ensure uranium supply. Several existing uranium production centres, such as Fuzhou and Yining, expanded their capacity to achieve both stable and increased production. Additionally, to promote uranium production, the development of other new uranium production centres based on uranium deposits with reliable reserves and favourable technological/economic feasibilities, such as the Tongliao production centre, was also accelerated. Finally, to construct new uranium production centres in the future, a series of pilot tests and feasibility studies were carried out in some newly discovered ISL-amenable sandstone uranium deposits with abundant reserves, such as the sandstone-type uranium deposits in the Erdos and Erlian Basins.

Status of production capability

As a response to the cost challenges brought by the sustained declining uranium price, plus meeting the ecological goals announced by the Chinese government, Chinese uranium companies reorganised from 2017 to 2018. First, several underground hard-rock uranium mines with depleted uranium resources or with high production costs were either closed or production was suspended. Second, the mining of ISL sandstone uranium deposits in Northern China continued including the expansion of ISL production capacity in Xin Jiang and Inner Mongolia. A uranium industry focus of production dominated by ISL mining in Northern China and supplemented by underground mining in Southern China emerged. The overall capacity of uranium production has remained steady after the reorganisation.

Among the seven production centres in China, the Fuzhou and Shaoguan production centres are still in operation. Also, the production capacity of the Yining centre in the Xinjiang Autonomous Region (north-west China), and the Tongliao centre in Inner Mongolia (north-east China) have been expanded. The Chongyi production centre in Jiangxi Province (south-east China), Lantian in Shaanxi Province (north-west China), and Qinglong in Hebei Province (northeast China) were suspended:

- The Fuzhou production centre in Jiangxi Province is an underground mine, which exploits Xiangshan volcanic-type uranium resources through conventional ion-exchange processing.
- The Shaoguan production centre in Guangdong Province is an underground mine, which exploits Xiazhuang and Zhuguang granite-related type uranium resources using an ion-exchange process. The Xiazhuang deposit was closed due to depletion of resources and high production costs; the other deposits are in operation.
- The Yining ISL production centre, located in Yining, Xinjiang Autonomous Region, mainly exploits sandstone type uranium resources in the Yili and Turpan-Hami Basins using an ion-exchange hydrometallurgical process. Construction of the new Mongqiguer ISL project in this centre significantly increases production capacity.
- The Tongliao production centre in Inner Mongolia is an ISL mine, which exploits sandstone type uranium resources in the southern Songliao Basin using an ion-exchange process. The ISL facilities of this centre are being expanded, and production capacity will be increased.
- The Chongyi production centre in Jiangxi Province, an underground mine, mainly exploits the Lujing and Taoshan granite-related type uranium resources with a hydrometallurgical process using heap leaching and ion-exchange. Production was suspended at this centre due to depletion of resources and high production costs.
- The Lantian production centre in Shannxi Province is an underground mine, which mainly exploits Lantian granite-related type uranium resources with an in-place leaching process. This centre suspended production due to depletion of resources and high production costs.
- The Qinglong production centre in Hebei Province is an underground mine, which mainly exploits Qinglong volcanic-related type uranium resources with heap leaching and solvent extraction. This centre was closed and put into decommissioning due to the depletion of resources and high production costs.

Uranium production in China in 2017 and 2018 amounted to 1 580 tU and 1 620 tU, respectively. It is expected to remain steady at 1 600 tU in 2019.

Regarding overseas uranium development, CNNC and CGN have been involved in several uranium mining projects mainly in Namibia, Kazakhstan and Niger. CNNC signed an agreement in 2014 to buy a 25% equity stake from Paladin Energy in its flagship Langer Heinrich uranium mine and acquired a total of 934 tU under the shareholder's equity in 2017 and 2018. The Langer Heinrich mine has been on care and maintenance since September 2018. The CNNC Azelik uranium project in Niger suspended production at the end of 2014 and is currently on care and maintenance. On 26 November 2018, CNNC signed share-sale agreement with Rio Tinto to buy a 68.62% equity stake of the Rössing uranium mine in Namibia. The CGN-Kazatomprom held Semizbay and Irkol mines in Kazakhstan provided 553 tU and 470 tU to CGN in 2017 and 2018, respectively. The CGN Husab project in Namibia has produced 1 100 tU and 3 000 tU in 2017 and 2018, respectively.

Ownership structure of the uranium industry

The uranium industry is owned by state-run enterprises in China. Six production centres (Fuzhou, Shaoguan, Chongyi, Yining, Lantian, and Qinglong) are sole proprietorship enterprises owned by CNNC. The Tongliao production centre is a joint venture owned by CNNC and CNPC.

The overseas uranium exploration and development are undertaken by CNNC and CGN. CNNC is the biggest stakeholder of the Azelik uranium mine in Niger, the Rössing uranium mine in Namibia, and holds an equity stake of the Langer Heinrich uranium mine in Namibia. CGN is the biggest shareholder of Husab uranium mine in Namibia and holds an equity stake in the Semizbay and Irkol mines in Kazakhstan.

Employment in the uranium industry

In 2017 and 2018, the industrial restructuring of domestic uranium production continued in China. Most of the underground uranium production centres of Southern China with relatively high costs have been closed, resulting in a significant reduction in the number of employees. ISL uranium production centres that have been expanded in Northern China are highly automated, with no requirement for increased employment. Consequently, employment in China's uranium production sector has decreased considerably.

Future production centres

Industrial ISL tests are being carried out in some parts of the Erdos and Erlian sandstone-type uranium deposits in Inner Mongolia. Encouraging results have been achieved from the ISL tests, which may render those deposits the principal uranium production centres in China.

Once the uranium market rebounds, the suspended uranium production centres are expected to be put into operation again.

Additionally, the Rössing uranium mine, acquired by CNNC, will be another large overseas uranium production centre.

Uranium requirements

As of 1 January 2019, the total installed capacity of the 44 NPPs in operation in mainland China is 44.6 GWe, ranking third in the world and accounting for 2.35% of total electricity installed capacity. Annual uranium requirements amount to about 8 100 tU. The total amount of electricity generated by nuclear power was 294.4 TWh in 2018, accounting for 4.22% of total generated electricity, which represented an 18.96% increase compared with the same period in 2017. Furthermore, an additional 13 NPPs with capacity of 14 GWe are under construction in China.

During the 13th Five-Year Plan period, the Chinese government promoted nuclear power construction, especially in coastal areas, and adherence to the principle of development in a clean, low-carbon and eco-friendly manner, as well as ensuring safety. It is projected that the total installed capacity of NPPs will reach between 50 GWe and 52 GWe by the end of 2020. Based on preliminary projections, uranium requirements will amount to between 9 000 tU and 9 400 tU in 2020, then rise to between 12 300 and 16 200 tU in 2030, and between 14 400 and 20 500 tU in 2035.

Supply and procurement strategy

To meet the demand of NPPs planned within the development programme approved by the government, the policy "Facing Two Markets and Using Two Kinds of Resources" has been adopted. Uranium supply will be guaranteed through a combination of domestic production, development of non-domestic resources and international trade. As a supplement and balance to domestic production and supply, international trade will ensure a stable supply with reasonable prices on both the spot and future markets.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

Uranium supply has been given more attention by the Chinese government, which an emphasis on safe, economic, and diverse supply sources to ensure reliability. Adequate commercial stocks are also required. Several measures have been taken by the government to support the exploration and development of uranium resources, such as stable investment for domestic exploration; allowing non-government organisations to engage in uranium exploration activities; reviewing the restrictions associated with regulation of domestic production; as well as promoting investment in overseas uranium resources and the establishment of overseas production centres.

Uranium stocks

NA.

Uranium prices

The uranium price has been gradually streamlined with the international market price in order to follow the global trend of uranium prices. Accordingly, uranium is priced in China following the fluctuations of the international market.

Uranium exploration and development expenditures and drilling effort – domestic

(USD millions)

	2016	2017	2018	2019 (expected)
Industry* exploration expenditures	17	15	13	13
Government exploration expenditures	98	98	95	130
Industry* development expenditures	13	12	12	11
Government development expenditures	0	0	0	0
Total expenditures	128	125	120	154
Industry* exploration drilling (m)	94 500	80 000	70 000	70 000
Government exploration drilling (m)	530 000	530 000	510 000	650 000
Industry* development drilling (m)	NA	NA	NA	NA
Industry* development holes drilled	NA	NA	NA	NA
Government development drilling (m)	0	0	0	0
Government development holes drilled	0	0	0	0
Subtotal exploration drilling (m)	624 500	610 000	580 000	720 000
Subtotal development drilling (m)	0	0	0	0
Subtotal development holes drilled	0	0	0	0
Total drilling (m)	624 500	610 000	580 000	720 000

* Non-government.

Uranium exploration and development expenditures – non-domestic
(USD millions)

	2016	2017	2018	2019 (expected)
Industry* exploration expenditures	9.29	0.98	0.78	1.08
Industry* development expenditures	368.72	107.13	40.70	22.5
Total expenditures	378.01	108.11	41.48	23.58

* Non-government.

Reasonably assured conventional resources by production method
(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Underground mining (UG)	0	7 000	56 290	61 010
Open-pit mining (OP)	0	0	0	0
In situ leaching acid	20 200	37 500	54 900	54 900
In situ leaching alkaline	0	0	0	0
Co-product and by-product	0	0	0	0
Unspecified (in situ leaching with CO_2+O_2*)	28 500	39 060	43 060	43 060
Total	48 700	83 560	154 250	158 970

* Considered a form of alkaline in situ leaching by some countries, as CO_2+O_2 ISL is alkaline at the beginning of the process, then neutral or slightly acidic at the end.

Reasonably assured conventional resources by processing method
(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Conventional from UG	0	7 000	56 290	61 010
In situ leaching acid	20 200	37 500	54 900	54 900
In situ leaching with CO_2+O_2*	28 500	39 060	43 060	43 060
Total	48 700	83 560	154 250	158 970

* Considered a form of alkaline in situ leaching by some countries, as CO_2+O_2 ISL is alkaline at the beginning of the process, then neutral or slightly acidic at the end.

Inferred conventional resources by production method
(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Underground mining (UG)	0	11 300	58 500	81 490
In situ leaching CO_2+O_2*	49 500	85 650	90 350	90 350
In situ leaching acid	9 700	12 100	13 190	13 190
Total	59 200	109 050	162 040	185 030

* Considered a form of alkaline in situ leaching by some countries, as CO_2+O_2 ISL is alkaline at the beginning of the process, then neutral or slightly acidic at the end.

Inferred conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Conventional from UG	0	11 300	58 500	81 490
In situ leaching with CO_2+O_2*	49 500	85 650	90 350	90 350
In situ leaching acid	9 700	12 100	13 190	13 190
Total	59 200	109 050	162 040	185 030

* Considered a form of alkaline in situ leaching by some countries, as CO_2+O_2 ISL is alkaline at the beginning of the process, then neutral or slightly acidic at the end.

Historical uranium production by deposit type

(tonnes U in concentrates)

Deposit type	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Sandstone	NA	1 000	1 050	1 070	NA	1 150
Granite-related	NA	200	200	200	NA	200
Volcanic-related	NA	450	330	350	NA	250
Total	NA	1 650	1 580	1 620	NA	1 600

Historical uranium production by processing method

(tonnes U in concentrates)

Processing method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Conventional	NA	350	330	350	NA	250
In-place leaching*	NA	0	0	0	NA	0
In situ leaching	NA	1 000	1 050	1 070	NA	1 150
Heap leaching**	NA	300	200	200	NA	200
Total	NA	1 650	1 580	1 620	NA	1 600

* Also known as stope leaching or block leaching.

** A subset of open-pit and underground mining, since it is used in conjunction with them.

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Underground mining	NA	650	530	550	NA	450
In situ leaching	NA	1 000	1 050	1 070	NA	1 150
Total	NA	1 650	1 580	1 620	NA	1 600

Ownership of uranium production in 2018

Domestic				Foreign				Totals	
Government		Private		Government		Private			
(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)
1 600	100							1 600	100

Uranium industry employment at existing production centres

(person-years)

	2016	2017	2018	2019 (expected)
Total employment related to existing production centres	6 750	5 950	2 350	2 290
Employment directly related to uranium production	5 880	5 020	1 550	1 490

Czech Republic

Uranium exploration and mine development

Historical review

Following its start in 1946, uranium exploration in former Czechoslovakia grew rapidly and developed into a large-scale programme in support of the country's uranium mining industry. A systematic exploration programme including geological, geophysical, geochemical surveys and related research was carried out to assess the uranium potential of the entire country. Areas with identified potential were explored in detail using drilling and underground exploration methods.

Exploration continued systematically until 1989, with annual exploration expenditures in the range of CZK 210-430 million (USD 10-20 million) and an annual drilling effort in the range of 70-120 km. Exploration was traditionally centred around vein deposits located in metamorphic complexes (Jáchymov, Horní Slavkov, Príbram, Zadní Chodov, Rozná, Olsí and other deposits), granitoids of the Bohemian massif (Vítkov deposit) and around the sandstone-hosted deposits in northern and north-western Bohemia (Hamr, Stráz, Brevniste, Osecná-Kotel, Hvezdov, Vnitrosudetská Pánev, Hájek and other deposits).

In 1989, the decision was made to reduce all uranium-related activities. Following this decision, in 1990, expenditures decreased to about CZK 150 million (USD 7 million) and have not reached that level since. No field exploration has been carried out since the beginning of 1994.

Recent and ongoing uranium exploration and mine development activities

Recent uranium exploration activities have been focused on the conservation and processing of previously collected exploration data from Czech uranium deposits. Advance processing of the exploration data and building the exploration database will continue in the coming years.

The last significant exploration work was carried out to accurately identify the uranium resources in the deep parts of the Rozná deposit (industry exploration expenditures were CZK 12.6 million in 2016; USD 600 000). The exploration work at the Rozná deposit confirmed and specified economically profitable resources until 2017. In the years 2017-2018, the geological survey data were processed, archived and final reports were completed (exploration expenditures were CZK 0.4 million in 2017, CZK 0.2 million in 2018, and an expected amount of CZK 0.4 million in 2019; approximately USD 20 000, USD 10 000, and USD 20 000, respectively).

Uranium resources

Historically, most of the known uranium resources of the Czech Republic occurred in 23 deposits, of which 20 have been mined out or closed. Of the three remaining deposits, only Rozná and Stráz are being mined. Resources at the Stráz deposit are, however, limited due to the remediation process and resources at the Rozná deposit have already reached the limits of economic profitability. Other deposits (the Osecná-Kotel part of the Stráz bloc and Brzkov) have resources that are not mineable because of environmental concerns.

Identified conventional resources (reasonably assured and inferred resources)

As of 1 January 2019, total identified conventional resources (reasonably assured resources and inferred resources) amounted to 119 169 tU. A decrease of 277 tU from previous estimates as of 1 January 2017, due to the mining and re-evaluation of uranium resources at the relevant deposits.

In detail, the reasonably assured resources recoverable at a cost of <USD 130/kgU amounted to 866 tU. These are recoverable resources in existing production centres at the Stráz deposits. The reasonably assured resources recoverable at a cost of <USD 260/kgU amounted to 50 910 tU, a decrease of 187 tU compared to the estimates as of 1 January 2017. The remaining resources of the Rozná deposit, in the amount of 187 tU, are also included in this cost category.

Inferred resources recoverable at a cost of <USD 260/kgU amounted to 68 259 tU and are unchanged compared to estimations as of 1 January 2017. These high-cost resources are located in the Rozná deposit (369 tU) and especially in the Stráz bloc (the Stráz, Hamr, Osecná-Kotel, and Brevniste deposits), but remain unmined due to environmental concerns.

Undiscovered conventional resources (prognosticated and speculative resources)

As of 1 January 2019, total undiscovered conventional resources (prognosticated resources and speculative resources) amounted to 239 915 tU. Prognosticated resources at a cost <USD 260/kgU amounted to 222 915 tU and are unchanged from previous estimates as of 1 January 2017. These resources occur mainly (98%) in the sandstone deposits of the Northern Bohemian Cretaceous Basin (Stráz block, Tlustec block and Hermanky deposits) and to a lesser extent (2%) in the metamorphic complex of Western Moravia (Rozná and Brzkov deposits).

Speculative resources at a cost of about or greater than USD 260/kgU are estimated to amount to 17 000 tU and are reported in the unassigned cost category. Since these resources occur in Northern Bohemian Cretaceous sandstone deposits in a groundwater source protection zone, further exploration and evaluation are not permitted.

Uranium production

Historical review

The history of uranium mining in the Czech Republic dates back to the early 19th century. Uranium ores have been mined for the glass, ceramic and ink industry in Jáchymov since 1858.

Industrial development of uranium production in former Czechoslovakia began in 1946. Between 1946 and the dissolution of the former Soviet Union in 1991, all uranium produced in former Czechoslovakia was exported to the former Soviet Union.

The first production came from Jáchymov and Horní Slavkov mines, which completed operations in the mid-1960s. Príbram, the main vein deposit, operated from 1950 to 1991. The Hamr and Stráz production centres, supplied by sandstone deposits, started operation in 1967. Peak annual national production of about 3 000 tU was reached around 1960 and production remained between 2 500 and 3 000 tU/yr from 1960 until 1989/1990 and declined thereafter. A cumulative total of 112 153 tU was produced in the Czech Republic during the period 1946-2018, of which about 84% was produced by underground and open-pit mining methods and the remainder was recovered by in situ leaching.

Status of production facilities, production capability, recent and ongoing activities and other issues

Two production centres remain in the Czech Republic. One is a conventional deep mine and mill (Rozná) in the Dolní Rozínka uranium production centre (Western Moravia) and the second is a chemical mining centre in Stráz pod Ralskem (Northern Bohemia). Both the Dolní Rozínka and Stráz pod Ralskem production centres are wholly operated by the state-owned enterprise DIAMO.

The Dolní Rozínka centre (Rozná metamorphite deposit, resources of 187 tU, extending to a depth of 1 100 m underground) produced 31 tU under the decommissioning process at Rozná mine by 27 April 2017 and 5 tU in 2018 from water treatment only. Because the mining of uranium resources located in the deepest peripheral parts of the mine became unprofitable, it was decided to terminate the operation and start the decommissioning of the production centre, as of 1 January 2017. Expected uranium production from water treatment at Dolní Rozínka production centre in 2019 is 6 tU.

At the Stráz pod Ralskem chemical mining centre (Stráz sandstone deposit, with resources of 866 tU recoverable at cost <USD 130/kgU), the former acid in situ leaching (~180 m underground) production centre, produced 36 tU in 2017 and 29 tU in 2018. Uranium produced at this centre is a product of environmental remediation activities that began in 1996. Production capability during remediation (without acid) has decreased because of lower uranium concentration in solutions. Production in 2019 is expected to amount to 33 tU. In the long term, a gradual decline in production is expected.

Uranium is also obtained from mine water treatment (at existing and former facilities), with a total recovery of 6 tU expected in 2019 (not including U recovery from ISL mining restoration activities).

Ownership structure of the uranium industry

All uranium activities, including exploration, production, and related environmental activities are being carried out by the state-owned enterprise, DIAMO, a mining and environmental engineering company, based in Stráz pod Ralskem.

Uranium production centre technical details

(as of 1 January 2019)

	Centre #1	Centre #2
Name of production centre	Dolní Rozínka	Stráz pod Ralskem
Production centre classification	Existing	Existing
Date of first production	1957	1967
Source of ore:		
Deposit name(s)	Rozná	Stráz
Deposit type(s)	Metamorphite	Sandstone
Recoverable resources (tU)	187	866
Grade (% U)	0.171	0.030
Mining operation:		
Type (OP/UG/ISL)	UG	ISL
Size (tonnes ore/day)	550	-
Average mining recovery (%)	90 (estimated)	60 (estimated)
Processing plant:		
Acid/alkaline	Alkaline	Acid
Type (IX/SX)	IX	IX
Size (tonnes ore/day) For ISL (kilolitre/day)	530 -	- 10 000
Average process recovery (%)	90 (estimated)	60 (estimated)
Nominal production capacity (tU/year)	300	100
Plans for expansion	No	No
Other remarks	Since 2018, only the processing is in operation	Since 1996, production occurs through the remediation process

Employment in the uranium industry

Total employment in the Czech uranium production centres was 1 672 workers in 2017 and 1 557 workers in 2018 (i.e. employment related to the production including head office, auxiliary divisions, mining emergency services).

Employment directly related to uranium production at Dolní Rozínka and Stráz pod Ralskem centres was 819 in 2017 and 786 in 2018, however, some uranium production is associated with remediation. The decrease in the number of workers is a result of the closure of the Rozná mine at the Dolní Rozínka production centre, as of 31 December 2016.

Future production centres

No other production centres are committed or planned in the near future. A potential production centre at the Brzkov deposit is a possibility to be discussed in the distant future.

Secondary resources of uranium

Production and/or use of mixed oxide fuels

The Czech power utility CEZ, a.s., is the sole owner and operator of NPPs in the Czech Republic and does not use MOX fuels in its reactors.

Production and/or use of re-enriched tails

CEZ does not use re-enriched tails in its reactors.

Production and/or use of reprocessed uranium

CEZ does not use reprocessed U in its reactors.

Environmental activities and socio-cultural issues

Both the environmental activities and the resolution of social issues are the responsibility of the government contraction programme of the Czech uranium mining industry. These activities began in 1989. Although this programme was formally terminated in 2009, extensive environmental remediation projects and some associated social issues continue to be addressed with the state budget and EU funding.

This programme has been aimed at gradually decreasing employment related to declining uranium production and the development of alternative (mainly environmental) projects to address social issues.

In general, the environmental activities include project preparation, environmental impact assessment, decommissioning, tailings impoundments and waste rock management, site rehabilitation and maintenance, water treatment and long-term monitoring.

The key environmental remediation projects are as follows:

- Remediation of the after-effects of the ISL used in Stráz pod Ralskem that impacted a total of 266 million m^3 groundwater and an enclosure of 600 ha surface area.
- Rehabilitation of the tailings impoundments in Mydlovary, Príbram, Stráz pod Ralskem and Rozná (a total of 19 ponds with a total area of 589 ha).
- Rehabilitation (including reprocessing) of the waste rock dumps in Príbram, Hamr, Rozná, Western Bohemia and other sites (a total of 67 dumps with a capacity 38.2 million m^3).
- Mine water treatment from former uranium facilities in Príbram, Stráz, Horní Slavkov, Olsí and others, amounting to a total of approximately 12 million m^3/yr, which results in the recovery of about 5 tU annually.

The major part of environmental expenses (about 85%) is being funded by the state budget, with the remainder financed by the EU (9-12%) and DIAMO (3-6%). Since 1989, CZK 59 650 million (about USD 2 800 million) has been spent on the environmental remediation projects. The projects, which would continue until approximately 2040, are expected to have a total cost of more than CZK 60 000 million (about USD 2 817 million).

The social part of the programme (obligatory spending, compensation, damages, and rent) is financed entirely by the state budget.

Expenditures related to environmental activities and social issues

(CZK millions)

	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Uranium environmental remediation	43 009	1 734	2 378	2 262	49 383	2 017
Social programme and social security	9 702	210	203	152	10 267	124
Total	52 711	1 944	2 581	2 414	59 650	2 141

Uranium requirements

There are two NPPs with a total of six units in operation in the Czech Republic: the older Dukovany NPP with four VVER-440 reactors, which have been uprated to 510 MWe (gross) in the period 2009-2019, and the younger Temelin NPP with two VVER-1000 reactors, which have been uprated to 1 080 MWe (gross). The sole owner and operator of these NPPs is the Czech power company CEZ, a.s.

There is a general consensus that it will be necessary to build new units in the Czech Republic, and a goal has been set to commission the first new unit by 2040. Negotiations between the Czech government and the company CEZ concerning the construction of new units are ongoing. However, by the end of 2018, no final decision related to a financial model has been made. CEZ is focused on long term operation projects of both current NPPs and preparation work for new builds at both sites.

Total uranium requirements of both NPPs have been averaging 675 tU/year on a long-term basis, with a present increase up to 700 tU/year as a result of advanced fuel deployment at the Temelin NPP. However, uranium requirements were unusually low in 2017 due to prolonged and rescheduled outages. On the other hand, both NPPs had exceptionally high fuel requirements in 2018 due to loading of more fuel assemblies (advance fuel, longer fuel cycles).

Supply and procurement strategy

CEZ has been obtaining uranium on the basis of middle and long-term contracts, as well as taking advantage of the current low spot market prices. Some uranium has been partially purchased in the world market, and partially purchased in the form of fabricated fuel, delivered from the Russian fabricator TVEL as a package.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

The reduction programme of the Czech uranium industry from the end of the 1980s has already been formally terminated. An extensive programme for the environmental remediation of former uranium production facilities continues.

Based on a government decision (Government Decree No. 1086/2014 Coll.), the existing Rozná uranium deposit was economically mined by DIAMO until 2017 with no government financial assistance. Since the end of mining at the Rozná deposit, environmental site remediation has been carried out with financial participation of the government.

According to the government's "Concept of the Raw Materials and Energy Security of the Czech Republic", a feasibility study of early development at Brzkov uranium deposits was completed in 2014, as well as new technological possibilities of uranium mining that strictly respect environmental concerns.

The government of the Czech Republic approved mining activities by DIAMO at the Brzkov deposit (Vysocina region); however, there has been significant opposition by local municipalities and strong public resistance to the resumption of uranium mining in the area.

Uranium stocks

The Czech power company CEZ maintains uranium stocks at the level of about two and a half years of forward reactor consumption in all forms of processed uranium. A substantial portion of these stocks is in the form of fabricated fuel stored at the NPP sites.

Uranium prices

Uranium prices are not available as they are commercially confidential. In general, uranium prices in supply contracts incorporate price indicators from the world market according to agreed formulas.

Uranium exploration and development expenditures and drilling effort – domestic

(CZK millions)

	2016	2017	2018	2019 (expected)
Industry* exploration expenditures	12.6	0.4	0.1	0.3
Government exploration expenditures	0.0	0.0	0.1	0.1
Industry* development expenditures	0.0	0.0	0.0	0.0
Government development expenditures	0.0	0.0	0.0	0.0
Total expenditures	12.6	0.4	0.2	0.4
Industry* exploration drilling (m)	0.0	0.0	0.0	0.0
Industry* exploration holes drilled	0.0	0.0	0.0	0.0
Industry* exploration trenches (m)	0.0	0.0	0.0	0.0
Industry* exploration trenches	0.0	0.0	0.0	0.0
Government exploration drilling (m)	0.0	0.0	0.0	0.0
Government exploration holes drilled	0.0	0.0	0.0	0.0
Government exploration trenches (m)	0.0	0.0	0.0	0.0
Government exploration trenches	0.0	0.0	0.0	0.0
Industry* development drilling (m)	0.0	0.0	0.0	0.0
Industry* development holes drilled	0.0	0.0	0.0	0.0
Government development drilling (m)	0.0	0.0	0.0	0.0
Government development holes drilled	0.0	0.0	0.0	0.0
Subtotal exploration drilling (m)	0.0	0.0	0.0	0.0
Subtotal exploration holes drilled	0.0	0.0	0.0	0.0
Subtotal development drilling (m)	0.0	0.0	0.0	0.0
Subtotal development holes drilled	0.0	0.0	0.0	0.0
Total drilling (m)	0.0	0.0	0.0	0.0
Total number of holes drilled	0.0	0.0	0.0	0.0

* Non-government.

Reasonably assured conventional resources by production method

(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	0	0	1 665	90
In situ leaching acid	0	0	866	49 245	60
Total	0	0	866	50 910	

Reasonably assured conventional resources by processing method

(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	0	0	1 665	90
In situ leaching acid	0	0	866	49 245	60
Total	0	0	866	50 910	

Reasonably assured conventional resources by deposit type

(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	866	49 245
Metamorphite	0	0	0	1 665
Total	0	0	866	50 910

Inferred conventional resources by production method

(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	0	0	459	90
In situ leaching acid	0	0	0	67 800	60
Total	0	0	0	68 259	

Inferred conventional resources by processing method

(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	0	0	459	90
In situ leaching acid	0	0	0	67 800	60
Total	0	0	0	68 259	

Inferred conventional resources by deposit type

(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	0	67 800
Metamorphite	0	0	0	459
Total	0	0	0	68 259

Prognosticated conventional resources

(tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
0	0	222 915

Speculative conventional resources

(tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
0	0	17 000

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Underground mining*	94 327	95	28	5	94 455	6
In situ leaching	17 590	43	36	29	17 698	33
Total	111 917	138	64	34	112 153	39

* Pre-2015 totals may include uranium recovered by heap and in-place leaching.

Historical uranium production by processing method

(tonnes U in concentrates)

Processing method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Conventional	91 600	87	23	0	91 710	0
In-place leaching*	3	0	0	0	3	0
Heap leaching**	125	0	0	0	125	0
In situ leaching	17 590	43	36	29	17 698	33
Other methods***	2 599	8	5	5	2 617	6
Total	111 917	138	64	34	112 153	39

* Also known as stope leaching or block leaching.

** A subset of open-pit and underground mining, since it is used in conjunction with them.

*** Includes mine water treatment and environmental restoration.

Historical uranium production by deposit type

(tonnes U in concentrates)

Deposit type	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Proterozoic unconformity	0	0	0	0	0	0
Sandstone	27 826	43	36	29	27 934	33
Granite-related*	60 875	8	5	0	60 894	6
Metamorphite	23 195	87	23	5	23 304	0
Metasomatite	0	0	0	0	0	0
Lignite and coal	1	0	0	0	1	0
Other/unspecified	20	0	0	0	20	0
Total	111 917	138	64	34	112 153	39

* Includes uranium recovered from mine water treatment; 8 tU in 2016, 5 tU in 2017, 5 tU in 2018 and 6 tU expected in 2019.

From 1945 to 1985, historical uranium production by deposit type was derived from the statement of production centres (more than one type of deposit was processed at the only production centre).

Ownership of uranium production in 2018

Domestic				Foreign				Totals	
Government		Private		Government		Private			
(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)
34	100	0	0	0	0	0	0	34	100

Uranium industry employment at existing production centres

(person-years)

	2016	2017	2018	2019 (expected)
Total employment related to existing production centres	1 955	1 672	1 557	1 556
Employment directly related to uranium production	985	819	786	806

Short-term production capability

(tonnes U/year)

2020				2025				2030			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
0	0	50	50	0	0	50	50	0	0	50	50

2035				2040			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
0	0	30	30	0	0	20	20

Net nuclear electricity generation (TWh net)

	2017	2018
Nuclear electricity generated (TWh net)	26.8	28.3

Installed nuclear generating capacity to 2040

(MWe net)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
4 290	4 290	4 290	4 290	4 290	4 290	4 290	4 290	4 290	4 290	4 290	5 490

Annual reactor-related uranium requirements to 2040 (excluding MOX)

(tonnes U)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
432	793	635	645	685	700	685	700	685	700	685	895

Total uranium stocks

(tonnes natural U-equivalent)

Holder	Natural uranium stocks in concentrates	Enriched uranium stocks	Enrichment tails	LWR reprocessed uranium stocks	Total
Government	0	0	0	0	0
Producer	>200	0	0	0	>200
Utility	NA	NA	0	0	NA
Total	NA	NA	0	0	NA

Denmark/Greenland

Uranium exploration and mine development

Historical review

Uranium exploration and assessment activities have been performed in South, East and West Greenland, and most recently, in North Greenland. The earliest exploration for uranium was carried out using Geiger counters over selected areas of South Greenland during 1955 to 1956, leading to the discovery of radiation anomalies associated with the Kvanefjeld deposit, a large low-grade U-Th-REE deposit associated within the Mesoproterozoic Ilímaussaq layered alkaline intrusive rock complex. In 1973, Denmark, including Greenland, joined the European Economic Community when uranium exploration was encouraged in member states to secure the community's uranium resources.

Since its discovery in the mid-1950s, exploration of the Kvanefjeld deposit in South Greenland continued through 1984 with various geophysical and geochemical surveys, drilling, detailed geological mapping, and test mining and assaying work. Resources at the time were estimated at 27 000 tU with 16 000 tU in the "additional resources" category. Additional activities in South Greenland included a regional exploration programme from 1979 to 1986 involving airborne gamma spectrometry, drainage geochemistry and geological studies. Three prospects were found: 1) uraninite in mineralised fractures and veins, 2) uranium rich pyrochlore mineralisation in alkaline rocks and, 3) uraninite in hydrothermally mineralised metasediments. These prospects at the time were believed to represent 60 000 tU in the "speculative resources" category.

Between 1972 and 1977, a reconnaissance uranium exploration programme was conducted in East Greenland involving airborne gamma spectrometry, drainage geochemistry, ground scintillometry, and geological studies, but no major discoveries were made. Additional reconnaissance in West Greenland with airborne gamma spectrometry and follow-up groundwork was performed also without a major discovery.

Following a decision in 1985 by the Danish government to exclude nuclear power from its energy supply sources, a policy was introduced in 1988 to ban the mining of uranium and other radioactive elements in Greenland. Exploration activities continued, however, and in 1995, a stream sediment survey was undertaken that included analysis for uranium and thorium, as well as scintillometre readings, covering 7 000 km^2 in north-west Greenland, but no prospects were found. In 2009, the "Self-Government Act" enacted the Danish Parliament granted Greenland control over its natural resources, and in 2013, the Greenland government lifted the ban on mining of uranium and other radioactive elements, generating renewed interest in evaluating the potential of Greenland's uranium resources.

In November 2016, an assessment of the uranium potential in Greenland was conducted jointly by the Geological Survey of Denmark and Greenland and the Ministry of Mineral Resources, Government of Greenland. Three uranium deposit types were considered: intrusive, sandstone-hosted and unconformity-related. The assessment concluded that intrusive and unconformity-related deposits have the highest potential for economic concentrations of uranium, and that South Greenland has the highest potential for hosting undiscovered deposits.

Recent and ongoing uranium exploration and mine development activities

Since 2007, Greenland Minerals and Energy Ltd (GMEL), a publicly listed company, has conducted exploration activities for REE-U-Zn mineralisation in the Kvanefjeld area, South Greenland, including drilling of 57 710 m of core. The business concept encompasses uranium and zinc by-products in addition to the main products of REE. A mining/exploitation licence application was submitted in July 2019, including updated environmental and social impact assessments (EIA and SIA) together with a navigational safety investigation study (NSS). It is expected that uranium will be recovered from leach solutions using industry standard solvent extraction to produce approximately 500 tonnes of U_3O_8 (425 tU) per year.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

The Ilímaussaq igneous complex of South Greenland hosts the REE-U-Zn-F deposit referred to Kvanefjeld. It is a high-tonnage, low-grade uranium-enriched layered intrusive deposit, with concentrations of around 300 ppm U. Uranium is planned to be mined as a by-product from a proposed open-pit mine. GMEL estimates that uranium will account for 5% of the revenue. Kvanefjeld is the only uranium deposit or occurrence in Greenland with reasonably assured uranium resources. The supply cost for uranium will be very low, as the majority of the costs will be borne by the production of the REE, the primary resource (Kvanefjeld is considered to be one of the largest REE deposits in the world). GMEL has reported a uranium specific supply cost of approximately USD 13/kgU (USD 5/lb U_3O_8), which is incremental to the cost of the REE production. The total identified in situ reasonably assured conventional mineral resource inventory for Kvanefjeld is 102 820 tU. Additional in situ inferred mineral resources of 338 Mt ore exist in the Zone Sørensen and Zone 3, related to the Kvanefjeld, equivalent to 125 143 tU. The recoverable uranium resource using the established and pilot plant tested flowsheet is approximately 50%.

Undiscovered conventional resources (prognosticated and speculative resources)

Several uranium occurrences are known in Greenland: seven in South Greenland, three in West Greenland and three in East Greenland. These include (1) large, low-grade magmatic deposits, (2) small syn- to epigenetic pyrochlore mineralisation related to alkaline syenite and carbonatite, and (3) small, high-grade epigenetic uraninite mineralisation hosted in fracture zones. Most of these are showings and prospects, with one (Kvanefjeld) that has a JORC-compliant reserve estimate. An evaluation of the potential for uranium deposits in Greenland is available at: https://eng.geus.dk/products-services-facilities/publications/minerals-in-greenland/geology-and-ore/geology-and-ore-28.

Unconventional resources and other materials

Unknown.

Uranium production

Historical review

No uranium has been produced in Greenland, however, 4 500 tonnes of ore was transported to the Risø National Laboratory, Denmark, for test work during the 1980s. Another 30 tonnes of ore was sent to Outokumpu, Finland, in 2014 where a pilot plant operation was conducted through the FP7 EURARE project.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

Greenland is part of the Danish Realm. Greenland enjoys autonomous authority in domestic affairs while Denmark remains constitutionally responsible for foreign affairs, defence and security. In 2009, the Act on Greenland Self-Government granted Greenland authority over its natural resources (Mineral Resources Act 2009). The Ministry of Mineral Resources and Labour (MMRL) is responsible for strategy and policymaking, legal issues, licence assessment, approvals and inspections, and marketing of mineral resources in Greenland. The Ministry of Industry, Energy and Research (MIER) is responsible for trade and export of mineral resources.

On 24 October 2013, the Greenland parliament, Inatsisartut, lifted a decades-long moratorium on mining radioactive elements, which has opened the way for potential future exploration of uranium and thorium.

Denmark and Greenland signed an agreement concerning the special foreign, defence and security policy issues related to the possible future mining and export of uranium in Greenland in January 2016. While Denmark is responsible for non-proliferation matters in Denmark, especially safeguards, security and dual-use exports, the agreement established a framework for a shared approach to ensure compliance with Denmark's international non-proliferation obligations. The agreement underlines the joint Danish and Greenlandic commitment to observe the highest international standards comparing with other uranium supplier states.

The agreement also served as a basis for the new Danish legislation for Greenland on safeguards and export controls, including export of nuclear material from Greenland, being subject to nuclear co-operation agreements to provide assurances that exports are properly protected and used for peaceful purposes. The Act no. 616 on export controls for Greenland and Act no. 621 on safeguards for Greenland were passed on 8 June 2016. The Executive Order on safeguard obligations for the peaceful use of nuclear material in Greenland was published on 10 July 2019.

As part of the agreement concerning the special foreign, defence and security policy issues related to the possible future mining and export of uranium in Greenland, the territorial restrictions regarding six nuclear conventions for Greenland are also in the process of being lifted. In 2019, the territorial restrictions for five of these nuclear conventions have been lifted. This includes:

- The International Convention for the Suppression of Acts of Nuclear Terrorism;
- The Convention on Assistance in Case of a Nuclear Accident or Radiological Emergency;
- The Convention on Nuclear Safety, Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management;
- The 2005 Amendment to the Convention on the Physical Protection of Nuclear Material;
- The International Labour Organisation Radiation Protection Convention (No. 115).

Uranium exploration and development expenditures and drilling effort – domestic

(AUD)

	2016	2017	2018	2019 (expected)
Industry* exploration expenditures[1]	2 001 000	2 567 000	3 936 000	2 653 000
Government exploration expenditures	NA	NA	NA	NA

* Non-government.

1. Total industry exploration expenditures; it is not possible to break the expenditures up according to the different commodities (e.g. U, etc.).

Reasonably assured conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Co-product and by-product				102 820	50*
Total				102 820	

* Recovery factor has been previously reported as 65%, but should have been reported as 50%, and is corrected here. Therefore, the recoverable resource reported in Chapter 1 has been updated to reflect this correction.

Reasonably assured conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from OP				102 820	50*
Total				102 820	

* Recovery factor has been previously reported as 65%, but should have been reported as 50%, and is corrected here. Therefore, the recoverable resource reported in Chapter 1 has been updated to reflect this correction.

Reasonably assured conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Intrusive*				102 820
Total				102 820

* Recovery factor has been previously reported as 65%, but should have been reported as 50%, and is corrected here. Therefore, the recoverable resource reported in Chapter 1 has been updated to reflect this correction.

Inferred conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Co-product and by-product	0	0	0	125 143	50*
Total	0	0	0	125 143	

* Recovery factor has been previously reported as 65%, but should have been reported as 50%, and is corrected here. Therefore, the recoverable resource reported in Chapter 1 has been updated to reflect this correction.

Inferred conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified	0	0	0	125 143	50*
Total	0	0	0	125 143	

* Recovery factor has been previously reported as 65%, but should have been reported as 50%, and is corrected here. Therefore, the recoverable resource reported in Chapter 1 has been updated to reflect this correction.

Inferred conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Intrusive*	0	0	0	125 143
Total	0	0	0	125 143

* Recovery factor has been previously reported as 65%, but should have been reported as 50%, and is corrected here. Therefore, the recoverable resource reported in Chapter 1 has been updated to reflect this correction.

Egypt

Uranium exploration and mine development

Historical review

Uranium exploration activity started in Egypt as early as 1956. Geophysical, radiometric and geologic exploration resulted in the discovery of many radioactive anomalies distributed across different geological environments in the Eastern Desert and Sinai.

Over the past several years and in several projects, uranium exploration activity resulted in the identification of the most prospective regions in the country. The uranium exploration programme was undertaken by the Egyptian Nuclear Materials Authority (NMA), which is the government body responsible for nuclear raw materials in the country. Uranium mineralisation was discovered in the northern part of the Gabal Gattar granite batholith by the NMA during the 1984-1985 field season. Within the framework of the resource evaluation programme, the first mining test shafts were excavated in 1998 and 1999 in the Sinai and Gabal Gattar prospects, respectively.

Uranium exploration and development expenditures and drilling effort – domestic

(Egyptian pounds – EGP)

	2016	2017	2018	2019 (expected)
Industry exploration expenditures	0	0	0	0
Government exploration expenditures	250 000	500 000	1 000 000	1 000 000
Industry development expenditures	0	0	0	0
Government development expenditures	NA	NA	500 000	500 000
Total expenditures	250 000	500 000	1 500 000	1 500 000
Industry exploration drilling (metres)	0	0	0	0
Industry exploration holes drilled	0	0	0	0
Industry exploration trenches (metres)	0	0	0	0
Industry trenches (number)	0	0	0	0
Government exploration drilling (metres)	0	1 000	1 500	2 000
Government exploration holes drilled	0	50	70	90
Government exploration trenches (metres)	0	160	360	480
Government trenches (number)	0	4	9	12
Industry development drilling (metres)	0	0	0	0
Industry* development holes drilled	0	0	0	0
Government development drilling (metres)	0	0	250	500
Government development holes drilled	0	0	12	22
Subtotal exploration drilling (metres)	0	0	0	0
Subtotal exploration holes drilled	0	0	0	0
Subtotal development drilling (metres)	0	0	0	0
Subtotal development holes drilled	0	0	0	0
Total drilling (metres)	0	1 000	1 750	2 500
Total number of holes drilled	0	50	82	112

Recent and ongoing uranium exploration and mine development activities

From 2016 to 2019, the NMA focused on the exploration of four prospects in the Eastern Desert and South Sinai. These activities involved exploratory trenching and shallow drilling programmes, supported by geophysical and geochemical surveys, to follow-up subsurface extensions of the formations hosting uranium mineralisation.

Granitic rocks are known to have a much higher uranium content than other common rock types, and uranium exploration activities led to the discovery of several uranium anomalies and occurrences within or near the periphery of some granitic plutons in the Eastern Desert of Egypt (e.g. Gabel Gattar, Gabel EI-Erediya, El Missikat and Um Ara areas). Secondary uranium minerals dominate the mineralogical composition of these deposits. Yellow mineral impregnations are found in fractured and albitised alkali-feldspar granites. The mineralisation occurs as stains along fracture surfaces and as acicular crystals filling cavities.

Uranium anomalies in southwestern Sinai are restricted to the early Carboniferous Bogma Formation. Uraniferous zones are associated with the lower and middle members of the Um Bogma Formation shales and dolomites.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

Abu Zenima project

Early Carboniferous succession of sandstones, claystones and siltstones host anomalous zones with secondary uranium mineralisation. The occurrences are found in several locations around Abu Zenima, western Gulf of Suez. The economic potential has not yet been fully assessed because of difficult drilling conditions. However, some target areas are now under development, where secondary uranium mineralisation was identified at the surface. Detailed geologic work, diamond drilling and test mine work is being conducted. A 2008 assessment reported in situ inferred resources of about 100 tU, hosted primarily in sandstones. Additional investigations from 2016 to 2019 increased in situ inferred resources to 515 tU.

Gabal Gattar project

This granite pluton, an elongated granite batholith trending over 40 km, is host to vein-type uranium mineralisation associated with molybdenite, defined in eight uraniferous occurrences. These occurrences are characterised by intense secondary uranium minerals with characteristic yellow to greenish-yellow colours. Nearly all the recorded uranium occurrences are associated with strongly deformed and deeply hematitised zones.

Uranium resources of 2 000 tU of in situ inferred resources were last reported in the 2009 Red Book for Gabal Gattar. In the last two years, the area has been the subject of some subsurface exploration work (deep trenching and shallow drilling) to follow-up prospective subsurface extensions of mineralisation and to correlate with surface occurrences. Thus far, no additional resource estimates have been made.

Undiscovered conventional resources (prognosticated and speculative resources)

Abu Rushid project

Uranium occurrences are associated with rare earth elements (REE) in the paragneiss and metamorphosed sandstones in the Abu Rushid project area. However, previous Red Book reports indicate that no speculative uranium resources were identified. Exploration activity in recent years has added an estimated potential of 1 365 tU as in situ prognosticated resources to the Abu Rushid area. The NMA intends to continue work by undertaking a drilling programme in the coming years.

El Sella project

Additional potential resources may be identified in the El Sella project area, where uranium exploration permits have been held over the past few years. Ongoing exploration is aimed at extending the existing orebody as well as identifying and evaluating new ore bodies, given the potential for additional resources. The area contains an estimated potential for 100 tU of in situ prognosticated uranium resources. Follow-up drilling is expected to continue through 2020-2022.

Unconventional resources and other materials

The Egyptian phosphate deposits represent one of the more promising unconventional uranium resources. Estimates of these phosphate ores reach about 700 million tonnes with uranium content ranging between 50-200 ppm (as reported in the 2009 Red Book). No reliable estimate of the uranium resources in Egyptian phosphate ores has been made since 2008, when it was reported in the 2009 Red Book that it is possible the deposits contain up to 42 000 tU.

Uranium production

Historical review

The development of a semi-pilot plant for uranium extraction at the Abu Zenima and Gattar projects has been completely suspended due to the difficulties in providing financial support for the projects.

Status of production facilities, production capability, recent and ongoing activities and other issues

The NMA is now, for the first time, preparing a strategy to begin work on a semi-pilot plant for uranium extraction by a heap and limited vat basin leaching process, after bench-scale testing, to develop optimised parameters for uranium extraction from phosphates. A semi-pilot plant has been successful in purifying phosphoric acid for agricultural, food-grade and other domestic purposes.

Inferred conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	0	0	2 000	
Open-pit mining (OP)	0	0	515	515	
In situ leaching acid	0	0	0	0	
In situ leaching alkaline	0	0	0	0	
Co-product and by-product	0	0	0	0	
Unspecified	0	0	0	0	
Total	0	0	515	2 515	

Inferred conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	515	515
Granite-related	0	0	0	2 000
Total	0	0	515	2 515

Prognosticated conventional resources

(tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
0	1 465	1 465

Speculative conventional resources

(tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
NA	NA	NA

Finland

Uranium exploration

Historical review

Uranium exploration in Finland was first carried out between 1955 and 1989, initially by the companies Atomienergia Oy, Imatran Voima Oy and Outokumpu Oy, and from 1973 by the Geological Survey of Finland (GTK). In the late 1980s, exploration activities were stopped. Exploration began again in the 2000s by Areva (now Orano) and some junior companies. In 2010, Areva closed down its Finnish subsidiary, and its exploration assets in Finland were purchased by Mawson Resources Ltd. Uranium exploration in Finland has slowed down since 2011, as Mawson's focus of exploration has shifted increasingly to gold.

Recent and ongoing uranium exploration

There is currently no uranium exploration in Finland.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

Finland reports a total of 1 500 tU of in situ reasonably assured conventional resources, recoverable at costs of USD 80-130/kgU in the Palmottu and Pahtavuoma uranium deposits. No inferred conventional resources are reported.

Undiscovered conventional resources (prognosticated and speculative resources)

None reported.

Unconventional resources

Unconventional resources of uranium in the Talvivaara black schist-hosted Ni-Zn-Cu-Co deposit are approximately 16 000 tU at an average grade of 0.0017% U in the measured and indicated resources of 970 Mt, and about 24 000 tU at an average grade of 0.0017% U in the total mineral resources (measured, indicated and inferred) of 1 458 Mt, calculated from the resource update 2016 by Terrafame Oy. In addition, subeconomic intrusive, quartzite-hosted, and polymetallic Au-Co-Cu-Fe-U uranium occurrences, as well as uraniniferous peat mineralisation, have been reported in the scientific literature.

Uranium production

Historical review

Uranium production in Finland has been confined only to the now remediated Paukkajanvaara mine that operated as a pilot-scale mine between 1958 and 1961. A total of 40 000 tonnes of ore was excavated and the concentrates produced amounted to about 30 tU. As reported in the NEA 2006 Red Book Retrospective, the total historical production calculated from the mining register statistics is no more than 41 tU from 1958 to 1961.

Uranium production centre technical details
(as of 1 January 2019)

	Centre #1
Name of production centre	Terrafame mine in Sotkamo
Production centre classification	Committed
Date of first production	2022
Source of ore:	
Deposit name(s)	Talvivaara (Kuusilampi and Kolmisoppi)
Deposit type(s)	Black schist
Recoverable resources (tU)*	7 200*
Grade (% U)	0.0017
Mining operation:	
Type (OP/UG/ISL)	OP
Size (tonnes ore/day)	41 000
Average mining recovery (%)	50
Processing plant:	
Acid/alkaline	Acid (heap leaching)
Type (IX/SX)	SX
Size (tonnes ore/day)	NA
Average process recovery (%)	90
Nominal production capacity (tU/year)	250
Plans for expansion	NA
Other remarks	Heap leaching by-product

* Overall recovery factor of 45% used in the estimate.

Future production centres

There is currently no uranium production in Finland. Between 2010 and 2015, Talvivaara Sotkamo Oy prepared for uranium recovery as a by-product from the Talvivaara deposit in Sotkamo, eastern Finland. The Talvivaara Ni-Zn-Cu-Co deposit is hosted by metamorphosed black shales in the Kainuu Schist Belt. It is a low-grade, large-tonnage deposit averaging 0.26 wt% Ni, 0.53 wt% Zn, 0.14 wt% Cu, 0.02 wt% Co, and 0.0017 wt% U.

Production of nickel, cobalt and zinc from the Talvivaara ore deposit commenced in 2008. The production process includes open-pit mining, crushing, heap leaching and metals recovery. The leach solution percolates to the bottom of the leach pads and is either recirculated through the heap or fed to metals recovery. During metals recovery, zinc, nickel and cobalt are precipitated from the pregnant leach solution (PLS) and filtered to produce saleable metal products. After the target metals have been recovered, the solution is further purified to remove unwanted metals, which are directed to process waste gypsum ponds.

In 2010, Talvivaara Sotkamo Oy announced plans to recover uranium as a by-product using solvent extraction, resulting from the fact that a large part of uranium dissolves in the PLS during heap leaching. Dissolved uranium has largely ended up in the process wastes and partly in the Ni-Co sulphide concentrate product. Uranium has been present as an impurity in the Ni-Co sulphide consigned to the Norilsk Nickel refinery at Harjavalta, western Finland. Uranium residuals have been extracted from the nickel products at Harjavalta Nickel Refinery, and reported to the Radiation and Nuclear Safety Authority (STUK). Norilsk Nickel Harjavalta refinery has been licensed by the STUK to extract uranium at less than 10 tU/year. As of 31 December 2018, the total amount of natural uranium stored at Norilsk Nickel Harjavalta was about 3.6 tU.

During 2011-2013, the uranium solvent extraction plant was built as a new unit in the metals recovery complex of Talvivaara. In March 2012, the Finnish government granted a uranium extraction licence to Talvivaara Sotkamo Oy in accordance with the nuclear energy legislation. In December 2013 however, the Supreme Administrative Court returned the licence to the Finnish government for reassessment due to several changes in the operations of Talvivaara Sotkamo Oy after the licence decision, including the corporate reorganisation. In November 2014, Talvivaara Sotkamo Oy filed for bankruptcy as a result of financial problems. In August 2015, state-owned company Terrafame Oy acquired the operations and assets of Talvivaara Sotkamo Oy from its bankruptcy estate, and as of 1 January 2019, was carrying on the mining operations in Sotkamo.

In October 2017, Terrafame Oy applied to the Finnish government for a licence to recover uranium as a by-product at Terrafame's mine in Sotkamo, in accordance with the nuclear energy legislation. In February 2020, the Finnish government granted a uranium extraction licence to Terrafame. However, the licence is not yet in legal force due to an ongoing appeal process. The mine site currently includes an almost fully completed uranium solvent extraction plant from the time of Terrafame's predecessor, Talvivaara Sotkamo Oy. Terrafame expects to start uranium production in Sotkamo in 2022, after completion of licensing processes.

Secondary sources of uranium

Production and/or use of mixed oxide fuels

Finland does not produce or use mixed oxide fuels.

Production and/or use of re-enriched tails

Re-enriched tails have not been used in 2017 and 2018.

Regulatory regime

The Mining Act regulates exploration and mining activities in Finland. All licences under the Mining Act are decided by the mining authority Tukes. An environmental permit according to the Environmental Protection Act is required for mining. The mine closure process is regulated by mining and environmental legislation, as well as a number of EU and other specifications.

The Radiation and Nuclear Safety Authority (STUK) is the regulatory body for uranium production, as specified in the Nuclear Energy Act and the Radiation Act. Production of uranium or thorium needs a licence from the Finnish government according to the Nuclear Energy Act. A licence application must be submitted to the government. Statements from different authorities (including STUK) are required for the decision on the licence, which is prepared by the Ministry of Economic Affairs and Employment and decided by the government.

According to the Mining Act of 2011, an exploration licence is required for uranium exploration (e.g. for drilling and trenching). Permit applications concerning a uranium mine under the Mining Act and the Nuclear Energy Act are handled jointly and decided on in a single decision by the government. The granting of a permit for a uranium mine requires that the mining activities are in line with the overall good of society, the municipality in question has given its consent, and safety requirements are fulfilled.

STUK's regulatory control covers radiation exposure of workers and the public, environmental monitoring, waste management, emergency preparedness, nuclear material accountancy and physical protection of nuclear materials. STUK verifies that safety and security requirements are fulfilled. Radioactive tailings are regarded as nuclear waste and are subject to funding for the future costs of waste management. Uranium concentrate export, controlled by the Ministry for Foreign Affairs, is also subject to national and international safeguards control.

The environmental impact assessment procedure is applied to all uranium mining projects, without any limitations on the annual amount of the extracted resources. In addition, other legislation to be applied for mining activities includes the Water Act, the Nature Conservation Act, the Wilderness Act, the Chemicals Act, the Land Use and Building Act, the Occupational Safety and Health Act, the Waste Act and various government decrees and decisions.

Uranium requirements

Four units (two each at the Olkiluoto and Loviisa NPPs) with a total generating capacity of 2.8 GWe (net) are in operation, providing about 32% of domestic electricity generation. These four reactors require about 440 tU annually. Olkiluoto units are owned and operated by Teollisuuden Voima Oyj (TVO), Loviisa units by Fortum Power and Heat Oy.

TVO's Olkiluoto 3 European pressurised reactor (EPR; 1.6 GWe net) is under construction. TVO selected EPR technology for Olkiluoto 3 in 2003 and Areva-Siemens Consortium started the construction works in 2005. According to the plant supplier Areva-Siemens Consortium, the start of the regular electricity production of the Olkiluoto 3 nuclear power plant unit is scheduled to being in February of 2022, 13 years later than originally planned.

In 2010, the Finnish parliament ratified the decisions in principle (DIP) for the construction of two new reactors, one at the existing Olkiluoto site (OL4) by TVO and a single reactor at the greenfield Pyhäjoki site by Fennovoima. According to the DIP, the deadline for submitting the applications for the construction licences of these units was the end of June 2015.

In June 2015, TVO decided not to apply for a construction licence for OL4 during the validity of the decision in principle made in 2010. The reason was the delay of the start-up of Olkiluoto 3 power plant unit. Consequently, the decision in principle made by the Finnish government and approved by parliament expired at the end of June 2015. TVO will remain prepared to apply for a new decision in principle for OL4. The application is subject to a separate decision.

Fennovoima is a new nuclear power company, established by a group of Finnish companies in 2007. Fennovoima will build a nuclear power plant unit (Hanhikivi 1) in Pyhäjoki, northern Finland. Fennovoima has two main owners: Voimaosakeyhtiö SF Oy (66%) and Rosatom's subsidiary RAOS Voima Oy (34%). Voimaosakeyhtiö SF is owned by Finnish energy and industrial companies.

A construction licence application for Fennovoima's Hanhikivi 1 nuclear power plant unit was submitted to the Finnish government in June 2015. Fennovoima expects that the construction licence for the Hanhikivi 1 reactor will be granted by the government by 2021, and for commercial operation to start in 2028. The nuclear power plant unit of Fennovoima (AES-2006; 1.2 GWe net) will be supplied by RAOS Project Oy, which is a part of Rosatom.

Supply and procurement strategy

TVO procures its nuclear fuel for the Olkiluoto nuclear power plant through a decentralised supply chain, entering into negotiations and making procurement contracts with each separate supplier at the various stages of the fuel production chain. There are several suppliers for each stage of the chain. Procurement operations are based on long-term contracts with suppliers. These companies have mining operations in many countries. The majority of the uranium procured by TVO comes from Kazakhstan, Canada, and Australia, and the fuel elements ordered by the company are constructed and assembled in Germany or Sweden.

The fuel assemblies used at the Fortum's Loviisa nuclear power plant are completely of Russian origin. Nuclear fuel is acquired from the Russian TVEL as a turnkey delivery, from the acquisition of the uranium to the production of the fuel assemblies. Conversion, enrichment and fuel fabrication are carried out by TVEL, which acquires the uranium used in the fuel assemblies from ARMZ Uranium Holding Co. In 2018, the uranium used in the Fortum's fuel assemblies originated from the Krasnokamensk, Khiagda and Dalur mines. The quality, environmental, and health and safety management systems of nuclear fuel suppliers and the production of the uranium and fuel assemblies are regularly assessed by Fortum. In 2018, Fortum's representatives assessed the operations of Fortum's Russian fuel supplier's uranium mine.

Fennovoima will acquire the nuclear fuel as an integrated fuel supply from TVEL. The integrated delivery will cover the procurement of the uranium and the manufacturing of the fuel for the first ten years of Hanhikivi 1 operation. Fuel supply agreement between Fennovoima and TVEL was approved by the Euratom Supply Agency in 2014. Fennovoima has chosen to use reprocessed uranium during the first years of operation.

Uranium policies, uranium stocks and uranium prices

Nuclear energy legislation

The Finnish Nuclear Energy Act requires that the use of nuclear energy must be safe and benefit society as a whole. It must not cause injury to people or damage to property or the environment. The use of nuclear energy creates several obligations for the licensee: the licensee must, among other things, ensure the safety of operations, manage the nuclear waste created through the operations, and assume responsibility for all nuclear waste management costs. Nuclear waste management costs are prepared for by collecting funds in advance in the price of electricity and depositing them in the Finnish State Nuclear Waste Management Fund.

The Nuclear Energy Decree and government decisions have been issued based on the Nuclear Energy Act. The government decisions concern nuclear plant safety, safety arrangements, preparedness arrangements, and the final disposal of operating waste and spent nuclear fuel. Based on the authorisation by the nuclear energy legislation, the STUK publishes YVL guides that set out the detailed safety requirements for the use of nuclear energy, and the supervisory practices adopted by the STUK. Radiation safety is regulated by the Radiation Act and the Radiation Decree. The Nuclear Liability Act stipulates that the licensee must have nuclear liability insurance that will compensate for injuries caused to outsiders by a possible nuclear accident, to the extent decreed by law.

Nuclear waste management

Spent nuclear fuel from the Olkiluoto and Loviisa nuclear power plants is stored in the water pools of the fuel storage facilities at Olkiluoto and Loviisa until finally disposed of in bedrock of Olkiluoto in Eurajoki. Posiva Oy, owned by TVO and Fortum, is responsible for the final disposal of spent nuclear fuel of the owners. Spent nuclear fuel from the nuclear power plants of TVO and Fortum will be packed in copper canisters and embedded in Olkiluoto bedrock at a depth of 400-450 m. The final disposal of spent nuclear fuel is based on the use of multiple release barriers to ensure that the nuclear waste cannot be released into organic nature or become accessible to humans. The release barriers include the physical state of the fuel, the disposal canister, the bentonite buffer, the backfilling of the tunnels and the surrounding rock.

In November 2015, the government granted Posiva Oy a licence for the construction of an encapsulation plant and disposal facility for spent nuclear fuel. In November 2016, the STUK decided that Posiva can start the construction of the final disposal facility at Olkiluoto in the municipality of Eurajoki.

Before the actual commencement of final disposal operations for spent nuclear fuel, an operation licence from the government is required for the encapsulation plant and final disposal facility. Posiva plans to submit the operation licence application in 2020. The final disposal is scheduled to start in 2020s. According to current plans, the repository would be sealed up by the 2120s.

An environmental impact assessment (EIA) programme for the final disposal of Fennovoima’s spent nuclear fuel was submitted to the Ministry of Economic Affairs and Employment in June 2016. The alternative final disposal locations in Fennovoima’s EIA programme are Pyhäjoki and Eurajoki. Fennovoima’s goal is to achieve long-term co-operation with Posiva and the current companies liable for nuclear waste management (TVO and Fortum). In December 2016, the ministry ruled that Fennovoima should continue co-operation with the current nuclear waste management custodians. The ministry noted that the most desirable solution for Fennovoima’s spent nuclear fuel would be the disposal in Posiva’s final disposal facility in Eurajoki.

Uranium stocks

The nuclear power utilities maintain reserves of fuel assemblies from seven months to one year’s use, although the legislation demands only five months’ use.

Uranium prices

Due to commercial confidentiality, price data are not available.

Reasonably assured conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Underground mining (UG)	0	0	500	500
Open-pit mining (OP)	0	0	1 000	1 000
Total	0	0	1 500	1 500

Reasonably assured conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Conventional from UG	0	0	500	500
Conventional from OP	0	0	1 000	1 000
Total	0	0	1 500	1 500

Reasonably assured conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Metamorphite	0	0	500	500
Intrusive	0	0	1 000	1 000
Total	0	0	1 500	1 500

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Open-pit mining	15	0	0	0	15	0
Underground mining	15	0	0	0	15	0
Total	30	0	0	0	30	0

Historical uranium production by processing method

(tonnes U in concentrates)

Processing method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Conventional	30	0	0	0	30	0
Total	30	0	0	0	30	0

Historical uranium production by deposit type

(tonnes U in concentrates)

Deposit type	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Sandstone	30	0	0	0	30	0
Total	30	0	0	0	30	0

Re-enriched tails production and use

(tonnes natural U-equivalent)

Re-enriched tails	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Production	0	0	0	0	0	0
Use	843	0	0	0	843	0

Net nuclear electricity generation

	2017	2018
Nuclear electricity generated (TWh net)	21.6	21.9

Installed nuclear generating capacity to 2040

(MWe net)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
2 760	2 760	4 380	4 380	4 380	4 540	5 080	5 240	4 580	4 740	2 800	2 800

Annual reactor-related uranium requirements* to 2040 (excluding MOX)

(tonnes U)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
446	430	690	750	590	760	700	780	700	780	450	530

* Refers to natural uranium acquisitions, not necessarily consumption during the calendar year.

France

Uranium exploration and mine development

Historical review

Uranium exploration began in 1946, focusing on previously discovered deposits and a few occurrences discovered during radium exploration. In 1948, exploration led to the discovery of the La Crouzille deposit, which at one time was of major importance. By 1955, additional deposits had been identified in the granite areas of Limousin, Forez, Vendée and Morvan. Prospecting activities were subsequently extended to sedimentary formations in small intra-granitic basins and terrigeneous formations derived from eroded granite mountains, mainly located north and south of the Massif Central.

Recent and ongoing uranium exploration and mine development activities

No domestic activities have been carried out in France since 1999.

As of 2018, Orano S.A. (formerly Areva S.A.) has been working outside France focusing on discovery of exploitable resources in Canada, Gabon, Kazakhstan, Mongolia, Namibia and Niger. In Canada, Kazakhstan, Namibia and Niger, Orano is involved in uranium mining operations and exploration projects. In addition, as a non-operator, it holds shares in several mining operations and research projects in different countries.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

Orano no longer reports resources or reserves in France since the historic data on which these estimates are based do not conform to modern international standards.

Undiscovered conventional resources (prognosticated and speculative resources)

No systematic appraisal has been made of undiscovered resources.

Uranium production

Status of production facilities, production capability, recent and ongoing activities and other issues

Following the closure of all uranium mines in 2001, all ore processing plants were shut down, dismantled and the sites reclaimed. Only a few tonnes of uranium per year are recovered from resins during the water cleaning process at the outflow of the former Lodève mine in the South of France. The resins are eluted at the Malvési refinery, where the uranium is recovered.

In France, a total of 244 sites, ranging from exploration sites to mines of various sizes, 8 mills and 17 tailings deposits (containing a total of 52 Mt of tailings) are the result of the production of about 80 000 tU. All of these sites have been remediated. Monitoring continues at only the most important sites, and 17 water treatment plants were installed to clean drainage from the sites. Orano is responsible for the management of 234 of these sites.

The purpose of remediation is to:

- ensure public health and safety;
- limit the residual impact of previous activities (ALARA);
- integrate the industrial sites into landscape;
- maintain a dialogue and consultation with local populations;
- allow the reconversion of the former sites to new activities (Tourism, industry, agriculture, energy (Solar panels).

Future production centres

There are no plans to develop new production centres in France in the near future.

Secondary sources of uranium

Production and/or use of mixed oxide fuels

The annual licensed capacity of MOX fuel production in France is about 195 tHM, roughly corresponding to 1 560 tU equivalent (tNatU) using the recommended Red Book conversion factor. Actual yearly production of MOX in France varies below this licensed capacity in accordance to contracted quantities. Most of the French MOX production is used to fuel French NPPs (a total of about 120 t/yr, or 960 tNatU) and the remainder is delivered abroad under long-term contract arrangements.

Production and/or use of reprocessed uranium

In France, reprocessed uranium is produced at the la Hague reprocessing plant. The annual production from Électricité de France (EDF) of spent fuel is around 1 000 tU. Reprocessed uranium was recycled at the EDF nuclear power plant of Cruas. The last fuel assemblies containing reprocessed uranium were loaded in 2013. EDF signed in 2018 contracts for the recycling, starting 2023, of reprocessed uranium (RepU) for use in PWRs. This solution enables EDF to diversify its uranium supply sources, allowing for savings of around 10-15% of its natural uranium requirements. It also ensures completeness of the French nuclear cycle, by reusing 96% of the nuclear material contained in spent fuel.

Regulatory regime

In France, mines are nationally regulated according to the mining code and processing plants according to regulations specified in the legislation governing the operation of installations that present environmental risks (ICPE – *installation classée pour la protection de l'environnement*). These regulations are applied by regional environmental authorities (DREAL – Directions régionales de l'Environnement, de l'Aménagement et du Logement) on behalf of the prefect (the state representative in a particular department or region).

In order to open a mine, the mining company must present a report to the regional authorities that will allow them to confirm that the project will be operated in accordance with all regulations. Once this is confirmed, a public enquiry must be held. If these processes are successfully completed, the mining company will be allowed to open the mine according to requirements laid out in an *Ordre du Préfet*. When mining is completed, the mining company must prepare a report for local authorities who can then give authorisation for decommissioning through an *Ordre du Préfet*.

In theory, according to the mining code, after remediation and a period of monitoring to verify that there is no environmental impact, the mining company can transfer the responsibility of the site to the state. However, if there is a problem, the state asks the mining company to remediate it.

After decommissioning, the mining company retains responsibility for the site, including monitoring and maintenance. There has not been a transfer of responsibility for a uranium mine from the mining company to the state because Orano is always present. However, Orano is in discussion with the authorities regarding the transfer of responsibility.

The cost of mine remediation is the responsibility of the mining company. In the case of processing plants (mills), local authorities request financial guarantees for the costs of all remediation works and monitoring. A draft revision of the mining code is currently under development.

Uranium requirements

France has 58 nuclear power reactors in operation (supplying 63 130 MWe) and one EPR reactor under construction at the Flamanville site. The development strategy for nuclear power is related to the goals set forth by the Energy Transition for Green Growth Act and the Multiyear Energy Plan (MEP). The draft of the MEP covering the period 2019-2028 was published in January 2019: A total of 14 power reactors are planned to be shut down in order to reduce the share of nuclear in France's electricity generation mix from the current 75% to 50% by 2035. Regarding new reactors, the MEP asks the government to work on different electric mix options, with or without nuclear energy.

Construction of the 1.6 GWe Flamanville 3 EPR began in late 2007. To date, commissioning cannot be expected before the end of 2022.

In 2006, Areva began work at the Tricastin site on construction of the Georges Besse II uranium centrifuge enrichment plant to replace the Eurodif gaseous diffusion plant that has been in service since 1978. In 2012, production at the Eurodif plant was stopped and the facility will be dismantled in the coming years. The Georges Besse II facility successfully reached its full production capacity of 7.5 million SWUs in 2016, on schedule as planned. The most recent qualification tests carried out have confirmed the performance capabilities of the plant's equipment with its industrial facilities showing rates of efficiency in excess of 99%.

Supply and procurement strategy

Since France is a net importer of uranium, its policy towards procurement is one of supply diversification. French entities participate in uranium exploration and production outside France within the regulatory framework of the host countries. Uranium is also purchased under short- or long-term contracts, either from mines in which French entities have shareholdings or from mines operated by third parties.

Uranium policies, uranium stocks and uranium prices

Uranium stocks

EDF possesses strategic uranium inventories, the minimum level of which has been fixed at the equivalent of a few years' forward consumption to offset possible supply interruptions.

Uranium prices

Information on uranium prices is not available.

Uranium exploration and development expenditures – non-domestic

(EUR millions)

	2016	2017	2018	2019 (expected)
Industry* exploration expenditures	34	35	35	30
Government exploration expenditures	0	0	0	0
Industry* development expenditures	NA	NA	NA	NA
Government development expenditures	0	0	0	0
Total expenditures	34	35	35	30

* Non-government.

Historical uranium production by production method

(tonnes U in ores)

Production method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Open-pit mining[1]	5 427	0	0	0	5 427	0
Underground mining[1]	1 511	0	0	0	1 511	0
Open-pit and underground[2]	73 925	0	0	0	73 925	0
Co-product/by-product	110	3	2	0	115	2
Total	80 973	3	2	0	80 978	2

1. Pre-2015 totals may include uranium recovered by heap and in-place leaching.

2. Not possible to separate in historic records.

Historical uranium production by processing method

(tonnes U in concentrates)

Processing method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Conventional	80 863	0	0	0	80 863	0
Other methods*	110	3	2	0	115	2
Total	80 973	3	2	0	80 978	2

* Includes mine water treatment and environmental restoration.

Historical uranium production by deposit type

(tonnes U in ores)

Deposit type	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Sandstone	16 781	0	0	0	16 781	0
Granite-related	63 683	0	0	0	63 683	0
Metamorphite	395	0	0	0	395	0
Volcanic-related	1	0	0	0	1	0
Black shale	3	0	0	0	3	0
Other/unspecified	110	3	2	0	115	2
Total	80 973	3	2	0	80 978	2

MOX production and use*

(tonnes natural U-equivalent)

Mixed-oxide (MOX) fuel	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Production	21 781	992	880	744	24 397	870
Use	NA	960	712	582	NA	NA
Number of commercial reactors using MOX		22	22	22		22

* Includes Cadarache historical production and Marcoule production adjustment.

Reprocessed uranium use

(tonnes natural U-equivalent)

Reprocessed uranium	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Production	25 904	1 026	1 026	1 026	28 982	1 026
Use	5 300	0	0	0	5 300	0

Net nuclear electricity generation

	2017	2018
Nuclear electricity generated (TWh net)	379.1	393.2

Installed nuclear generating capacity to 2040

(GWe net)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
63	63	63	63	63	63	NA	NA	NA	NA	NA	NA

Annual reactor-related uranium requirements to 2040 (excluding MOX)

(tonnes U)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
8 300	7 370	7 400	7 400	6 900	6 900	5 400	NA	4 500	NA	NA	NA

Germany

Uranium exploration and mine development

Historical review

After World War II, and until reunification in 1990, exploration for uranium occurred in two separate countries in what is today Germany:

Former German Democratic Republic (GDR; "East Germany") before 1990

Uranium exploration and mining were undertaken from 1946 to 1953 by the Soviet stock company, SAG Wismut. These activities were centred around old mining locations of silver, cobalt, nickel and other metals in the Erzgebirge (Ore Mountains) and in Vogtland, Saxony, where uranium had first been discovered in 1789.

Uranium exploration had started in 1950 in the vicinity of the radium spa at Ronneburg. Using a variety of ground-based and aerial techniques the activities covered an extensive area of about 55 000 km^2 in the southern part of the GDR. About 36 000 holes in total were drilled in an area covering approximately 26 000 km^2. Total expenditures for uranium exploration over the life of the GDR programme were on the order of 5.6 billion GDR marks.

Uranium mining first began shortly after World War II in cobalt and bismuth mines near Schneeberg and Oberschlema (a former famous radium spa). During this early period more than 100 000 people were engaged in exploration and mining activities. The rich uraninite and pitchblende ore from the vein deposits was hand-picked and shipped to the USSR for further processing. Lower-grade ore was treated locally in small processing plants. In 1950, the central mill at Crossen near Zwickau, Saxony was brought into operation.

In 1954, a new joint Soviet-German stock company was created, Sowjetisch-Deutsche Aktiengesellschaft Wismut (SDAG Wismut). The joint company was held equally by both governments. All production was shipped to the USSR for further treatment. The price for the final product was simply agreed upon by the two partners. Profits were used for further exploration.

At the end of the 1950s, uranium mining was concentrated in the region of Eastern Thuringia. From the beginning of the 1970s, the mines in Eastern Thuringia provided about two-thirds of SDAG Wismut's annual production.

Between the mid-1960s and the mid-1980s, about 45 000 people were employed by SDAG Wismut. In the mid-1980s, Wismut's employment decreased to about 30 000. In 1990, only 18 000 people worked in uranium mining and milling and the number of employees has declined since as remediation activities are completed.

Federal Republic of Germany (FRG; "West Germany") before 1990

Starting in 1956, exploration was carried out in several areas of geological interest: the Hercynian Massifs of the Black Forest, Odenwald, Frankenwald, Fichtelgebirge, Oberpfalz, Bayerischer Wald, Harz, the Paleozoic sediments of the Rheinisches Schiefergebirge, the Permian volcanics and continental sediments of the Saar-Nahe region and other areas with favourable sedimentary formations.

The initial phase included hydrogeochemical surveys, car borne surveys, field surveys, and, to a lesser extent, airborne prospecting. Follow-up geochemical stream sediment surveys, radon surveys and detailed radiometric work, followed by drilling and trenching, were carried out in promising areas. During the reconnaissance and detailed exploration phases both the federal and state geological surveys were involved, whereas the actual work was carried out mainly by industrial companies.

Three deposits of economic interest were found: (1) the partly high-grade hydrothermal deposit near Menzenschwand in the southern Black Forest, (2) the sedimentary Müllenbach deposit in the northern Black Forest, and (3) the Grossschloppen deposit in north-eastern Bavaria. Uranium exploration ceased in Western Germany in 1988 but by then about 24 800 holes had been drilled, totalling about 354 500 m. Total expenditures were on the order of USD 111 million.

Recent and ongoing uranium exploration and mine development activities

There have been no exploration activities in reunified Germany since the end of 1990. Several German mining companies, however, did perform exploration abroad (mainly in Canada) through 1997.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

Identified conventional resources were last assessed in 1993. These identified conventional resources occur mainly in the closed mines that are in the process of being decommissioned. Their future availability remains uncertain.

Undiscovered conventional resources (prognosticated and speculative resources)

All undiscovered conventional resources are reported as speculative resources in the cost category <USD 260/kgU.

Unconventional resources and other materials

None reported.

Uranium production

Historical review

Federal Republic of Germany (FRG; "West Germany") before 1990

In the FRG, a small (125 tonnes per year) uranium processing centre in Ellweiler, Baden-Württemberg began operating in 1960 as a test mill. It was closed on 31 May 1989 after producing a total of about 700 tU.

Former German Democratic Republic (GDR; "East Germany") before 1990

Two processing plants were operated by SDAG Wismut in the territories of the former GDR. A plant at Crossen, near Zwickau in Saxony, started processing ore in 1950. The ore was transported by road and rail from numerous mines in the Erzgebirge. The composition of the ore from the hydrothermal deposits required carbonate pressure leaching. The plant had a maximum capacity of 2.5 million tonnes of ore per year. Crossen was permanently closed on 31 December 1989.

The second plant at Seelingstadt, near Gera, Thuringia, started ore processing operations in 1960 using the nearby black shale deposits. The maximum capacity of this plant was 4.6 million tonnes of ore per year. Silicate ore was treated by acid leaching until the end of 1989.

Carbonate-rich ores were treated using the carbonate pressure leaching technique. After 1989, Seelingstadt's operations were limited to the treatment of slurry produced at the Königstein mine using the carbonate method.

A total of over 200 000 tU was produced in the GDR between 1950 and 1989.

Status of production facilities, production capability, recent and ongoing activities and other issues

There is no commercial production of uranium in Germany today. Decommissioning of the historic German production facilities started in 1989 (former FRG) and 1990 (former GDR). Between 1991 and 2018, uranium recovery from mine water treatment and environmental restoration amounted to a total of 2 679 tU. Since 1992, all uranium production in Germany has been derived from the clean-up operations at the Königstein mine. In 2018, conversion work of the water treatment facility at the Königstein mine halted uranium production. The facility will be adapted to future requirements, with the technological process stage of selective uranium separation being eliminated.

Ownership structure of the uranium industry

The production facilities in the former GDR were owned by the Soviet-German company Wismut (SDAG Wismut). After reunification, the German Ministry of Economy inherited the ownership from SDAG Wismut. The German federal government through Wismut GmbH took responsibility for the decommissioning and remediation of all production facilities. The government retains ownership of all uranium recovered in clean-up operations.

In August 1998, Cameco completed its acquisition of Uranerz Exploration and Mining Ltd (UEM), Canada, and Uranerz USA Inc. (UUS), from their German parent company Uranerzbergbau GmbH (Preussag and Rheinbraun, 50% each). As a result, there remains no commercial uranium industry in Germany.

Employment in the uranium industry

All employment is engaged in decommissioning and rehabilitation of former production facilities. Employment decreased within the last four years from 1 043 in 2016 to 1 010 in 2018.

Future production centres

None reported.

Uranium policies, uranium stocks and uranium prices

According to the energy concept 2010, the federal government decided to phase out use of nuclear power for commercial electricity generation on a staggered schedule. With the adoption of the Thirteenth Act amending the Atomic Energy Act (*Dreizehntes Gesetz zur Änderung des Atomgesetzes*), all reactors will be shut down by no later than the end of 2022. The German Bundestag (parliament) passed the amendment on 30 June 2011 and it came into force on 6 August 2011. For the first time in the modern history of Germany, a fixed deadline has been laid down in law for the end of the use of nuclear power in the country. The withdrawal is to be undertaken in stages with specific shutdown dates.

A total of 37 nuclear power plants have been built in Germany and put into commercial operation since 1962. In 2018, there were seven nuclear power plants operating with installed generating capacity of approximately 9.5 GW. The final shutdown schedule for these seven remaining nuclear power plants are as follows: 2019, Philippsburg 2; 2021, Grohnde, Gundremmingen C and Brokdorf; and 2022, the three newest nuclear power plants, Isar 2, Emsland and Neckarwestheim 2.

Reasonably assured conventional resources by production method
(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified				3 000	
Total				3 000	

Reasonably assured conventional resources by processing method
(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified				3 000	
Total				3 000	

Inferred conventional resources by production method
(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified				4 000	
Total				4 000	

Inferred conventional resources by processing method
(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified				4 000	
Total				4 000	

Historical uranium production by processing method
(tonnes U in concentrates)

Processing method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Other methods*	2 600	45	34	0	2 679	30
Total	219 686	45	34	0	219 765	

* Includes mine water treatment and environmental restoration.

Speculative conventional resources
(tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
		74 000

Ownership of uranium production in 2018

Domestic				Foreign				Totals	
Government		Private		Government		Private			
(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)
0	100							0	100

Uranium industry employment at existing production centres

(person-years)

	2016	2017	2018	2019 (expected)
Total employment related to existing production centres	1 043	1 031	1 010	982
Employment directly related to uranium production	NA	NA	NA	NA

Mixed oxide fuel production and use

(tonnes natural U-equivalent)

Mixed oxide (MOX) fuel	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Production	0	NA	NA	NA	NA	NA
Use	6 730	NA	NA	NA	NA	NA
Number of commercial reactors using MOX		NA	NA	NA		

* Reactors loading fresh MOX.

Re-enriched tails production and use

(tonnes natural U-equivalent)

Re-enriched tails	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Production	NA	NA	NA	NA	NA	NA
Use	NA	0	0	0	0	0

Reprocessed uranium use

(tonnes natural U-equivalent)

Reprocessed uranium	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Production	NA	0	0	0	0	0
Use	NA	NA	NA	NA	NA	NA

Net nuclear electricity generation

	2017	2018
Nuclear electricity generated (TWh net)	72.2	71.9

Installed nuclear generating capacity to 2040

(MWe net)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
10 800	9 515		8 100		0		0		0		0

Annual reactor-related uranium requirements to 2040 (excluding MOX)

(tonnes U)

2016	2017	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
1 747	1 644		NA-1 644		0		0		0		0

Total uranium stocks

(tonnes natural U-equivalent)

Holder	Natural uranium stocks in concentrates	Enriched uranium stocks	Enrichment tails	LWR reprocessed uranium stocks	Total
Government	NA	NA	NA	NA	NA
Producer	NA	NA	NA	NA	NA
Utility	NA	NA	NA	NA	NA
Total	NA	NA	NA	NA	NA

Hungary

Uranium exploration and mine development

Historical review

The first reconnaissance for uranium started in 1952 when, with Soviet participation, material from Hungarian coal deposits was checked for radioactivity. The results of this work led to a geophysical exploration programme (airborne and surface radiometry) in 1953 over the western part of the Mecsek Mountains. The discovery of the Mecsek deposit was made in 1954 and further work was aimed at the evaluation of the deposit and its development. The first shafts were excavated in 1955 and 1956 for the mining of sections I and II. In 1956, the Soviet-Hungarian uranium joint venture was dissolved and the project became the sole responsibility of the Hungarian state. That same year, uranium production began. Production began to decline in the late 80’s and ended after 1998.

Recent and ongoing uranium exploration and mine development activities

The non-governmental exploration started in 2007 with a focus in the Mecsek Mountains, in the area of the Mecsek deposit. In 2017, a borehole was drilled to the depth of 950 m, intersecting uranium mineralisation. By the end of 2017, a summary report of this exploration effort, including all activities from 2007 to 2017, was submitted to the Mining Authority and approved. Environmental licensing of the planned uranium ore mining and milling at the Mecsek deposit is currently on hold pending late submission of additional documents. If a licence is obtained, a mining property will be established and likely merged with the existing, historic mining properties in the area.

Uranium resources

Hungary’s reported uranium resources are limited to those of the Mecsek deposit. The ore is hosted by Upper Permian sandstones with a thickness of up to 600 m. During Cretaceous time, the Permo-Triassic sandstones were folded into an anticline that makes up the framework structure of the Mecsek Mountains. The ore-bearing sandstone in the upper 200 m of the unit is underlain by a very thick Permian siltstone and covered by Lower Triassic sandstone. The thickness of the green-grey ore-bearing sandstone, locally referred to as the “productive complex”, varies from 15 to 90 m. The ore minerals include uranium oxides and silicates associated with pyrite and marcasite.

Identified conventional resources (reasonably assured and inferred resources)

Identified conventional in situ resources amount to a total of 17 946 tU, according to the Hungarian National Mineral Resource Inventory, the same as reported in the previous three editions of the Red Book (note all are inferred resources, no RAR are reported). However, the non-governmental exploration report in 2017 indicated an increase of identified resources by 2 271 tU compared to the historic resources of the same area. This resource update in the National Inventory is ongoing and not yet confirmed.

Undiscovered conventional resources (prognosticated and speculative resources)

Prognosticated resources amount to a total of 13 427 tU, the same as reported in the previous three editions of the Red Book. However, the non-governmental exploration report in 2017 indicated an increase of prognosticated resources by 2 979 tU compared to the historic resources of the same area. This resource update in the National Inventory is ongoing and not yet confirmed. These resources are tributary to the former Mecsek production centre. Speculative resources are not estimated.

Uranium production

Historical review

The Mecsek underground mine and mill situated near the city of Pécs was the only uranium production centre in Hungary. Prior to 1 April 1992, it was operated by the state-owned Mecsek Ore Mining Company (MÉV). The mine began operation in 1956 and produced ore from a depth of 100 to 1 100 m until it was ultimately shut down in 1997. During operation, it produced about 500 000-600 000 tonnes ore/yr with an average mining recovery of 50-60%. The ore processing plant had a capacity of 1 300 to 2 000 tonnes ore/day and employed radiometric sorting, agitation acid leach (and alkaline heap leaching) with ion-exchange recovery. The nominal production capacity of the plant was about 700 tU/yr.

The Mecsek mine consisted of five sections with the following history:

- section I: operating from 1956 to 1971;
- section II: operating from 1956 to 1988;
- section III: operating from 1961 to 1993;
- section IV: operating from 1971 to 1997;
- section V: operating from 1988 to 1997.

The ore processing plant became operational in 1963. Prior to its operation, 1.2 million tonnes of unprocessed ore was shipped to the Sillimae metallurgy plant in Estonia. After 1963, processed uranium concentrates were shipped directly to the former Soviet Union.

Mining and milling operations were shut down at the end of 1997 because changes in market conditions made the operation uneconomic. Throughout its operational history, total production from the Mecsek mine and mill, including heap leaching, amounted to a total of about 21 000 tU.

Status of production capability

Since the closure of the Mecsek mine in late 1997, the only production of uranium in Hungary has been as a by-product recovery of water treatment activities, amounting to a total of about 2-6 tU/yr. During this reporting period 3-5 tU/yr was recovered. Section III of the historic mine workings below the water drainage horizon (formerly the main haulage adit) was completely flooded, and it is expected that Sections II-IV-V will be flooded by 2024.

Environmental activities and socio-cultural issues

Closure and large-scale site remediation activities at the Mecsek uranium production centre were carried out between 1998 and 2008. The remediation consisted of: (1) removing several hundred thousand tonnes of contaminated soil from various areas around the site to an on-site disposal facility, (2) remediation of tailings ponds and waste rock piles by the placement of isolating soil covers, and (3) abandonment and closure of underground mine workings, as well as groundwater extraction and treatment. Although the large-scale remediation programme was completed by the end of 2008, long-term care activities – such as groundwater remediation, environmental monitoring and maintenance of the engineered disposal systems – will likely need to continue for some years to come. To prepare for the entire flooding of the abandoned underground mining openings, the water management system and the mine water treatment plant have been expanded. In addition, the water drainage system of the reclaimed waste rock piles has been improved, and for monitoring the tailings ponds, three new wells have been installed, for a total of 34 wells.

Since July 2016, long-term care of Hungarian uranium mining and ore processing legacy sites is under the direct responsibility of the Mining Property Utilization Company in the Public Interest (www.bvh.hu). The legal successor of the former Mecsek mine (a state-owned venture) is responsible for paying compensation, including damages for occupational disease, income and pension supplements, reimbursements of certified costs and dependent expenses to people formerly engaged in uranium mining. Costs associated with the environmental remediation of the Mecsek mine are provided in the following table.

Costs of environmental management

(HUF thousands)

	Pre-1998	1998 to 2008
Closing of underground spaces	NA	2 343 050
Reclamation of surficial establishments and areas	NA	2 008 403
Reclamation of waste rock piles and their environment	NA	1 002 062
Reclamation of heap leaching piles and their environment	NA	1 898 967
Reclamation of tailings ponds and their environment	NA	8 236 914
Water treatment	NA	1 578 040
Reconstruction of electric network	NA	125 918
Reconstruction of water and sewage system	NA	100 043
Other infrastructural service	NA	518 002
Other activities including monitoring, staff, etc.	NA	2 245 217
Total	5 406 408	20 056 616

NA = Not available.

After remediation of the uranium mining and ore processing legacy sites, the annual cost of long-term care activities amounts to some HUF 600-750 million (about USD 2.2-2.6 million).

Uranium requirements

In January 2020, the government approved the new National Energy Strategy 2030 and the National Energy and Climate Plan, and opted for the long-term maintenance of nuclear in the energy mix. In 2019, the MVM Paks Nuclear Power Plant (Paks NPP) generated 16 285 GWh electricity, which accounted for around 50% of gross electricity generation and 49.24% of domestic electricity consumption. The Unit Capability Factor has been as follows: Unit 1: 99.5%; Unit 2: 92.6%; Unit 3: 83.1%; Unit 4: 83.1%. Average for the plant: 92.4%.

The permitting procedure for lifetime extension of the Paks nuclear power plant from 30 to 50 years has been fully completed. In 2017, the Hungarian Atomic Energy Authority granted the licence for the lifetime extension programme for the last unit (Unit 4). There are also two new units planned, named Paks II NPP. By the end of 2020, the environmental licence, the site permit, the preliminary water rights, the preliminary connection licences and the electricity implementation licence had been obtained.

National policies relating to uranium

Since the shutdown of the Hungarian uranium mining industry in 1997, there have been no uranium-related policies. The Energy Mineral Resources Utilisation and Stock Management Action Plan summarises the available Hungarian uranium resources. It concludes that if uranium ore mining is profitable, the Government should consider partnerships with private investors in mining, through state-owned companies. However, there is no Government measure or action planned to facilitate mining.

Uranium stocks

The by-product ($UO_4 \cdot 2H_2O$) of the water treatment activities on the former uranium mining and ore processing site is stored at the mine water treatment facility until export. At the end of 2018, the inventory amounted to 2 204 kgU. In 2018, 10 114.89 kgU, accumulated through previous years, was exported.

Uranium prices

Uranium prices are not available as they are commercially confidential.

Uranium exploration and development expenditures and drilling effort – domestic

(EUR)

	2016	2017	2018	2019 (expected)
Industry* exploration expenditures	NA	NA	NA	NA
Government exploration expenditures	NA	NA	0	0
Industry* development expenditures	NA	NA	NA	NA
Government development expenditures	NA	NA	0	0
Total expenditures	NA	NA	NA	NA
Industry* exploration drilling (m)	1 867	950	0	0
Industry* exploration holes drilled	2	1	0	0
Total drilling (m)	1 867	950	0	0
Total number of holes drilled	2	1	0	0

* Non-government.

Inferred conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	0	0	17 946	NA
Total	0	0	0	17 946	NA

Inferred conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	0	0	17 946	NA
Total	0	0	0	17 946	NA

Inferred conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	0	17 946
Total	0	0	0	17 946

Prognosticated conventional resources

(tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
0	0	13 427

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Underground mining*	21 000	0	0	0	21 000	0
Co-product/by-product	71	4	3	5	83	3
Total	21 071	4	3	5	21 083	21 086

* Pre-2015 totals may include uranium recovered by heap and in-place leaching.

Historical uranium production by processing method

(tonnes U in concentrates)

Processing method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Conventional	20 475	0	0	0	20 475	0
Heap leaching*	525	0	0	0	525	0
In situ leaching	0	0	0	0	0	0
Other methods**	71	4	3	5	83	3
Total	21 071	4	3	5	21 083	21 086

* A subset of open-pit and underground mining since it is used in conjunction with them.

** Includes mine water treatment and environmental restoration.

Historical uranium production by deposit type

(tonnes U in concentrates)

Deposit type	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Sandstone	21 071	4	3	5	21 083	3
Total	21 071	4	3	5	21 083	21 086

Ownership of uranium production in 2018

Domestic				Foreign				Totals	
Government		Private		Government		Private			
(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)
5	100	0	0	0	0	0	0	5	100

Installed nuclear generating capacity to 2040

(MWe net)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
1 890	1 900	1 900	1 900	1 900	1 900	4 300	4 300	3 400	3 400	2 400	2 400

Annual reactor-related uranium requirements to 2040 (excluding MOX)

(tonnes U)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
394	324	345	345	342	342	807	807	615	615	466	466

Total uranium stocks

(tonnes natural U-equivalent)

Holder	Natural uranium stocks in concentrates	Enriched uranium stocks	Enrichment tails	LWR reprocessed uranium stocks	Total
Government	0	0	0	0	0
Producer	2	0	0	0	2
Utility	0	0	0	0	0
Total	2	0	0	0	2

India

Uranium exploration and mine development

Historical review

The history of uranium exploration in India dates from 1949. Until the mid-1970s, uranium exploration was mainly confined to uranium provinces in the Singhbhum Shear Zone (SSZ), Jharkhand, and the Umra-Udaisagar belt in Rajasthan, targeting vein-type mineralisation. This resulted in discovering 16 low-grade uranium deposits of varying sizes in the SSZ, Jharkhand and one deposit at Umra, Rajasthan. Seven out of the fourteen deposits in the SSZ are under exploitation. Exploration is currently being carried out in several sectors of the 160 km long SSZ. Subsequent investigations were expanded to other favourable geological domains, which resulted in establishing several small uranium deposits such as Bodal and Bhandaritola, Chhattisgarh in Paleoproterozoic amphibolites; Jajawal, Chhattisgarh in Paleoproterozoic sheared migmatites of the Chhotanagpur Granite Gneiss Complex; and Walkunji, Karnataka in basal quartz-pebble conglomerates of the Dharwar Group.

During the mid-1970s, exploration was initiated targeting sandstone-type uranium deposits. The exploration for sandstone-type uranium mineralisation resulted in the discovery of a high-grade, medium-tonnage deposit at Domiasiat (Kylleng-Pyndengsohiong-Mawthabah) in the Cretaceous sandstones of Meghalaya. Exploration in contiguous sectors has established several small uranium deposits.

During the mid-1980s, a low-grade, stratabound deposit hosted by dolostones of the Vempalle Formation was established at Tummalapalle, Andhra Pradesh in the Cuddapah Basin. Since the dolostone ore was not amenable for conventional leaching procedures in vogue at that time, exploration in this sector was discontinued. However, the development of an economically viable alkali pressure leaching process rejuvenated the exploration activities in the Vempalle Formation along the Southern part of the Cuddapah Basin, targeting carbonate-hosted uranium mineralisation. Intensive multi-parametric exploration was carried out in Tummalapalle and adjacent sectors and led to the identification of substantial uranium resources.

During the early 1990s, a near-surface deposit was discovered adjacent to the unconformity contact between basement granites and the overlying Proterozoic Srisailam Quartzite at Lambapur in the Nalgonda district, Andhra Pradesh. These occurrences were investigated and several exploration areas were subsequently identified. Favourable geological criteria and sustained exploration efforts resulted in establishing deposits at Peddagattu and Chitrial. Exploration in the adjacent Palnad Sub-Basin identified a small deposit at Koppunuru. Exploration is continuing in the adjacent sectors.

Sustained exploration in the North Delhi Fold Belt (NDFB), in parts of Rajasthan and Haryana, targeting metasomatic type uranium mineralisation, led to the discovery of the Rohil uranium deposit, Rajasthan. Exploration is being carried out in various sectors of the ~300 km long albitite line in Rajasthan and Haryana.

Recent and ongoing uranium exploration and mine development activities

In the past few years, exploration activities have been concentrated in the following areas:

- Proterozoic Cuddapah Basin, Andhra Pradesh, and Telangana.
- Mesoproterozoic Singhbhum Shear Zone, Jharkhand.
- Mesoproterozoic North Delhi Fold Belt, Rajasthan & Haryana.

- Cretaceous Mahadek Basin, Meghalaya.
- Neoproterozoic Bhima Basin, Karnataka.
- Proterozoic Kaladgi Basin, Karnataka.
- Paleozoic – Mesozoic Satpura Gondwana Basin, Madhya Pradesh.
- Mesoproterozoic Chhotanagpur Granite Gneiss Complex, Uttar Pradesh, Madhya Pradesh, and Jharkhand.
- Cenozoic Siwalik Group, Himachal Pradesh.
- Proterozoic Aravalli Fold belt, Rajasthan.
- Other potential geological domains are under active exploration such as the: Dharmapuri Shear Zone in the Southern Granulite Terrain, Tamil Nadu; basement rocks of the Cuddapah Basin, Andhra Pradesh; Shillong Basin, Assam; basement crystallines, Arunachal Pradesh; Vindhyan and Bijwar basins, Uttar Pradesh and Madhya Pradesh; Kotri-Dongargarh belt, Chhattisgarh.
- Extensive exploration including ground and heliborne geophysical (ZTEM, TDEM, magnetic and radiometric), ground geological, radiometric and geochemical surveys and drilling are planned in other geological domains of the country that have the potential to host uranium.

Proterozoic Cuddapah Basin, Andhra Pradesh and Telangana

The Cuddapah Basin (Paleo- to Neoproterozoic) of the Dharwar Craton of Southern Peninsular India is one of the major uranium provinces hosting uranium mineralisation at various stratigraphic levels. Three types of uranium mineralisation/deposits have been identified in the Cuddapah Basin: carbonate-hosted stratabound-type, unconformity-related, and fracture-controlled.

a) Stratabound Carbonate-hosted

The southern part of the Cuddapah Basin hosts a unique, low-grade and large-tonnage uranium deposit in the dolostones of the Vempalle Formation in the Tummalapalle-Rachakuntapalle sector. This formation occurs at the lower stratigraphic sequence of the Cuddapah Basin. Uranium mineralisation has been traced intermittently over a strike length of 160 km from Reddipalle in the north to Maddimadugu in the southeast. The vast extent of the deposit, its stratabound nature hosted by dolostone, and point-to-point correlation with uniform grade and thickness of the mineralisation over considerable lengths along the strike and dip, make the deposit unique. Two ore lodes with an average thickness of 2.30 m and 1.75 m, separated by a lean/unmineralised band of 3.0 m, are under active exploration at vertical depths of up to 825 m. Sustained exploration activities over the 16 km segment within the 160 km long belt have added additional uranium resources. Intensive exploration in the eastern extension of the Tummalapalle-Rachakuntapalle sector has established another sizeable ore block, named Rachakunatapalle East. Also, intensive exploration activities in various sectors belt (Velamvaripalle, Nandimandalam) have substantially increased the uranium resource potential of this geological domain.

b) Unconformity-related uranium deposits

The northwestern margin of the Cuddapah Basin, comprising the Meso- to Neoproterozoic Srisailam and Palnad Sub-Basins, are known for their potential for unconformity-related uranium deposits. Intensive exploration over the past few decades in the northern part of the Srisailam Sub-Basin had established three low-tonnage, low-grade uranium deposits named Lambapur, Peddagattu, and Chitrial. Exploration efforts along the northern margin of the Palnad Sub-Basin have resulted in locating a low-grade and low-tonnage deposit at Koppunuru. Exploration is underway in other parts of the Srisailam and Palnad Sub-Basins that have a similar lithostructural character. Substantial dimensions of uranium mineralisation occurring close to the unconformity between the basement granite and Gulcheru quartzite have been established in the Kappatralla outlier.

c) Fracture-controlled uranium mineralisation

The Gulcheru quartzite of the Cuddapah Supergroup, overlying the basement granitoid in the southern parts of the Cuddapah Basin, are intensely fractured, faulted and intruded by E-W trending basic dykes. Uranium mineralisation is associated with the quartz-chlorite-breccia occurring along the contact between the Gulcheru quartzite and basic dykes. Furthermore, the fracture systems within the crystalline basement, proximal to the southern and eastern margins of the Cuddapah Basin, are known to host uranium mineralisation and are currently under exploration (e.g. Kamaguttapalle-Kammapalle and Kasturigattu).

Mesoproterozoic Singhbhum Shear Zone, Jharkhand

The Singhbhum Shear Zone is a 160 km long, arcuate belt of tectonised rocks fringing the northern boundary of the Singhbhum craton along the contact with the Singhbhum Group rocks. Exploration efforts since the early fifties led to the identification of several low-grade and low- to medium-tonnage uranium deposits, some of which are under active exploitation. The established uranium deposits are mainly located in the central and eastern sectors of the shear zone. Intensive exploration in various sectors in the shear zone has added significant resources to the uranium inventory. Notable among them are the Singridungri-Banadungri, Rajdah, Jaduguda North, Bangurdih and Narwapahar sectors.

Mesoproterozoic North Delhi Fold Belt of Rajasthan and Haryana

The metasediments of North Delhi Fold Belt, comprising the Khetri, Alwar and Bayana-Lalsot Sub-Basins in the states of Rajasthan and Haryana, are host for several uranium occurrences. The 300 km long NNE-SSW trending "Albitite Line" passing through the Delhi Supergroup and Banded Gneissic Complex is the site for extensive sodic metasomatism and holds great potential to host metasomatite-type uranium mineralisation. Integrated exploration including litho-structural, ground geophysics, and drilling resulted in the discovery of a fracture-controlled metasomatite-type uranium deposit near Rohil, Rajasthan. The entire "Albitite Line" holds immense potential for the discovery of additional uranium resources. Intensive multi-parametric exploration discovered another deposit at Jahaz, Rajasthan. Further, extensive ground and heliborne geophysical surveys and drilling have been deployed in the contiguous sectors of Rohil for the delineation of prospective areas. These exploration efforts resulted in establishing promising new sectors in Gumansingh-Ki-Dhani, Narsinghpuri, and Hurra-Ki-Dhani in the contiguous area of Rohil, which have similar geological settings.

Cretaceous Mahadek Basin, Meghalaya

The Upper Cretaceous Lower Mahadek Formation, exposed along the southern margin of Shillong plateau, Meghalaya is a potential host for uranium mineralisation. This geological domain has been under exploration since the late 1970s. Substantial exploration over the years led to the discovery of seven low- to medium-grade, low- to medium-tonnage, uranium deposits at Domiasiat, Wahkyn, Wahkut, Gomaghat, Tyrnai, Umthongkut, and Lostoin.

Neoproterozoic Bhima Basin, Karnataka

The Bhima Basin comprises calcareous sediments with minor arenaceous lithostratigraphic units of the Bhima Group, which were deposited over basement granite and have been affected by several east-west trending faults. A small-size, medium-grade uranium deposit has been established at Gogi along the Gogi-Kurlagare-Gundahalli fault. Intensive multi-parametric exploration also established another deposit at Kanchankayi, Karnataka, adjacent to the Gogi uranium deposit. Current exploration efforts are concentrated to the east of the Kanchankayi sector along the northeastern extensions of Gogi uranium deposit.

Palaeozoic – Mesozoic Satpura Gondwana Basin, Madhya Pradesh

The Gondwana age sedimentary basins of India possess suitable environments for hosting sandstone-type uranium mineralisation. The lower Motur Formation of the Satpura Gondwana Basin of Central India has been identified as the potential geological domain for hosting sandstone-type uranium mineralisation. Extensive surface and subsurface exploration in the Motur Formation has delineated significant uranium mineralisation in the Dharangmau – Kachhar sector.

Meso-Neoproterozoic Kaladgi Basin, Karnataka

The E-W trending Meso-Neoproterozoic Kaladgi Basin is located on the north-western margin of the western Dharwar Craton. The unmetamorphosed sediments of Kaladgi Supergroup overlie the basement granitoids and Chitradurga schists. The northern and western extensions of the basin are covered by the Deccan Traps. The basement comprises schist belts having slivers of graphite-bearing meta-pelites and granites with associated tectonism. Significant surface uranium mineralisation over a considerable extent hosted by arenites has been identified near Deshnur. Subsurface exploration in the western part of Kaladgi Basin led to the emergence of another prospective sector in the Suldhal-Gujanal-Malarmardi area. Uranium mineralisation is hosted by the lower conglomerate, basal arenite, and basement schist close to the unconformity.

Mesoproterozoic Chhotanagpur Granite Gneissic Complex (CGGC), Uttar Pradesh, Madhya Pradesh, and Jharkhand

The Chhotanagpur Granite Gneiss Complex (CGGC) forms part of the prominent Middle Proterozoic linear mobile belt in East and Central India lying between the Narmada-Son-Brahmaputra lineaments designated as "Central Indian Tectonic Zone" (CITZ) in the North and the Central Indian Suture (CIS) to the south. The CGGC, hosts a thick pile of arkosic to psammo-pelitic metasediments that has undergone multiple phases of tectonic, plutonic, thermal and metamorphic events, which resulted in ultra-metamorphism of the transition sediments, leading to the prolific development of migmatites. The exposed rocks include banded gneisses and metasedimentary enclaves, overlain by the Mahakoshal supracrustals and sediments of the Vindhyan Supergroup in the north and Gondwana Supergroup in the south. Uranium mineralisation within migmatites comprising arkosic to psammo-pelitic metasediments is hosted by varied lithological units spread over a large area of about 350 km^2 area in Son valley crystallines forming the Northwestern extensions of CGGC. Uranium mineralisation has been discovered at Naktu, Kudar, Lakhar, Sirsoti, Nawatola, Dhanbhadua, Kudri and Anjangira, where the host rock is essentially an albite-rich pegmatoid leucosome mobilizate (PLM) and to a lesser extent, a biotite melanosome/melanosome mobilizate (MM).

Cenozoic Siwalik Basin, Himachal Pradesh

The Siwalik Group constitutes a thick sequence of molasse deposits laid down in a long narrow fore-deep, formed to the south of the rising Himalayas during the Middle Miocene to the Pleistocene. The sediments are traceable in India from Jammu in the west to the Brahmaputra valley in the east. Multi-parametric exploration has helped in identifying numerous uranium occurrences spread over the entire Siwalik belt between Poonch (Jammu and Kashmir) in the west and Tanakpur (Uttar Pradesh) in the east. More than 350 uranium occurrences forming eight major clusters have been identified. The majority of these occurrences are confined to three distinct stratigraphic horizons: (1) lower part of Upper Siwaliks, (2) upper part of Middle Siwaliks, and (3) upper part of Lower Siwaliks. The important uranium zones identified are (1) Maler in Jammu and Kashmir, (2) Astotha - Khya - Loharian, (3) Galot - Andalada – Sibal - Loharkar, (4) Rajpura - Polian, (5) Romehra in Himachal Pradesh, (6) Morni - Nathai in Haryana, (7) Naugajiya Rao - Sanbarsot - Sakhumbari Rao, and (8) Kathaul - Danaur - Kholgarh in Uttar Pradesh. Of these, the Rajpura-Polian sector and Sibal-Loharkar sectors, Himachal Pradesh is presently under active exploration.

Proterozoic Aravalli Fold Belt, Rajasthan

The Aravalli Supergroup (ASG) occupies the eastern part of the Aravalli Mountain Range from Nathdwara in the north to Champaner in the south over a distance of approximately 350 km with width varying from 40 km to 150 km. It has an arcuate form with a NE-SW trend in the north, N-S in Udaipur, and NW-SE in the south. ASG can be divided into two distinct sedimentary facies: (1) the shelf facies, comprising mafic volcanic, coarse clastics and carbonates accumulated in the epicontinental sea along the pericontinental slope, and (2) a carbonate-free deep-sea facies, comprising dominantly metapelites with bands of quartzite. The ASG has undergone polyphase deformation and witnessed three main events of magmatism. The Aravalli Fold Belt is known for its uranium metallogeny of different styles among which uranium mineralisation associated with carbon phyllite is the most promising. Several anomalies have been located at the Umra, Udaisagar, Kalamagra, Haldughati, Sukher, Oda (Ord/Ora) – Kevda (Keora) and Undwala areas.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

India's known conventional in situ uranium resources (reasonably assured resources and inferred) are estimated to be 259 524 tU hosted in the following deposit types:

Carbonate	14 3096 tU	55.14%
Metamorphite	62 743 tU	24.18%
Sandstone	20 528 tU	7.91%
Proterozoic Unconformity	18 072 tU	6.96%
Metasomatic	9 416 tU	3.63%
Granite-related	5 317 tU	2.05%
Paleo-quartz-pebble conglomerate	352 tU	0.13%
Total	**259 524 tU**	**100%**

As of 1 January 2019, the known conventional in situ resources include 249 058 tU of reasonably assured resources (RAR) and 10 466 tU of inferred resources (IR). This amounts to a substantial increase in RAR, compared to what was reported for the Red Book 2018. These changes are mainly due to appreciable resource additions in the contiguous area of the stratabound deposit in the southern part of the Cuddapah Basin and the extension areas of known deposits in the Singhbhum Shear Zone, Bhima Basin, and North Delhi Fold Belt.

Undiscovered conventional resources (prognosticated and speculative resources)

In parts of Andhra Pradesh, Meghalaya, Rajasthan, Jharkhand, and Karnataka, potential areas for uranium resources were re-evaluated with a higher degree of confidence. As of 1 January 2019, undiscovered resources increased to 127 200 tU under the prognosticated category and 55 120 tU under the speculative category, both as in situ resources.

The increase in the prognosticated resources category (from 114 480 tU in 2017 to 127 200 tU in 2019) is mainly because of the greater degree of confidence obtained by carrying out multidisciplinary exploration in some of the potential geological domains, such as the Southern Cuddapah Basin, Andhra Pradesh; Singhbhum Shear Zone, Jharkhand and Bhima Basin, Karnataka; and North Delhi Fold Belt, Rajasthan; Satpura Gondwana Basin, Madhya Pradesh; Chhotanagpur Granite Gneiss Complex, Uttar Pradesh; Madhya Pradesh and Jharkhand and Siwalik Group, Himachal Pradesh.

Similarly, the increase in the speculative resources category (from 50 880 tU in 2017 to 55 120 tU in 2019) is mainly due to the identification of several potential exploration targets in a number of geological domains, namely the Dharmapuri Shear Zone, Tamil Nadu; Shillong Basin, Assam, and Meghalaya, Kaladgi Basin, Karnataka; Aravalli Fold Belt, Rajasthan.

Uranium production

Historical review

The Uranium Corporation of India Limited (UCIL) was formed in October 1967 under the administrative control of the Department of Atomic Energy, Government of India. The UCIL operates six underground uranium mines (Jaduguda, Bhatin, Narwapahar, Turamdih, Bagjata, and Mohuldih) and one open-pit mine (Banduhurang in Singhbhum East district of Jharkhand State). The ore produced from the mines is processed in two processing plants located at Jaduguda and Turamdih. All of these facilities are located in a multi-metal mineralised sector – the Singhbhum Shear Zone in the eastern part of India. In addition to these, UCIL has also constructed a uranium mine and a processing plant in the YSR district (formerly Kadapa) of Andhra Pradesh.

Status of production facilities, production capability, recent and ongoing activities and other issues

The total installed capacity of UCIL's three operating production plants is as follows:

- Jaduguda Plant: 2 500 t ore/day;
- Turamdih Plant: 3 000 t ore/day;
- Tummalapalle Plant: 3 000 t ore/day.

Recent and ongoing activities

Jaduguda mine

The Jaduguda uranium deposit lies within the metasediments of Singhbhum Shear Zone. The host rocks are of Proterozoic age. There are two prominent parallel ore lenses: the Footwall lode (FWL) and the Hangingwall lode (HWL). These lodes are separated by a 100 m barren zone. The FWL extends over a strike length of about 600 m in a south-east to north-west direction. The strike length of HWL is about 250 m and is confined to the eastern part of the deposit. Both the lodes have an average dip of 40 degrees towards the north-east. Of the two lodes, the FWL is better mineralised. The Jaduguda deposit has been explored up to a depth of 880 m.

Entry to the mine is through a 640 m deep vertical shaft. An underground auxiliary vertical shaft, sunk from 555 m to 905 m, provides access to deeper levels. The cut-and-fill stoping method is practised, giving about 80% ore recovery. De-slimed mill tailings are used as backfill material. Ore is hoisted by the skip in stages through shafts to surface and sent to the Jaduguda mill by conveyor for further processing.

Bhatin mine

The Bhatin uranium deposit is located 4 km north-west of Jaduguda. A major strike-slip fault lies between the Jaduguda and Bhatin deposits. Both of the deposits lie in similar geological settings. The Bhatin mine began production in 1986. The ore lens has a thickness of 2 to 10 m with an average dip of 35 degrees and entry to the mine is through an adit, with deeper levels accessed by inclines. Cut-and-fill stoping is practised and deslimed mill tailings from the Jaduguda mill are used as backfill. Broken ore is trucked to the Jaduguda mill. UCIL has planned for increasing underground productivity of this mine by further mechanising its working methods.

Narwapahar mine

The Narwapahar deposit (about 12 km west of Jaduguda) has been operating since 1995. In this deposit, discrete uraninite grains occur within chlorite-quartz schist with associated magnetite, with several lenticular-shaped ore lenses extending over a strike length of about 2 100 m, each with an average north-easterly dip of 30 to 40 degrees. The thickness of the individual ore lenses varies from 2.5 to 20 m. The deposit is accessed by a 355-metre-deep vertical shaft and a 7-degree decline from the surface. Cut-and-fill stoping is also practised using deslimed mill tailings of the Jaduguda plant as backfill. Ore is trucked to the Jaduguda plant for processing.

Turamdih mine

The Turamdih deposit is located about 12 km west of Narwapahar. Discrete uraninite grains within feldspathic-chlorite schist form a series of ore lenses with very erratic configuration. The mine was commissioned in 2003 and three levels (70 m, 100 m, and 140 m depth) have been accessed through an 8-degree decline from the surface and a vertical shaft has been sunk to provide access to deeper levels. Ore from this mine is processed at the Turamdih plant. Cut-and-fill stoping is also practised using deslimed mill tailings of the Turamdih plant. Considering the ore geometry, possibilities of adopting sub-level stoping methods in specific segments of the orebody are being explored with higher productivity. Trial stoping in one such area has been undertaken.

Bagjata mine

The Bagjata deposit, situated about 26 km east of Jaduguda, has been developed as an underground mine with a 7-degree decline for entry and a vertical shaft to access deeper levels. This mine was commissioned in 2008. Ore from the Bagjata mine is transported by road to the Jaduguda plant for processing. Cut-and-fill stoping is practised in the Bagjata mine and deslimed mill tailings from the Jaduguda mill are used as backfill.

Banduhurang mine

The Banduhurang deposit has been developed as a large opencast mine. The orebody is the western extension of ore lenses at Turamdih. The mine was commissioned in 2009 and ore is transported by road to the Turamdih plant for processing.

Mohuldih mine

The deposit is located in the Seraikela-Kharswan district of Jharkhand, about 2.5 km west of Banduhurang. The mine was commissioned in 2012. The ore from the mine is treated at the Turamdih plant.

Tummalapalle mine

Hosted in carbonate rock, this deposit is located in the YSR district (formerly Kadapa) of Andhra Pradesh. It is the first uranium production centre in the country located outside Jharkhand. This underground mine is accessible by three declines along the apparent dip of the orebody. The central decline is equipped with a conveyor for ore transport and the other two declines are used as service paths. The ore is treated in the plant adjacent to the mine at Tummalapalle. The expansion of the mine and processing plant at Tummalapalle has been planned to augment uranium production.

Jaduguda mill

Ore produced at the Jaduguda, Bhatin, Narwapahar and Bagjata mines is processed in the mill located at Jaduguda. Commissioned in 1968, the mill is capable of treating about 2 500 t/day of dry ore. Following crushing and grinding to 60% (passing 200 mesh), the ore is leached in pachuca tanks using sulphuric acid under controlled pH and temperature. After filtration of the pulp, ion exchange resin is used to recover the uranium. After elution, the product is precipitated using hydrogen peroxide to produce uranium peroxide as a final product containing about 88% U_3O_8. The treatment of mine water and reclaiming tailings water has resulted in reduced freshwater requirements, as well as increasing the purity of the final effluent. A magnetite recovery plant is also in operation at Jaduguda producing very fine-grained magnetite as a by-product.

Turamdih mill

Uranium ore from the Turamdih and Banduhurang mines is being processed in the Turamdih mill. The mill, commissioned in 2009, is capable of treating about 3 000 t/day dry ore. The plant adopts similar processing technology as that of Jaduguda. Presently, this plant produces magnesium diuranate as the final product. Plans to produce uranium peroxide as the final product is under implementation. The expansion of this plant to process 4 500 t/day dry ore has been taken up.

Tummalapalle mill

The uranium processing plant at Tummalapalle in the YSR district (formerly Kadapa) of Andhra Pradesh is based on indigenously developed alkali leaching (under high temperature and pressure) technology. The plant to process 3 000 t/day ore was put into regular operation in January 2017. The expansion of this plant to process 4 500 t/day ore has also been planned.

Uranium production centre technical details

(as of 1 January 2019)

	Centre #1	Centre #2	Centre #3	Centre #4	Centre #5	Centre #6	Centre #7	Centre #8
Name of production centre	Jaduguda	Bhatin	Narwapahar	Bagjata	Turamdih	Banduhurang	Mohuldih	Tummalapalle
Production centre classification	Existing	Existing	Existing	Existing	Existing	Existing	Existing	Existing
Start-up date	1967	1986	1995	2008	2003	2007	2011	2017
Source of ore:	Uranium ore	Uranium ore	Uranium ore	Uranium ore	Uranium ore	Uranium ore	Uranium ore	Uranium ore
Deposit name(s)	Jaduguda	Bhatin	Narwapahar	Bagjata	Turamdih	Banduhurang	Mohuldih	Tummalapalle
Deposit type(s)	Vein	Vein	Vein	Vein	Vein	Vein	Vein	Strata bound
Resources (tU)	-	-	-	-	-	-	-	-
Grade (% U)	-	-	-	-	-	-	-	-
Mining operation:								
Type (OP/UG/ISL)	UG	UG	UG	UG	UG	OP	UG	UG
Size (tonnes ore/day)	650	150	1 500	500	750	3 500	500	3 000 (4 500 planned)
Average mining recovery (%)	80	75	80	80	75	65	80	60
Processing plant:	Jaduguda				Turamdih			Tummalapalle
Type (IX/SX/AL)	IX/AL				IX/AL			ALKPL*
Size (tonnes ore/day)	2 500				3 000			3 000
Average process recovery (%)	80				78			70
Nominal production capacity (tU/year)	200				190			211
Plans for expansion	-				Turamdih mine (1 000 TPD) and Turamdih plant (4 500 TPD) are under expansion			Tummalapalle mine (4 500 TPD) and Tummalapalle plant (4 500 TPD) are under expansion
Other remarks	Ore being processed in Jaduguda plant				Ore being processed in Turamdih plant			

* Pressurised alkali leach. TPD = tonnes per day.

Uranium production centre technical details *(cont'd)*

(as of 1 January 2019)

	Centre # 9	Centre # 10	Centre # 11
Name of production centre	Gogi	Lambapur-Peddagattu	Kylleng-Pyndengsohiong Mawthabah (KPM)
Production centre classification	Planned	Planned	Planned
Start-up date	2024	2024	2028
Source of ore:	Uranium ore	Uranium ore	Uranium ore
Deposit name(s)	Gogi	Lambapur-Peddagattu	KPM
Deposit type(s)	Vein	Unconformity	Sandstone
Resources (tU)	-	-	-
Grade (% U)	-	-	-
Mining operation:			
Type (OP/UG/ISL)	UG	UG/OP	OP
Size (tonnes ore/day)	500	1 250	2 000 (250 days/yr working)
Average mining recovery (%)	60	75	90
Processing plant:	Gogi	Seripally	KPM
Type (IX/SX/AL)	AL	IX/AL	IX/AL
Size (tonnes ore/day)	500	1 250	2 000 (275 days/yr working)
Average processing ore recovery (%)	88	77	87
Nominal production capacity (tU/year)	130	130	340
Plans for expansion	-	-	-
Other remarks	Ore to be processed in the plant at Saidapur	Ore to be processed in the plant at Seripally	

Ownership structure of the uranium industry

In India, uranium prospecting/exploration and mining are carried out exclusively by the central government. The uranium industry is wholly owned by the Department of Atomic Energy, Government of India. The Atomic Minerals Directorate for Exploration and Research under the Department of Atomic Energy is responsible for uranium exploration programmes in India. Following the discovery and deposit delineation, the economic viability is evaluated. The evaluation stage may also include exploratory mining. Once a deposit of sufficient tonnage and grade is established, UCIL initiates activities for commercial mining and production of uranium concentrates.

Employment in the uranium industry

About 5 000 people are engaged in uranium mining and milling activities.

Future production centres

The uranium deposit located at Gogi in the Yadgir (former name Gulbarga) district, Karnataka, is planned for development as an underground mine. Exploratory mining work is in progress to establish the configuration of the orebody. The plant at Gogi will utilise alkali leaching technology.

A sandstone uranium deposit in the north-eastern part of the country at Kylleng-Pyndengsohiong, Mawthabah (formerly Domiasiat) in West Khasi Hills District, Meghalaya State, is planned for development by open-pit mining, with a processing plant to be situated near the mine.

Uranium deposits located at Lambapur-Peddagattu in the Nalgonda district, Andhra Pradesh are also slated for development, with an open-pit and three underground mines proposed. An ore processing plant is being proposed at Seripally, 50 km from the mine site. Pre-project activities are in progress.

Environmental activities and socio-cultural issues

There are no environmental issues related to the existing uranium mines and processing plants operated by UCIL. However, provisions are made for the management of environmental impacts. The organisation responsible for this task is the Health Physics Group of the Bhabha Atomic Research Centre, located in Mumbai. It carries out environmental health monitoring for radiation, radon, and dust at uranium production facilities. The Health Physics Unit operates the Environmental Survey Laboratory at Jaduguda and has establishments at all operating facilities.

Regulatory regime

In India, all nuclear activities, including mining of uranium or other atomic minerals, falls within the purview of the central government and are governed by the Atomic Energy Act, 1962 (AE Act) and regulations made thereunder. The Department of Atomic Energy (DAE) oversees the development and mining of uranium and other atomic minerals. Accordingly, policies of DAE and provisions of the AE Act and regulations framed thereunder play a key role in the prospecting, exploration, and mining of uranium. Relevant provisions of the Mines and Minerals (Development and Regulation) Act, 1957 (MMDR Act) and the Mines Act, 1952 are also applicable in the case of mining of uranium. In addition, all mining activities must comply with environmental regulations. The mining, milling, and processing of uranium ore require a licence under the AE Act. The Atomic Energy (Radiation Protection) Rules (2004) and the Atomic Energy (Working of Mines and Minerals and Handling of Prescribed Substances) Rules (1984) provide procedural details for obtaining a licence and specify conditions required to carry out these activities.

A mining lease for uranium is granted by the state government after the mining plan is approved by the Atomic Minerals Directorate for Exploration and Research as per the provisions of the MMDR Act. The Atomic Energy Regulatory Board (AERB), an independent authority, regulates the safety and other regulatory provisions under the AE Act and ensures the safety of workers, the public and the environment. The AERB oversees various aspects of a mining plan that are required to conform to radiological safety, siting of the mill, disposal of tailings and other waste rocks, as well as decommissioning the facility. Opening, operation and decommissioning of uranium mines require compliance with the various provisions under different legislation and regulations.

Uranium requirements

As of 1 January 2017, the total installed nuclear capacity in India was 6 780 MWe (gross), which is comprised of 18 pressurised heavy water reactors, two boiling water reactors, and two light water reactors. Construction of four pressurised heavy water reactors (KAPP 3 and 4: 2 x 700 MWe and Rajasthan Atomic Power Station 7 and 8: 2 x 700 MWe), and one prototype fast breeder (500 MWe) is in progress. Total nuclear power generating capacity is expected to grow to about 8 680 MWe by 2020 as projects under construction are progressively completed.

The current plan is to increase nuclear installed capacity to about 10 080 MWe by 2022.

Annual uranium requirements in 2015 amounted to about 1 300 tU and this would increase in tandem with increases in installed nuclear capacity. Identified conventional uranium resources are sufficient to support 10-15 GWe installed capacity of pressurised heavy water reactors operating at a lifetime capacity factor of 80% for 40 years.

With international co-operation in peaceful nuclear energy being opened to India, installed nuclear generating capacity is expected to grow significantly as more international projects are envisaged. However, the exact size of the programme based on technical co-operation with other countries is yet to be finalised.

Supply and procurement strategy

Uranium requirements for pressurised heavy water reactors are being met with a combination of domestic and imported sources. Two operating boiling water reactors and two light water reactors of VVER-type require enriched uranium and are fuelled by imported uranium. Future light water reactors will also be fuelled by imported uranium.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

Uranium exploration, mining, production, fuel fabrication and the operation of nuclear power reactors are controlled by the government of India. National policies relating to uranium are governed by the Atomic Energy Act 1962 and the provisions made thereunder.

Imported light water reactors to be built in the future will be purchased with assured fuel supply for the lifetime of the reactor.

Uranium exploration and development expenditures and drilling effort – domestic

(Indian rupee millions)

	2016	2017	2018	2019 (expected)
Government exploration expenditures	3 547	4 114	4 186	4 574
Total expenditures	3 547	4 114	4 186	4 574
Government exploration drilling (m)	178 572	203 688	250 808	292 000
Total drilling (m)	178 572	203 688	250 808	292 000

* Non-government.

Reasonably assured conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	Cost range unassigned
Underground mining (UG)	NA	NA	NA	225 918
Open-pit mining (OP)	NA	NA	NA	23 140
Total	NA	NA	NA	249 058

Reasonably assured conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	Cost range unassigned
Conventional from UG	NA	NA	NA	225 918
Conventional from OP	NA	NA	NA	23 140
Total	NA	NA	NA	249 058

Reasonably assured conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	Cost range unassigned
Proterozoic unconformity	NA	NA	NA	18 072
Sandstone	NA	NA	NA	17 638
Granite-related	NA	NA	NA	5 317
Metamorphite	NA	NA	NA	56 185
Metasomatic	NA	NA	NA	8 750
Carbonate	NA	NA	NA	143 096
Total	NA	NA	NA	249 058

Inferred conventional resources by production method
(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	Cost range unassigned
Underground mining (UG)	NA	NA	NA	8 372
Open-pit mining (OP)	NA	NA	NA	2 094
Total	NA	NA	NA	10 466

Inferred conventional resources by processing method
(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	Cost range unassigned
Conventional from UG	NA	NA	NA	8 372
Conventional from OP	NA	NA	NA	2 094
Total	NA	NA	NA	10 466

Inferred conventional resources by deposit type
(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	Cost range unassigned
Sandstone	NA	NA	NA	2 890
Paleo-quartz-pebble conglomerate	NA	NA	NA	352
Metamorphite	NA	NA	NA	6 558
Metasomatic	NA	NA	NA	666
Total	NA	NA	NA	10 466

Prognosticated conventional resources
(tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	Cost range unassigned
NA	NA	127 200

Speculative conventional resources
(tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
NA	NA	55 120

Ownership of uranium production in 2018

Domestic				Foreign				Totals	
Government		Private		Government		Private			
(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)
NA	100	NA	NA	NA	NA	NA	NA	NA	100

Uranium industry employment at existing production centres
(person-years)

	2016	2017	2018	2019 (expected)
Total employment related to existing production centres	4 741	4 722	4 633	4 569
Employment directly related to uranium production	NA	NA	NA	NA

Short-term production capability
(tonnes U/year)

2013				2015				2020			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
NA				NA				NA			

2025				2030				2035			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
NA				NA				NA			

Net nuclear electricity generation

	2017	2018
Nuclear electricity generated (TWh net)	38.36	37.8(?)

Installed nuclear generating capacity to 2040
(MWe gross)

2017	2018	2020		2025		2030		2035		2040	
6 780	6 780	Low	High	Low	High	Low	High	Low	High	Low	High
		NA	8 680	NA	10 080	NA	NA	NA	NA	NA	NA

Annual reactor-related uranium requirements to 2040 (excluding MOX)
(tonnes U)

2017	2018	2020		2025		2030		2035		2040	
1 300	1 100	Low	High	Low	High	Low	High	Low	High	Low	High
		NA	1 350	NA	1 600	NA	NA	NA	NA	NA	NA

Indonesia

Uranium exploration and mine development

Historical review

Uranium exploration by the Centre for Development of Nuclear Ore and Geology of the National Nuclear Energy Agency of Indonesia (BATAN) started in the 1960s. Up to 1996, reconnaissance surveys had covered 79% of a total of 533 000 km^2 identified for survey on the basis of favourable geological criteria and promising exploration results. Since that year, the exploration activities have been focused on the Kalan, Kalimantan, in which the most significant indications of uranium mineralisation have been found. During 1998-1999, exploration consisted of systematic geological and radiometric mapping, including a radon survey carried out at Tanah Merah and Mentawa, Kalimantan in order to delineate the mineralised zone. The results of those activities increased speculative resource estimates by 4 090 tU to 12 481 tU. From 2000 up to 2002, exploration drilling was carried out at upper Rirang (178 m), Rabau (115 m) and Tanah Merah (181 m) in west Kalimantan.

In 2003-2004, additional exploration drilling was conducted at Jumbang 1 (186 m) and Jumbang 2 (227 m). In 2005, exploration drilling was carried out at Jumbang 3 (45 m) and at Mentawa (45 m), in 2006 at Semut (454 m) and Mentawa (45 m) and 2007 at Semut (174 m). In 2008, no exploration drilling was undertaken.

In 2009, exploration drilling was continued in the Kalan sector and detailed, systematic prospection in the Kawat area and its surroundings was carried out. General prospection in Bangka Belitung Province was also undertaken. Plans to extend exploration in Kalimantan and Sumatera by prospecting from general reconnaissance to systematic stages in order to discover new uranium deposits have been adopted. In 2010, efforts were devoted to evaluating drilling data from the Kawat sector to re-evaluate estimates of speculative resources.

Uranium and thorium exploration in 2015 continued in the Mamuju area, West Sulawesi Province and in the Ella Ilir area, West Kalimantan Province. In the Mamuju area, detailed ground radiometric mapping was conducted in the Takandeang, Taan, Ahu, Pangasaan, and Hulu Mamuju sectors. Geophysical resistivity and induced polarisation surveys conducted in the Botteng and Takandeang sectors were followed by reconnaissance drilling for a total depth of 1 600 m, which was comprised of 570 m in the Botteng sector, 830 m in the Takandeang sector, and 200 m in the Taan sector. Drilling targets were anomalous uranium occurring as stratabound and supergene enrichment in volcanic deposits. Exploration in the Ella Ilir area included geological and radiometric mapping, and reconnaissance drilling with 400 m of total depth. The drilling in this area focused on uranium veins in metapelite schistose and metatuff.

Recent and ongoing uranium exploration and mine development activities

In 2016, a regional geophysical survey, which included ground geomagnetic and gravity measurements, was conducted in the Mamuju area. Systematic exploration was conducted in the eastern part of the Hulu Mamuju sector, which included geological and radiometric mapping, soil geochemistry, radon gas measurements, and trenching. In other parts of the Mamuju area, systematic radiometric mapping was conducted in the Orobatu sector.

Exploration activities in 2017 were carried out in Kalan-Kalimantan and Mamuju-West Sulawesi. The activities in Kalan included a re-estimation of the resources using a geostatistical approach, database formulation, and UNFC resources classification for the deposit in Kalan area. Also, georeferencing of the semi-regional maps of Kalan was undertaken.

Exploration in Mamuju-West Sulawesi was carried out in more detailed stages. Geological mapping at a scale of 1:25 000 was completed and geochemical stream sediments were taken to identify the area of anomalous uranium. Detailed geophysical investigations using resistivity, induced polarisation, and geomagnetic methods were conducted in Ahu and Taan sectors. Estimation of uranium resources in Taan sector based on borehole drilling in 2015 was also carried out, with the result of 431 tU, classified as inferred resources. Prior to estimation, the quality assurance programme was conducted to compare the grade from radiometric well-logging and chemical analysis.

Exploration in 2018 was carried out in Kawat-East Kalimantan. The mapping was aimed at identifying the distribution of favourable uranium areas through radiometric measurements. In Kalan-West Kalimantan detailed structural geology mapping was conducted in Eko-Remaja exploration tunnel including re-mapping the control of mineralisation in the area.

Uranium exploration in Sulawesi was conducted in Mamuju-West Sulawesi. The activity included detailed geological mapping at a scale of 1:10 000 in the sectors of Hulu-Mamuju and Botteng. Geophysical investigations using seismic refraction methods were also applied in the Botteng sector.

Resources estimation was calculated in some prospect areas with the borehole data from Sibolga-North Sumatera and Mamuju-West Sulawesi. Inferred uranium resources for Sibolga is 415 tU, while in Mamuju, 221 tU.

In 2019, the exploration will continue in Mamuju -West Sulawesi, Harau-West Sumatera, and Kalan-West Kalimantan. Exploration in Mamuju is planned with 425 m of drilling in Ahu and Takandeang sectors. Detailed geological mapping of lateritic soil in Takandeang sector was also conducted to understand uranium, thorium, and REE deposit characteristics and its distribution. The geophysical investigation using resistivity method will be used to identify the soil thickness and bedrock morphology. Exploration in Harau-West Sumatera was conducted to identify the radioactive minerals in the area. The research is revisiting the previous discovery of radiometric anomaly in the area.

No mining activity is currently under consideration.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

The reasonably assured resource was categorised from measured and indicated resources. The measured resources and indicated resources are 7 123 tU categorised in the cost category <USD 130/KgU.

Resource estimation in the inferred category for the Mamuju area during 2017 to 2018 resulted in an additional 431 tU from Taan sector. An additional 165 tU and 56 tU was obtained from Salumati and Rantedunia sub-sectors respectively; both are part of Takandeang Sector. Besides Mamuju, resource estimation from the Aloban sector, Sibolga added an additional 415 tU. The total inferred resources by the addition of Mamuju and Sibolga is 4 065 tU (2 998 + 431 + 165 + 56 + 415 tU) categorised in the cost category <USD 130/KgU.

Aloban Sector, Sibolga, North Sumatera

Uranium explorations in the Sibolga area has been conducted since 1978. The mineralisation is sandstone-type uranium mineralisation. The mineralisation in Aloban sector has been identified from 22 boreholes and includes radiometric and detailed geological mapping. Uranium resources were estimated from conglomerate and sandstone, which are considered to have thick and wide distribution of mineralisation. The average uranium grade for conglomerate and sandstone are 173 ppm U and 162 ppm U, respectively. Uranium resource estimation for the Aloban sector is 415 tU as inferred resources.

Takandeang sector, Mamuju, West Sulawesi

Since 2013, the Mamuju area, West Sulawesi has been intensively explored to find uranium and thorium mineralisation and its resource potential is based on radiometric anomalies detected in the area. In 2015, drilling activities were carried out in the Botteng, Takandeang, and Taan sectors with 21 boreholes with a total depth of 1 600 m drilled. The resources have been estimated from drillholes in the Taan sector and Takandeang sector including the Salumati and Rantedunia sub-sectors. Uranium resource estimation for the Taan sector is 431 tU. Uranium resources from Takandeang sector include Salumati and Rantedunia sub sectors with 165 tU and 56 tU, respectively.

Undiscovered conventional resources (prognosticated and speculative resources)

There has been no addition to the prognosticated resources of 30 179 tU previously reported from Kalan, Kawat, Mentawa, and Mamuju.

Unconventional resources and other materials

The uranium resource potential in Bangka and Belitung comprises placer deposits of monazite within a tin deposit. Monazite, a uranium/thorium phosphate mineral, was deposited in the alluvium and has mostly accumulated as a tailings by-product material of tin mining. The total resource from deposits in Bangka and Belitung islands totals 25 236 tU. In Singkep, the uranium potential is in lateritic soil, with a resource of 1 100 tU. In Semelangan, West Kalimantan, uranium is present in bauxite lateritic deposit with resources of 624 tU. This has been previously reported and amounts to 26 960 tU.

Additionally, in the Katingan-Central Kalimantan, monazite is present as a by-product material of zircon mining, with resources of 485 tU. Adding this resource to the previous reported amount of 26 960 tU updates the unconventional resources to 27 445 tU for this reporting period.

Uranium exploration and development expenditures and drilling effort – domestic

(Indonesian rupiah [IDR])

	2016	2017	2018	2019 (expected)
Government exploration expenditures	3 079 162 855	1 618 560 692	1 165 110 957	3 266 869 000
Total expenditures	3 079 162 855	1 618 560 692	1 165 110 957	3 266 869 000
Government exploration drilling (m)	0	0*	0	425
Government exploration holes drilled	0	0*	0	6
Total drilling (m)	0	0	0	425
Total number of holes drilled	0	0	0	6

* For 2017, as tabulated in Red Book 2018, expected drilling at the time was estimated at 350 m and 4 holes, but it has not been verified if this was realised or not.

Reasonably assured conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	2 029	7 123	7 123	75
Total	0	2 029	7 123	7 123	75

Reasonably assured conventional resources by processing method
(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	2 029	7 123	7 123	75
Total	0	2 029	7 123	7 123	75

Reasonably assured conventional resources by deposit type
(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Metamorphite	0	2 029	7 123	7 123
Total	0	2 029	7 123	7 123

Inferred conventional resources by production method
(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	0	2 998	2 998	75
Unspecified	0	0	1 067	1 067	75
Total	0	0	4 065	4 065	75

Inferred conventional resources by processing method
(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	0	2 998	2 998	75
Unspecified	0	0	1 067	1 067	75
Total	0	0	4 065	4 065	75

Inferred conventional resources by deposit type
(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	415	415
Metamorphite	0	0	2 998	2 998
Volcanic-related	0	0	652	652
Total	0	0	4 065	4 065

Prognosticated conventional resources
(tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
0	0	30 179

Iran (Islamic Republic of)

Uranium exploration and mine development

Historical review

Exploration

In 1935, the first occurrence of radioactive minerals was detected in the Anarak mining region. In 1959 and 1960, through co-operation between the Geologic Survey of Iran (GSI) and a French company, preliminary studies were carried out in Anarak and Khorassan (central Iran and Azarbaijan regions) to evaluate the uranium mineralisation potential.

Systematic uranium exploration in Iran began in the early 1970s to provide uranium ore for planned processing facilities. Between 1977 and the end of 1978, one-third of Iran (650 000 km²) was covered by airborne geophysical surveys. Many surficial radiation anomalies were identified and follow-up field surveys have continued to the present. The airborne coverage is mainly over the central, south-eastern, eastern and north-western parts of Iran. The favourable regions studied by this procedure are the Bafq-Robateh Posht e Badam region (Saghand, Narigan, Khoshumi), Maksan and Hudian in south-eastern Iran and Dechan, Mianeh and Guvarchin in Azarbaijan. Outside of the airborne geophysical coverage area, uranium mineralisation at Talmesi, Meskani, Kelardasht and the salt plugs of south Iran are also worthy of mention.

Mine development

At the Saghand uranium mine (1 and 2), feasibility studies and basic engineering designs (1994-1995) and mining preparation reports (1996) led to the construction of administration and industrial buildings and procurement of equipment (1997-1998). Shafts No. 1 and No. 2 were sunk from 1999 to 2002 and the underground development of the Saghand mine began in 2003.

The Khoshumi area is composed of 47 anomalies that are mainly related to metamorphite-type uranium deposits. Orefield No. 6 of this area was considered for feasibility studies. Five anomalies in Narigan turned out to be ore fields of hydrothermal and metasomatite-type uranium deposits. Mineral deposit No. 3 in the Narigan area was a candidate for feasibility studies.

Recent and ongoing uranium exploration and mine development activities

Uranium exploration activities

Following the development of a comprehensive plan, exploration activities are being performed within favourable areas from reconnaissance to detailed phases. The reconnaissance and prospecting phases are being undertaken in the central, southern, eastern, south-eastern and north-western provinces of the country, and uranium mineralisation with positive indications has been found in various geological environments. Uranium exploration (prospecting and general exploration) is being conducted in different parts of the country for different types of deposits, such as granite-related, metasomatite, volcanogenic, intrusive, and sedimentary types.

Mine development activities

The development of mines No. 1 and 2 is being carried out in the Saghand mining and industrial complex. In mine No. 1 open-pit methods is being used to access orebodies after overburden stripping. Ore at mine No. 2 is being extracted by underground methods. For this purpose, main and ventilation shafts have been sunk and adits are being drilled. Also, some stopes are being developed at different levels for ore production. The uranium ores extracted from mines No. 1 and No. 2 are transported to the uranium production centre after being mixed.

Feasibility studies of other uranium ore deposits such as Narigan and Khoshoumi have been planned. The conceptual design of the Narigan deposit and detailed design of the Khoshumi deposit have been completed.

Identified conventional resources (reasonably assured and inferred resources)

Based on exploration activities completed during 2017 and 2018, and considering overall changes since the last report, the total in situ RAR is 4 316 tU. These resources are related to metasomatic, granite-related and metamorphite deposit types.

Changes in inferred resources have occurred as a result of new discoveries, most of which are metasomatic-type mineralisation. Some of the inferred resources were moved to the RAR category because of additional studies. Total in situ inferred resources as of 1 January 2019 are 5 535 tU.

Undiscovered conventional resources (prognosticated and speculative resources)

Prognosticated resources amount to 9 800 tU in the <USD 130/kgU cost category, whereas speculative resources are 48 100 tU in the unassigned cost category in 2019. Ongoing exploration is focused on the following areas.

Kerman-Sistan metallogenic trend

The uranium mineralisation potential in this trend is associated with volcanic-related, metasomatic, granite-related and sedimentary types. Exploration is being conducted in several areas and considering the potential of these areas, some of them are expected to be selected for further exploration.

Naiin-Jandagh metallogenic trend

The uranium mineralisation potential occurs in granite-related, volcanic-related and polymetallic types. Surface studies are being undertaken in favourable areas and if results are positive, subsurface exploration will be performed.

Birjand-Kashmar metallogenic trend

The uranium mineralisation potential is associated with sedimentary, granite-related and volcanic-related types. Surface studies are being conducted on favourable areas, and if favourable results are obtained, further exploration, including borehole drilling and logging, will be undertaken.

Hamedan-Marand metallogenic trend

The uranium mineralisation potential is associated with granite-related, volcanogenic, intrusive, and sedimentary types. Surface exploration has identified favourable areas for further subsurface exploration.

Unconventional resources

Recent studies have identified favourable areas for investigation of potential unconventional resources. This includes phosphate rocks, non-ferrous ores, ferrous ores, carbonatite, and black shales. The evaluation of the potential of these resources is being carried out through a staged approach that includes conceptual designs for mining, extraction, and processing. Speculative unconventional resources in the unassigned cost category are estimated to amount to 53 000 tU.

Uranium production

Historical review

Uranium ore recovered by open-pit mining of the Gachin salt plug (surficial type) has been processed at the Bandar Abbas uranium plant since 2006.

Status of production facilities, production capability, recent and ongoing activities and other issues

The Bandar Abbas uranium plant began operating in 2006 with a nominal annual production capacity of 21 tU and closed down in 2016. A second production facility, located near Ardakan, began operating in 2017. It has a nominal annual production capacity of 50 tU and will be supplied with ore from the Saghand uranium mine.

Ownership structure of the uranium industry

The owner of the uranium industry is the Government of Iran and the operator is the Atomic Energy Organization of Iran (AEOI).

Future production centres

In addition to the currently operating Ardakan uranium plant production centre, feasibility studies for the planning of the Narigan production centre are underway.

Uranium production centre technical details

(as of 1 January 2019)

	Centre #1	Centre #2
Name of production centre	Gachin	Ardakan
Production centre classification	Closed down in 2016	Existing
Date of first production	2006	2017
Source of ore:		
Deposit name(s)	Gachin	Saghand
Deposit type(s)	Salt Plug (Surfical)	Metasomatic
Recoverable resources (tU)	84.1	500
Grade (% U)	0.068	0.0552
Mining operation:		
Type (OP/UG/ISL)	OP	OP/UG
Size (tonnes ore/day)	70	400
Average mining recovery (%)	80	90
Processing plant:		
Acid/alkaline	Acid	Acid
Type (IX/SX)	SX	IX/SX
Size (tonnes ore/day)	70	280
Average process recovery (%)	73	80
Nominal production capacity (tU/year)	21	50
Plans for expansion	Yes	Yes
Other remarks		

Uranium exploration and development expenditures and drilling effort – domestic

(In IRR millions [Iranian Rial])

	2016	2017	2018	2019 (preliminary)
Government exploration expenditures	319 791	934 000	208 500	174 000
Government development expenditures	210 012	495 000	365 750	617 700
Total expenditures	529 803	1 429 000	574 250	791 700
Government exploration drilling (m)	7 216	6 062	1 883	4 757
Government exploration holes drilled	28	27	11	48
Government exploration trenches (m)	1 931	1 933	2 670	1 509
Government exploration trenches (no.)	26	98	67	53
Government development drilling (m)	1 680	3 350	8 252	4 326
Government development holes drilled	278	670	1 650	721
Total drilling (m)	8 896	9 412	10 135	9 083
Total number of holes drilled	306	697	1 661	769

Reasonably assured conventional resources by production method

(in situ tonnes U*)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	0	491	491	80-90
Open-pit mining (OP)	0	0	136	136	40-50
Unspecified	0	0	3 689	3 689	NA
Total	0	0	4 316	4 316	

* In situ resources.

Reasonably assured conventional resources by processing method

(in situ tonnes U*)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	0	491	491	80-90
Heap leaching** from OP	0	0	136	136	40-50
Unspecified	0	0	3 689	3 689	NA
Total	0	0	4 316	4 316	

* In situ resources.

** A subset of open-pit and underground mining, since it is used in conjunction with them.

Reasonably assured conventional resources by deposit type

(in situ tonnes U*)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Granite-related	0	0	653	653
Metamorphite	0	0	136	136
Metasomatic	0	0	3 527	3 527
Total	0	0	4 316	4 316

* In situ resources.

Inferred conventional resources by production method

(in situ tonnes U*)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	0	876	876	80-90
Unspecified	0	0	4 659	4 659	NA
Total	0	0	5 535	5 535	

* In situ resources.

Inferred conventional resources by processing method

(in situ tonnes U*)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	0	876	876	80-90
Unspecified	0	0	4 659	4 659	NA
Total	0	0	5 535	5 535	

* In situ resources.

Inferred conventional resources by deposit type

(in situ tonnes U*)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Granite-related	0	0	479	479
Metamorphite	0	0	25	25
Volcanic-related	0	0	128	128
Metasomatic	0	0	4 903	4 903
Total	0	0	5 535	5 535

* In situ resources.

Prognosticated conventional resources

(tonnes U*)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
0	9 800	9 800

Speculative conventional resources

(tonnes U*)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
0	0	48 100

Historical uranium production by production method

(tonnes U in concentrate)

Production method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Open-pit mining[1]	76	8.1	3.0	3.9	91.0	4.2
Underground mining[1]	0	0.0	12.1	15.6	27.8	16.8
Total	76	8.1	15.1	19.5	118.8	21.0

1. Pre-2015 totals may include uranium recovered by heap and in-place leaching.

Historical uranium production by processing method

(tonnes U in concentrate)

Processing method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Conventional	76	8.1	15.1	19.5	118.8	21.0
Total	76	8.1	15.1	19.5	118.8	21.0

Historical uranium production by deposit type

(tonnes U in concentrate)

Deposit type	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Metasomatic	0	0.0	15.1	19.5	34.7	21.0
Surficial	76	8.1	0.0	0.0	84.1	0.0
Total	76	8.1	15.1	19.5	118.8	21.0

Ownership of uranium production in 2018

Domestic				Foreign				Totals	
Government		Private		Government		Private			
(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)
19.5	100							19.5	100

Uranium industry employment at existing production centres

(person-years)

	2016	2017	2018	2019 (expected)
Total employment related to existing production centres	340	290	280	280
Employment directly related to uranium production	135	95	95	95

Short-term production capability

(tonnes U/year)

2020				2025				2030			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
0	0	50	80	NA	NA	NA	NA	NA	NA	NA	NA

2035				2040			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
NA	NA	NA	NA	NA	NA	NA	NA

Net nuclear electricity generation

	2017	2018	2019
Nuclear electricity generated (TWh net)	6.37	6.30	6.30*

* Estimate, based on normal operation of Bushehr-1 reactor unit.

Installed nuclear generating capacity to 2040

(MWe gross capacity)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
915	915	915	915	1 889	1 889	2 863	5 075	6 975	7 925	6 975	7 925

Annual reactor-related uranium requirements to 2040 (excluding MOX)

(tonnes U)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
160	160	160	160	320	325	490	910	1 230	1 390	1 230	1 390

Jordan

Uranium exploration and mine development

Historical review

Uranium exploration in Jordan started in the 1980s by the Natural Resource Authority (NRA). The work included an airborne gamma-spectrometric survey covering the entire Hashemite Kingdom of Jordan, and ground radiometric surveys over selected sites and exploration trenches.

During the 1990s, reconnaissance and exploration studies revealed surficial uranium deposits distributed in several areas of the country:

- Central Jordan: exploration, including 1 700 trenches and over 2 000 samples, were analysed for uranium using a fluorometer, which revealed the occurrence of uranium mineralisation as minute mineral grains disseminated within fine calcareous Pleistocene sediments and as yellowish films of carnotite and other uranium minerals coating fractures of fragmented chalk or marl of Mastrichtian-Paleocene age. Results of channel sampling in three areas indicated uranium contents ranging from 120 to 1 870 ppm U (0.012% to 0.187% U) over an average thickness of about 1.3 m, with overburden of about 0.5 m.
- Several other area with radiation anomalies were identified by the airborne gamma-spectrometric survey (Mafraq, Ruwayshid, Russeifa, Hasa-Qatrana, Dana, Wadi Al-Bahiyyah, Dubaydib, Al Awja, and WadiSahabAlabyad) with potential for hosting uranium mineralisation, but only three areas were covered with follow-up reconnaissance studies (Mafraq, Wadi Al-Bahiyyah and WadiSahabAlabyad).

In 2008, the Jordan Atomic Energy Commission (JAEC) was established, in accordance with the Nuclear Energy Law (Law No. 42) of 2007 and amendments in 2008. The JAEC is the official entity entrusted with the development and implementation of the Jordanian nuclear power programme. The exploration, extraction, and mining of all nuclear materials, including uranium, thorium, zirconium, and vanadium, are under the authority of JAEC.

The Nuclear Fuel Cycle Commission of JAEC is in charge of developing and managing all aspects of the nuclear fuel cycle, including uranium exploration, extraction, production, securing fuel supply and services, nuclear fuel management and radioactive waste management. The JAEC uranium policy is to maximise sovereignty while creating value from resources and to avoid concessions to foreign companies. To attract investors and operate on a commercial basis, JAEC created Jordan Energy Resources Inc. as its commercial arm.

In September 2008, JAEC signed an exploration agreement with Areva S.A. (now Orano S.A.) and created the Jordanian French Uranium Mining Company (JFUMC), a joint venture created to carry out all exploration activities and which led to a feasibility study of developing resources in the Central Jordan Area. In January 2009, JAEC signed a memorandum of understanding entitling Rio Tinto to carry out reconnaissance and prospecting in three areas (north of Al-Bahiyyah, Wadi SahbAlabiadh, and Rewashid). Exploration activities by Jordanian teams in co-operation with the China Nuclear International Uranium Corporation were carried out in two other areas (Mafraq and Wadi Al-Bahiyyah).

During 2009-2012, JFUMC explored the northern part of the central Jordan license area, which included geological mapping, a radiometric survey, trenching, sampling, chemical analyses, development of an environmental impact assessment and a hydrogeological study, building a database inventory, and drilling a total of 5 691 boreholes that were surveyed for gamma radiation at 0.10 m intervals. These data have been integrated to intervals of 0.50 m, which is equal to the length of the drill core samples that were assayed by Inductively Coupled Plasma (ICP) and X-Ray Fluorescence (XRF) methods and used for calibration of the equivalent uranium (eU) data. Jordan terminated the mining agreement with JFUMC at the end of 2012.

Recent and ongoing uranium exploration and mine development activities

In 2013, JAEC established the Jordan Uranium Mining Company (JUMCO) as a commercial arm to complete the exploration and resource estimation of the Central Jordan Uranium Deposits.

During 2013-2018, JUMCO completed several exploration activities, including trenching, channel sampling (QA/QC) and chemical analyses. In June 2018, the third JORC compliant report was issued.

The estimated resources for the Central Jordan Uranium Project (CJUP) deposit are reported in compliance with JORC (2012) as mineral resources at an 80 ppm U cut-off grade, and include measured, indicated and inferred categories. In total, the CJUP deposit contains approximately 303 Mt of uranium mineral ore at an average grade of 116 ppm U_3O_8 (0.01% U), as of February 2018.

Plans for 2019-2020 include a drilling programme on a 50 x 50 m grid in selected areas to upgrade the resource category of the deep mineralised layer to measured resources leading to pre-feasibility studies.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

Central Jordan Area

JORC compliant resource estimation includes 33 300 tU as inferred resources and 8 000 as reasonably assured resources (in situ).

Hasa-Qatrana Area

In 2012, a preliminary resource estimation was carried out in this area, covering seven mineralised zones with a total in situ inferred resource of about 28 700 tU.

Undiscovered conventional resources (prognosticated and speculative resources)

No change (about 50 000 tU as speculative resources in carbonate rock deposits in Mafraq and Wadi Al-Bahiyyah areas and sandstone deposits in Dubaydib Area).

Unconventional resources and other materials

No change (about 100 000 tU in the phosphate deposits).

Uranium production

Historical review

Jordan does not currently produce uranium. In 1982, a feasibility study for uranium extraction from phosphoric acid was completed by an engineering company (Lurgi A.G. of Frankfurt, Germany) on behalf of the Jordan Fertiliser Industry Company, and the company was subsequently purchased by the Jordan Phosphate Mines Company. One of the extraction processes evaluated was originally found to be economically feasible, but as uranium prices dropped in the 1990s, the process became uneconomic and construction of an extraction plant was deferred.

In 2009, SNC-Lavalin performed a technological and economic feasibility study for the recovery of uranium from the phosphoric acid produced at the Aqaba Fertilizer Complex. This study was performed jointly with Prayon Technologies S.A. The profitability was evaluated to be 6.8% for the internal rate of return.

JUMCO is currently conducting research to develop optimised extraction parameters, including:

- Research on dynamic alkaline leaching of central Jordan ore, which has provided promising results of more than 90% recovery.
- The evaluation of process parameters and recovery of uranium at a laboratory scale, using 1-2 m high, 0.14 m diameter extraction columns. The results were promising with more than 80% recovery.
- The evaluation of a scale-up parameters and extraction process at a small scale pilot plant, using 6 m high, 0.5 m diameter extraction columns for a large -scale heap leach. Recovery was in line with previous laboratory studies.
- Installation and commissioning of a pilot-scale extraction plant (three cribs, 3 x 3 x 6 m) with a capacity of approximately 180 tons of ore. The plant is scheduled to be commissioned for ore extraction in 2020. The data collected from the plant will be used for commercial-scale extraction plant.
- Planning to build one cell heap leaching pad (30 x 50 x 6 m) to evaluate the extraction process for real scenarios.

Status of production capability

Jordan does not have firm plans in place to produce uranium. Nevertheless, JUMCO is investigating the perspectives of uranium production in the country and will prepare a bankable feasibility study as soon as other related studies are finished.

Uranium requirements

In 2010, Jordan announced plans to pursue the development of civil nuclear power, stating its intention to have four units in operation by 2040. Nuclear co-operation agreements have been signed with a number of countries, including Canada, China, France, Japan, Korea, Russia, and the United Kingdom. In 2011, it was reported that Jordan would be receiving bids from nuclear power plant vendors. Currently, the kingdom imports over 95% of its energy needs, and disruptions in natural gas supply from Egypt have reportedly cost Jordanians more than USD 1 million a day.

Despite the need to generate electricity by other means, the accident at the Fukushima Daiichi nuclear power plant has created some local resistance to the plan to have one 700-1 200 MWe reactor operating by 2020 and a second unit of similar size by 2025. This has created some issues related to site selection for the planned reactor construction.

Applying exclusion and discretionary criteria, a country-wide survey was carried out and a proposed site (2.5 km^2) was selected for the construction of the nuclear power plant. Currently, detailed studies are being carried out to evaluate and characterise the selected site, as well as other studies related to the construction and operation of the nuclear power plant.

National policies related to uranium

With Jordan's intention to develop a peaceful atomic energy programme for generating electricity and water desalination, JAEC restarted uranium exploration in the country with the goal of achieving some energy self-sufficiency.

Uranium exploration and development expenditures and drilling effort – domestic

(JOD [Jordanian dinars])

	2016	2017	2018	2019 (expected)
Government exploration expenditures	2 043 200	2 500 000	3 420 000	2 500 000
Total expenditures	2 043 200	2 500 000	3 420 000	2 500 000
Government exploration trenches (m)	4 856	3 152	6 944	0
Government trenches	1 214	788	1 736	0

Reasonably assured conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	0	0	8 000	8 000	NA
Total	0	0	8 000	8 000	

Reasonably assured conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Heap leaching* from OP	0	0	8 000	8 000	NA
Total	0	0	8 000	8 000	

* A subset of open-pit and underground mining, since it is used in conjunction with them.

Reasonably assured conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Surficial	0	0	8 000	8 000
Total	0	0	8 000	8 000

Inferred conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	0	0	62 000	62 000	NA
Total	0	0	62 000	62 000	

Inferred conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Heap leaching* from OP	0	0	33 300	33 300	NA
Unspecified	0	0	28 700	28 700	NA
Total	0	0	62 000	62 000	

* A subset of open-pit and underground mining, since it is used in conjunction with them.

Inferred conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Surficial	0	0	62 000	62 000
Total	0	0	62 000	62 000

Speculative conventional resources

(tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
0	50 000	NA

Kazakhstan

Uranium exploration

Historical review

Since the beginning of uranium exploration in 1944 in Kazakhstan, about 60 uranium deposits have been identified in six uranium ore provinces – Shu-Sarysu, Syrdarya, Northern Kazakhstan, Caspian, Balkhash and Ili.

By the late 1970s, deposits suitable for uranium mining by in situ leaching (ISL), such as Inkai, Mynkuduk, Moinkum, Kanzhugan and North and South Karamurun, were discovered.

Recent and ongoing uranium exploration and mine development activities

During 2017 and 2018, exploration was undertaken at Inkai, Budenovskoye in the Shu-Sarysu Uranium Province and at the Northern Kharasan and Zarechnoye deposits in the Syrdaria Uranium Province.

Inkai JV LLP returned sites No. 2 and 3 to the state in 2017 and in 2018-2019 continued further exploration of site No. 1 of the Inkai deposit.

Kyzylkum LLP and the Baiken-U LLP completed exploration at the Northern Kharasan deposit.

Zarechnoye JSC is performing additional exploration and re-evaluation of resources at the Zarechnoye deposit.

NAC Kazatomprom JSC has restarted exploration and ISL pilot production at the Zhalpak deposit in 2017.

Volkovgeology JSC started geological prospecting of sandstone-type deposits amenable for ISL mining at new perspective areas of the Shu-Sarysu uranium provinces, with funding from the NAC Kazatomprom JSC budget.

Exploration in 2017-2018 resulted in an increase of identified resources by 149 621 tU. These resource increases occurred at the Budenovskoye (sites No. 6 and No. 7), Inkai (sites No. 1 and 4), Tortkuduk block at Moinkum and Northern Kharasan (site Kharasan-1) deposits.

No uranium exploration and development was performed by Kazakh enterprises outside of Kazakhstan.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

As of 1 January 2019, identified in situ uranium resources available at a cost <USD 260/kgU amounted to 1 102 679 tU, including 808 976 tU of resources amenable for ISL recovery. Total recoverable resources, with mining and processing losses taken into consideration, amounted to 969 169 tU, including 719 989 tU amenable for ISL mining.

Identified in situ uranium resources increased by 71 348 tU compared to the previous report as a result of geological exploration at sandstone deposits during 2015-2018 (depletion of the resources by mining in 2017 and 2018 was taken into account). These resource increases occurred at the Budenovskoye (sites No. 6 and No. 7), Inkai (sites No. 1 and 4), Tortkuduk block at Moinkum and Northern Kharasan (site Kharasan-1) deposits.

In Kazakhstan, 95% of all identified in situ uranium resources (RAR plus IR) available at <USD 40/kgU are associated with existing and committed production centres, whereas 94% at <USD 80/kgU, 71% at <USD 130/kgU and 66% at <USD 260/kgU are associated with existing and committed production centres.

Undiscovered conventional resources (prognosticated and speculative resources)

Re-evaluation of prognosticated and speculative resources was done during this reporting period (2017-2018). The majority of the total of 109 754 tU of prognosticated resources are related to sandstone deposits, while the remaining are metasomatite deposits. Of the 186 280 tU of speculative resources, 90% are related to sandstone deposits and 10% to metasomatite deposits.

Unconventional resources and other materials

Estimates are not made of Kazakhstan's unconventional uranium resources and other materials.

Uranium production

Historical review

The growth of uranium production in Kazakhstan is connected with the development of sandstone-type deposits of uranium, suitable for ISL mining, which is one of the lowest cost methods of uranium production that has a minimal impact on the environment when done properly.

Production capability and recent and ongoing activities

Over the two-year reporting period (2017 and 2018), uranium production in Kazakhstan totalled 45 096 tU.

Uranium was mined at the Kanzhugan, Moinkum, Akdala, Uvanas, Mynkuduk, Inkai, Budenovskoye, North and South Karamurun, Irkol, Zarechnoye, Semizbay, Northern Kharasan deposits. All uranium deposits were mined by the ISL method.

Shu-Sarysu uranium province

The Uvanas, Mynkuduk (Eastern and Central sites), Kanzhugan, Moinkum (the southern part of site No. 1 and site No. 3) deposits were transferred by NAC Kazatomprom JSC to the Ortalyk LLP and Kazatomprom-SaUran LLP (uniting Stepnoye Mining Group LLP and Taukent Mining Chemical Plant LLP) enterprises. NAC Kazatomprom JSC started ISL pilot production at the Zhalpak deposit in 2017.

JV Katco LLP takes part in the operation of the Moinkum deposit (northern part of sites No. 1 (Southern) and No. 2 (Tortkuduk).

JV Inkai LLP operates the Inkai deposit (site No. 1) and sites No. 2 and No. 3 were returned to the state fund. In 2018, NAC Kazatomprom JSC obtained exploration contracts for areas No. 2 and No. 3 of the Inkai deposit.

Appak LLP develops the Western site of the Mynkuduk deposit.

JV Akbastau JSC operates sites No. 1, No. 3 and No. 4 of the Budenovskoye deposit, Karatau LLP develops site No. 2 of the Budenovskoye deposit, and performs processing of solutions extracted from the sites No. 1 and No. 3 of Budenovskoye deposit.

JV South Mining Chemical Company LLP (SMCC) operates the Akdala and Inkai (site No. 4) deposits.

Syrdarya uranium province

NAC Kazatomprom JSC through the Mining Group-6 LLP operated the North and South Karamurun deposits.

The Irkol deposit was developed by Semizbay-U LLP and Baiken-U LLP carries out uranium production at the Northern Kharasan (site Kharasan-2) deposit.

Khorasan-U LLP operates the Northern Kharasan (site Kharasan-1) deposit, and processing is carried out by Kyzylkum LLP.

JV Zarechnoye JSC develops Zarechnoye deposit.

The company Balausa LLP is developing the vanadium Bala-Sauskandykskoye deposit by open-pit mining. A very small amount of uranium bearing ore, containing about 745 kgU, was mined and stockpiled during 2017-2018.

Northern Kazakhstan uranium province

Stepnogorsk Mining Chemical Complex LLP has stopped production at the Vostok and Zvezdnoe deposits and the mine was closed in 2013.

Semizbay-U LLP operates the Semizbay deposit by acid in situ leaching.

As of 1 January 2019, the total capacity of uranium production centres in Kazakhstan was 25 000 tU/yr.

Uranium production at ISL mines in Kazakhstan is carried out using sulphuric acid to produce pregnant uranium solutions. Further processing of pregnant solutions using ion-exchange sorption-elution technologies produces a uranyl salts precipitate that, with further extraction refining, results in the production of natural uranium concentrates.

A number of mining enterprises (Appak LLP, Karatau LLP, JV South Mining Chemical Company LLP, Inkai LLP, Baiken-U LLP) obtain natural uranium concentrate by precipitation of uranium using hydrogen peroxide and further calcination without an extraction stage.

Ownership structure of the uranium industry

In 2018, the state share of uranium production in Kazakhstan was 55% (11 842 tU), including 36% from NAC Kazatomprom owing to its partnership in joint ventures and 19% by NAC Kazatomprom's own production. NAC Kazatomprom is majority owned (85%) by the state-owned company, the Samruk-Kazyna JSC national wealth fund, and 15% of its shares are traded on the London Stock Exchange.

NAC Kazatomprom JSC owns 100% of the following production centres: Kazatomprom-SaUran LLP, Mining Group-6 LLP, and Ortalyk LLP, all of which produce uranium by ISL method.

In 2018, NAC Kazatomprom held shares in joint ventures with private companies from Canada, Japan and Kyrgyzstan (JV Inkai LLP, Appak LLP, Kyzylkum LLP, Khorasan-U LLP, Baiken-U LLP, JV Zarechnoe JSC, JV Budennovskoye LLP), and with foreign state companies from China, Russia and France (Semizbai-U LLP, JV Katco LLP, SMCC LLP, JV Akbastau JSC, Karatau LLP, JV Zarechnoe JSC, Kyzylkum LLP, Khorasan-U LLP). In 2018, the production share of private foreign companies in Kazakhstan amounted to 17%, while the share of state foreign companies in Kazakhstan amounted to 28% of total production.

Uranium production centre technical details

(as of 1 January 2019)

	Centre #1	Centre #2	Centre #3	Centre #4	Centre #5	Centre #6	Centre #7	Centre #8
Name of production centre	Kazatomprom-SaUran LLP: Taukent Mining Chemical Plant	Kazatomprom-SaUran LLP: Stepnoye Mining Group	Mining Group-6 LLP	South Mining Chemical Company LLP	JV Katco LLP	JV Inkai LLP	JV Zarechnoe JSC	Karatau LLP
Production centre classification	Existing	Existing	Existing	Existing	Existing	Existing	Existing	Existing
Start-up date	1982	1978	1985	2001	2004	2004	2007	2007
Source of ore:								
Deposit name(s)	Kanzhugan, Moinkum (sites 1, 3)	Mynkuduk (Eastern site), Uvanas	North & South Karamurun	Akdala, Inkai (site 4)	Moinkum (sites 1, 2), Tortkuduk	Inkai (sites 1)	Zarechnoye	Budenovskoe (site 2)
Deposit type(s)	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone
Recoverable resources (tU)	29 036	7 374	18 108	86 085	58 102	141 834	9 554	46 892
Grade (% U)	0.052	0.031	0.080	0.052	0.071	0.056	0.050	0.096
Mining operation:								
Type (OP/UG/ISL)	ISL	ISL	ISL	ISL	ISL	ISL	ISL	ISL
Size (tonnes ore/day)								
Average mining recovery (%)	87	90	91	90	85	85	90	90
Processing plant:								
Acid/alkaline	Acid	Acid	Acid	Acid	Acid	Acid	Acid	Acid
Type (IX/SX/AL)	IX, SX	IX	IX	IX	IX	IX	IX	IX
Size (kilolitre/day)	85 000	60 000	60 000	140 000	100 000	80 000	80 000	60 000
Average process recovery (%)	98.9	98.7	98.7	98.9	98.9	98.9	98.5	98.9
Nominal production capacity (tU/year)	1 000	1 300	1 000	3 000	4 000	2 500	1 000	3 000
Plans for expansion	No	No	No	No	No	Yes	No	Yes
Other remarks								

Uranium production centre technical details *(continued)*

(as of 1 January 2019)

	Centre #9	Centre #10	Centre #11	Centre #12	Centre #13	Centre #14	Centre #15	Centre #16
Name of production centre	Ortalyk LLP	Appak LLP	Khorasan-U LLP	Bayken-U LLP	JV Akbastau JSC	Semyzbai-U LLP	Ortalyk LLP	Budenovskoe LLP
Production centre classification	Existing	Existing	Existing	Existing	Existing	Existing	Committed	Prospective
Start-up date	2007	2008	2008	2009	2009	2007	2016 pilot mining	2020 pilot mining
Source of ore:								
Deposit name(s)	Mynkuduk (Central site)	Mynkuduk (Western site)	North Kharasan (site 1)	North Kharasan (site 2)	Budenovskoe (sites 1, 3, 4)	Semyzbai, Irkol	Zhalpak	Budenovskoe (sites 6, 7)
Deposit type(s)	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone
Recoverable resources (tU)	27 895	18 792	41 737	21 480	43 001	34 055	14 396	32 665
Grade (% U)	0.047	0.027	0.204	0.117	0.089	0.050	0.033	0.072
Mining operation:								
Type (OP/UG/ISL)	ISL	ISL	ISL	ISL	ISL	ISL	ISL	ISL
Size (tonnes ore/day)								
Average mining recovery (%)	90	90	90	90	90	87	90	NA
Processing plant:								
Acid/alkaline	Acid	Acid	Acid	Acid	Acid	Acid	Acid	Acid
Type (IX/SX/AL)	IX	IX	IX	IX	IX	IX	IX	IX
Size (kilolitre/day)	70 000	60 000	50 000	60 000	20 000	85 000	0	0
Average process recovery (%)	98.5	98.9	98.5	98.5	98.9	98.6	NA	NA
Nominal production capacity (tU/year)	2 000	1 000	1 400	2 000	600	1 200	0	0
Plans for expansion	Yes	No	Yes	No	Yes	No	Yes	Yes
Other remarks								

Employment in the uranium industry

One of the important areas of personnel policy of NAC Kazatomprom JSC and its subsidiaries and affiliates (hereinafter referred to as Subsidiaries) is the development and training of personnel.

Within the framework of personnel training in specialties relevant to the nuclear industry, the Company and its Subsidiaries work with leading universities and colleges of the Republic of Kazakhstan and abroad. In particular, the training of highly qualified personnel in unique programmes of the undergraduate and graduate specialties that are relevant for the nuclear industry is carried out on the basis of the International Scientific and Educational Centre of the Nuclear Industry (ISECNI), created under the KazNITU Non-profit JSC named after K.I. Satpayev, as well as in EKSTU (East Kazakhstan State Technical University) named after D. Serikbayev, where the international department "New Materials for the Nuclear Industry" operates, which includes leading scientists and specialists from the St. Petersburg Polytechnic University and Tomsk Polytechnic University of the Russian Federation and implements master's programmes in the specialities "Nuclear Energy Materials" and " Innovative technologies for producing uranium products".

At the same time, on the initiative of NAC Kazatomprom JSC, new professions were opened in the Republic of Kazakhstan: "Operator of Fuel Assemblies" and "Operator of Refining Production", educational programmes for which will be implemented in universities and colleges of the country.

In addition to educational training programmes, NAC Kazatomprom JSC and its Subsidiaries also pay great attention to employee development programmes, both in professional areas, including compulsory training in accordance with the legislation of the Republic of Kazakhstan, and for the implementation of targeted programmes and projects (leadership development, efficient manufacturing, corporate culture, safety culture, etc). Also, in order to preserve the unique knowledge, industrial experience of veterans and to transmit and transfer experience and knowledge to a new generation of specialists of NAC Kazatomprom JSC and its Subsidiaries, the Council of Honorary Professors "Aqsaqaldar kenesi" is functioning, uniting 21 veterans of the nuclear industry from among current employees of NAC Kazatomprom JSC and its Subsidiaries, as well as workers on well-deserved rest, whose average work experience in the uranium industry is 36.8 years.

Within the framework of increasing experience and professional competencies, NAC Kazatomprom JSC and its Subsidiaries successfully practice internships at the production facilities of the Company's Subsidiaries, as well as in foreign partner companies.

Future production centres

In October 2016, a new enterprise JV Budenovskoe LLP was formed. The founders of the enterprise were NAC Kazatomprom JSC and Stepnogorsk Mining Chemical Complex LLP. LLP JV Budenovskoye is engaged in exploration of sections No. 6 and No. 7 of the Budenovskoye deposit. The subsoil use contract was transferred from NAC Kazatomprom JSC to JV Budenovskoye in 2017.

The contract for exploration of the Zhalpak deposit was transferred from NAC Kazatomprom JSC to DP Ortalyk LLP.

The prospecting of promising areas of Shu-Sarysu and Syrdaria Uranium Provinces is ongoing and new ISL production centres may be established at discovered deposits.

Secondary sources of uranium

Production and/or use of mixed oxide fuels

Mixed oxide (MOX) fuel is neither produced nor used in Kazakhstan.

Production and/or use of re-enriched tails

Uranium obtained through enrichment of depleted uranium tails is neither produced nor used in Kazakhstan.

Environmental activities and social cultural issues

Environmental activities

Subsoil users created a liquidation fund to eliminate the effects of operations on subsoil use in Kazakhstan. Contributions to the liquidation fund during the exploration and extraction of subsurface users are produced annually at a rate of at least 1% of the annual cost of exploration and production in a special deposit account in any bank in the state.

In 2017-2018, liquidation work in the uranium mines in Kazakhstan was not carried out.

In the framework of ecological policy in Kazakhstan, a number of measures to improve environmental protection and encourage rational use of natural resources have been implemented in recent years.

Each uranium venture in Kazakhstan developed a short-term waste management plan, which includes measures to reduce their generation and accumulation.

Environmental safety has a significant role in the effective functioning of the system of industrial environmental monitoring.

Social and/or cultural issues

All contracts for uranium exploration and mining provided by the government require financial contributions to local social and cultural improvements. All subsoil users are obliged to finance the establishment, development, maintenance and support of the regional social sphere, including health care facilities for employees and local citizens, education, sport, recreation and other activities in accordance with the Strategy of NAC Kazatomprom JSC and by an agreement with local authorities.

Contributions from each operator amount to:

- USD 30 000 to 100 000 per year (during the exploration period);
- up to 15% of annual operational expenses or USD 50 000 to 350 000 per year (during the mining period).

Expenditures on environmental activities and social cultural issues in 2017-2018

(KZT million)

	2017	2018	Total
Environmental impact assessments Monitoring	2 014.3	2 892.9	4 907.3
Tailings impoundment	936.8	1 366.0	2 302.8
Waste rock management	388.8	268.8	657.6
Effluent management	106.1	108.5	214.7
Site rehabilitation	0.0	0.0	0.0
Regulatory activities	0.0	0.0	0.0
Social and/or cultural issues	1 146.2	1 461.4	2 607.6

Uranium demand

Construction of a nuclear power plant is under consideration.

Supply and procurement strategy

At present the entire amount of uranium produced in Kazakhstan is exported to the world market.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

In January 2017, due to the prolonged depression of the uranium market, Kazakhstan's national atomic company, Kazatomprom reduced Kazakhstan's uranium production by approximately 10% for 2017. In December 2017, given the challenging market conditions, and in light of continued oversupply in the uranium market, Kazatomprom announced further production cuts by 20% below the original Subsoil Use Contracts for 2018-2020. In August 2019, Kazatomprom announced its intention to continue to flex down production by 20%, compared to the planned levels under Subsoil Use Contracts through 2021.

On 13 November 2018, Kazatomprom made its stock market debut after raising USD 450 million from investors in London and Astana. Kazatomprom sold 15% of its stock in the dual-listing offering, which valued the company at USD 3 billion.

Taking into account international practice and trends in the regulation of relations in the field of the use of subsoil and their resources, in July 2018, the Code on Subsoil and Subsoil Use entered into force in the Republic of Kazakhstan, and the introduction of the CRIRSCO international system of reporting standards for mineral reserves has also begun.

Adoption of the Code will make it possible to transform the sphere of subsoil use, bring it to a qualitatively new level, increase efficiency, and give its regulation a comprehensive and systematic character, thereby creating conditions for long-term growth.

Uranium exploration and development expenditures and drilling effort – domestic

(KZT million)

	2016	2017	2018	2019 (expected)
Industry* exploration expenditures	6 920	11 122	11 324	9 290
Government exploration expenditures	0	0	0	0
Industry* development expenditures	1 194	739	1 404	1 520
Government development expenditures	0	0	0	0
Total expenditures	8 114	11 861	12 728	10 810
Industry* exploration drilling (m)	497 955	452 415	712 250	745 660
Industry* exploration holes drilled	1 035	795	1 598	1 285
Industry exploration trenches (m)	0	0	0	0
Industry trenches (number)	0	0	0	0
Government exploration drilling (m)	0	0	0	0
Government exploration holes drilled	0	0	0	0
Government exploration trenches (m)	0	0	0	0
Government trenches (number)	0	0	0	0
Industry* development drilling (m)	193 859	202 737	217 718	254 395
Industry* development holes drilled	551	508	503	547
Government development drilling (m)	0	0	0	0
Government development holes drilled	0	0	0	0
Subtotal exploration drilling (m)	497 955	452 415	712 250	745 660
Subtotal exploration holes drilled	1 035	795	1 598	1 285
Subtotal development drilling (m)	193 859	202 737	217 718	254 395
Subtotal development holes drilled	551	508	503	547
Total drilling (m)	691 814	655 152	929 968	1 000 055
Total number of holes drilled	1 586	1 303	2 101	1 832

* Non-government.

Reasonably assured conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	4 179	74 403	98 048	83
Open-pit mining (OP)	0	0	47 237	47 237	91
In situ leaching acid	305 813	382 420	382 420	382 420	89
Total	305 813	386 599	504 060	527 705	88

Reasonably assured conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	4 179	74 403	98 048	83
Conventional from OP	0	0	47 237	47 237	91
In situ leaching acid	305 813	382 420	382 420	382 420	89
Total	305 813	386 599	504 060	527 705	88

Reasonably assured conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	305 813	382 420	395 770	395 770
Metasomatite	0	4 179	61 097	75 471
Phosphate deposits	0	0	29 184	38 455
Lignite-coal	0	0	18 009	18 009
Total	305 813	386 599	504 060	527 705

Inferred conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	4 896	76 630	128 075	83
Open-pit mining (OP)	0	0	18 471	18 471	91
In situ leaching acid	290 333	416 385	426 556	426 556	89
Co-product and by-product	0	1 872	1 8 72	1 872	91
Total	290 333	423 153	523 529	574 974	88

Inferred conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	4 896	76 630	128 075	83
Conventional from OP	0	1 872	20 343	20 343	91
In situ leaching acid	290 333	416 385	426 556	426 556	89
Total	290 333	423 153	523 529	574 974	88

Inferred conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	290 333	418 257	441 019	441 019
Metasomatite	0	4 896	80 226	126 814
Phosphate	0	0	0	4 857
Lignite-coal	0	0	2 284	2 284
Total	290 333	423 153	523 529	574 974

Prognosticated conventional resources

(tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
81 809	109 754	109 754

Speculative conventional resources

(tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
186 280	186 280	NA

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019
Open-pit mining[1]	21 618	0	0	0	21 618	0
Underground mining[1]	42 549	0	0	0	42 549	0
In situ leaching	204 346	24 689	23 391	21 705	274 131	22 808
Total	268 513	24 689	23 391	21 705	338 298	22 808

1. Pre-2015 totals may include uranium recovered by heap and in-place leaching.

Historical uranium production by processing method

(tonnes U in concentrates)

Processing method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019
Conventional	42 109	0	0	0	42 109	0
Heap leaching*	440	0	0	0	440	0
In situ leaching	204 346	24 689	23 391	21 705	274 131	22 808
U recovered from phosphate rocks	21 618	0	0	0	21 618	0
Total	268 513	24 689	23 391	21 705	338 298	22 808

* A subset of open-pit and underground mining, since it is used in conjunction with them.

Historical uranium production by deposit type

(tonnes U in concentrates)

Deposit type	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019
Sandstone	204 346	24 689	23 391	21 705	274 131	22 808
Metasomatite	42 549	0	0	0	42 549	0
Phosphate	21 618	0	0	0	21 618	0
Total	268 513	24 689	23 391	21 705	338 298	22 808

Ownership of uranium production in 2018

Domestic				Foreign				Totals	
Government		Private		Government		Private			
(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)
11 842	55	0	0	6 171	28	3 692	17	21 705	100

Uranium industry employment at existing production centres

(person-years)

	2017	2018	2019 (expected)
Total employment related to existing centres	8 120	7 822	7 802
Employment directly related to uranium production	7 298	7 021	6 979

Short-term production capability

(tonnes U/year)

2020				2025				2030			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
26 000	27 000	27 000	28 000	25 000	26 000	27 000	28 000	20 000	22 000	22 000	24 000

2035				2040			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
12 000	14 000	14 000	16 000	4 000	4 500	4 500	5 000

Madagascar

Uranium exploration and mine development

Historical review

The first uranium exploration activities in Madagascar date back to the "radium period" and focused on pegmatites at Itasy and secondary uranium occurrences at Antsirabe. Uranium deposits were discovered in a lacustrine basin in the central part of Madagascar. Small scale mining started in 1909 and ended in 1939.

The first mission of the French Atomic Energy Commission (CEA) arrived in Madagascar in late 1946. From 1954 to the early 1960s, the CEA explored and mined uranothorianite from the Tranomaro area in southern Madagascar. From 1958 to 1963, the CEA explored for uranium in the Morondava Basin and discovered radiometric anomalies leading to the discovery of the Folakara deposit. After 1963, the CEA ceased all activity in Madagascar.

After geological, geophysical and geochemical surveys were completed by the CEA, OMNIS (Office of National Mines and Strategic Industries), in partnership with the UNDP and the IAEA, continued to undertake geological, geochemical and drilling work in the central, southern and western parts of Madagascar, from 1976 to 1984.

In 1999-2000, OMNIS and COGEMA carried out a brief review of the uranium potential of Madagascar. Detailed exploration activities were only carried out at the Folakora deposit.

In 2003, as part of Madagascar's World Bank funded project, *Projet de Gouvernance sur les Ressources Minérales* (PGRM), the US Geological Survey conducted a preliminary assessment of undiscovered mineral resources, which included sandstone-hosed, metasomatite (U-Th skarn), and phosphate uranium-bearing deposit types. Areas permissive for uranium mineralisation were identified. A follow-up multi-resource assessment that included areas permissive for uranium mineralisation was carried out for the Anosy Region in 2006.

Uranium exploration was revived in 2015. Through OMNIS, the government of Madagascar renewed technical co-operation with the IAEA and carried out limited geological studies and exploration activities in the Makay region in the southern part of the Morondava Basin.

Recent and ongoing uranium exploration and mine development activities

Since 2015, OMNIS with the help of the IAEA, examined the general geology of the Morondava Basin and uranium mineralisation previously discovered in the Karoo formations in the Makay mountain range.

In 2016, OMNIS carried out several ground surveys, including field verification of preliminary geological maps and radiometric anomalies discovered by the CEA in the Makay area. Activities included geological mapping, and structural, geochemical and radiometric studies. Trenches and pits were made, and stream sediments were collected.

In 2017, 16 trenches (10 m long) and 17 pits were completed in the Ambakaka and MAN 20 areas. Uranium anomalies and potentially significant structures were identified and explored. Rock samples were collected for analysis.

In 2018, OMNIS continued its uranium project with detailed exploration in two sectors: MAN 20 and Ambakaka areas. Rock samples were sent for analysis to CNEA in Argentina and CREGU in France.

In 2019, OMNIS continued detailed exploration activities in the Makay area (MAN 20), including geophysical and radiometric surveys (systematic scintillometer and radon coverage), coupled with tectonic/structural studies, trench and pit sampling, stream-sediment sampling, and geological mapping.

Uranium exploration and development expenditures

(in EUR)

	2016	2017	2018	2019 (expected)
Government exploration expenditures	12 000	21 000	NA	20 000
Total expenditure	12 000	21 000	NA	20 000
Trenches (m)	0	160	0	NA
Trenches (no.)	0	16	0	16

Uranium resources

Identified conventional resources (reasonably assured and inferred resources

At present there are no uranium resources in Madagascar which can be reported in the identified resources category.

Undiscovered resources

In 1981 and 1983, the IAEA International Uranium Resources Evaluation Project (IUREP) study estimated Madagascar's speculative resources to be in the range of 10 000-50 000 tU.

Uranium production

Madagascar was one of the first uranium producing countries. During the period 1909-1921, approximately 57 t of uranocircite, containing about 36 tU, were produced from a deposit located in the Antsirabe Basin. Also, between 1912 and 1927, betafite concentrates containing about 24 tU were produced from pegmatites in the Itasy-Antsirabe-Handoto area.

Between 1953 and 1966, the French Atomic Energy Commission and local miners produced uranothorianite from alluvial and primary deposits hosted in the Precambrian metasediments in the Fort Dauphin area. The most important mines were Marosohy, Amboanemba, and Ambindrakembe. A total of 3 986 t of concentrate was produced. The total production is estimated at 785 tU and 3 000 tTh.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

Exploration and mining activities in Madagascar are regulated by the Mining Code. Other policies and laws related to uranium include protection against the risks of ionising radiation, the management of radioactive waste, and the protection of nuclear material, nuclear installations and other sources of radiation.

Malawi*

Uranium exploration and mine development

Historical review

Historical studies indicate that economically recoverable resources of uranium and coal only occur within the Kayelekera area of Malawi. Coal is present in the project tenement area in two deposits: the Nkhachira deposit (850 000 tonnes, recoverable by open-pit and underground mining) and the Kayelekera deposit. Uranium is associated with coal at the Kayelekera deposit, and due to this association, coal is therefore unavailable for commercial extraction (moreover, this coal is of very low quality).

The Kayelekera deposit was discovered in the early 1980s by the Central Electricity Generating Board of Great Britain (CEGB). Kayelekera is a sandstone-hosted uranium deposit, located close to the north tip of the North Rukuru Basin. This basin contains a thick (at least 1 500 m) sequence of Permian Karoo sandstones preserved in a semi-graben about 35 km to the west of and broadly parallel to the Lake Malawi section of the East African Rift System. Mineralisation lies within the uppermost 150 m of the Muswanga Member, which is the upper part of the Karoo Formation. The Muswanga Member consists of a total of eight separate arkose units with intervening silty mudstones in an approximate 1:1 ratio. Such a succession is indicative of cyclic sedimentation within a broad, shallow, intermittently subsiding basin. The arkose units contain most of the uranium mineralisation. They are on average about 8 m thick, are generally coarse grained and poorly sorted, and contain a high percentage of fresh, pink feldspar grains. The basal arkose units are usually a quartz-feldspar pebble conglomerate. Coffinite has been identified as the principal uranium-bearing species and it occurs together with minor uraninite. Near-surface weathering of primary ore has produced a zone of oxide ore characterised by yellow and green secondary uranium minerals (meta-autunite and boltwoodite). Approximately 40% of the total ore occurs within reduced arkose, 30% within oxidised arkose, 10% in mixed arkose, and 20% is considered of the mudstone type.

Extensive drilling from 1982 to 1988 defined an initial inferred resource of 9 800 tU at an average grade of 0.13% U. From 1989 to 1992, geotechnical, metallurgical, hydrological and environmental activities were conducted, as well as a feasibility study to assess the viability of a conventional open-pit mining operation. This work was completed in 1991 at a total cost of USD 9 million. The CEGB study concluded that the project was uneconomic using the mining model adopted and the low uranium prices of that time and so the project was abandoned in 1992.

In 1998, Paladin Resources Ltd (Paladin Energy Ltd as of 1 February 2000) acquired an interest in the Kayelekera Project through a joint venture with Balmain Resources Ltd, which at that time held exploration rights over the project area. Engineering and financial evaluation work indicated a positive outcome for the project. In 2004, additional drilling was completed to improve confidence in resource estimates, and the pre-feasibility study was updated. Resource drilling and bulk sample drilling for metallurgical test work was completed in 2005 and a bankable feasibility study was then undertaken. Paladin purchased Balmain's remaining stake in the project in 2005 and became the sole owner.

* Report prepared by the NEA/IAEA, based on previous Red Books and company reports.

Uranium exploration increased as a result of expanding resources at the Kayelekera mine and the potential for discovery of additional deposits in a similar geological setting in the Karoo Group sedimentary rocks. Since 2010, Paladin Energy has completed exploration drilling in areas to the north-west and south of the mine area with objectives of extending the existing orebody, as well as identifying and evaluating new ore bodies, including Mpata to the east and Juma to the south.

The Livingstonia uranium project is a joint venture between two Australian companies, Resource Star and Globe Metals and Mining. The geological setting is very similar to that of Kayelekera. In 2006, Globe drilled 94 holes totalling 11 533 m. In July 2010, Resource Star did an additional 1 502 m of drilling in 13 holes to prove up a JORC compliant inferred resource of 7.7 million tonnes ore grading 0.0229% U. In 2013, Resource Star, the operator of the Livingstonia Project, reported that thickened zones of mineralisation are open to the north-east, and the sparse drilling in the southern zone increases potential for additional mineralisation being defined. The mineralisation is also open to the north where the project adjoins tenements owned by Paladin Energy Ltd.

Another potential uranium resource is the Kanyika Niobium Project held by Globe Metals. Uranium is an important by-product in the complex polymetallic ore in a pegmatite quartz vein, hosted in Proterozoic felsic schists. Niobium and tantalum products would be produced with uranium and zircon as by-products. In 2011-2012, Globe Metals & Mining continued development of the Kanyiba deposit. Total drilling, reverse circulation and diamond drilling, amounted to 40 540 m. As of December 2012, total resources amount to 68.3 Mt of ore at average grade of 0.28% Nb_2O_5, 0.0135% Ta_2O_5 and 0.0666% U (4 550 tU). Globe Metals & Mining submitted an environmental impact assessment for the Kanyika Niobium Project for public review in May 2012.

Recent and ongoing uranium exploration and mine development activities

The anticipated early approval by the Department of Mines of applications for five exclusive prospecting licences (EPLs), covering areas north, south and east of Kayelekera mine, which would have enabled exploration activity to commence in July 2015, did not occur. The government of Malawi imposed a moratorium on applications and grants of all mining and exploration tenements until it introduces a new cadastral system and a new minerals act. As a result, Paladin suspended exploration activities in Malawi until there is clarity on the provisions of the new mining code and its EPL applications have been granted.

In 2013, Global Metals & Mining approved a demonstration plant to further optimise process design and reduce project risk of Kanyika Niobium Project. The focus of the pilot plant is to validate bench-scale testing results obtained during the optimisation phase of the Kanyika Definitive Feasibility Study, and also to validate engineering data for plant design. The Kanyika bulk sample is located at the Guangzhou Research Institute of Non-Ferrous Metallurgy (China) and the pilot plant is in progress. The mineral concentrate produced from this pilot plant exercise will be used for further downstream metallurgical testing and production of marketing samples.

In February 2018, Globe Metals started a feasibility study aimed at updating and finalising the technical components of the engineering programme in order to support project funding initiatives.

In January 2019, Globe metals announced that it had finalised the feasibility study, including revision of the mineral resource estimates, mining, metallurgical studies, processing, engineering design and infrastructural support. It obtained updated capital and operating cost estimates and updated its financial model. However, Globe Metals is not yet in a position to finalise the financial model and the key outcomes of the project, due to the current uncertainty associated with the status of the mining law in Malawi, and to the status of negotiations between Globe Metals and the Government on the Development Agreement.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

Malawi's total recoverable identified resource is 14 277 tU. This is based on resources at three locations: Paladin's Kayelekera operating mine (9 725 tU), Resource Star's Livingstonia deposit (1 822 tU) (both sandstone deposits), and Globe Metal's Kanyika niobium deposit (2 730 tU), where uranium will be produced as a by-product.

Uranium production

Historical review

The Kayelekera mine is located in the Karonga district of the northern region of Malawi, about 600 km by road from the capital city of Lilongwe. Transport of the first product to Walvis Bay, Namibia, via Zambia, took place on 17 August 2009. Uranium production is by open pit with an annual production of 1 270 tU planned with a mine life of nine years.

Uranium is recovered using a solvent extraction process, with sulphuric acid as the lixiviant and sulphur dioxide/air mixture as the oxidant. The plant utilises a resin-in-pulp (RIP) process which is a first in the Western world for uranium production. Expected uranium mill recovery is 90%. Production was hampered in 2009 and 2010 by technical problems with the RIP process. In addition, land slip problems in 2010 resulted in remediation work being implemented and made it necessary to relocate certain parts of the plant and machinery.

Kayalekera was the first mine to have produced uranium in Malawi. However, as a result of the sustained low uranium price, it was announced in February 2014 that processing would cease at Kayelekera and that the site would be placed on care and maintenance.

Status of production facilities, production capability, recent and ongoing activities and other issues

In 2013, Kayelekera mine made progress on cost reductions, mainly on the acid supply front, where the project became acid independent through a number of measures. Improvements included increases in on-site acid production and the addition of the nano-filtration plant, which assisted with acid recycle. In addition to acid management, other improvements were realised in the milling, leach and RIP efficiencies, particularly with completion of modifications in the RIP section.

In 2014, the site was placed on care and maintenance. Following a period of reagent run-down, processing was completed in early May 2014. This was expected to cost about USD 12 million per year, ongoing, compared with operating losses of double of that. It is expected that production will recommence once the uranium price provides a sufficient incentive (circa USD 75/lb U_3O_8; USD 195/kgU) and grid power supply is available on-site to replace the existing diesel generators with low-cost hydroelectricity.

In 2013 and 2014, the Kayelekera mine produced 1 132 tU and 369 tU, respectively. Once uranium prices offer sufficient incentive for restart, production, with some RIP/elution upgrades, is expected to be up to 1 270 tU per year.

Ownership structure of the uranium industry

Two Australian companies, Paladin Energy and Resource Star, used to be active in Malawi in the primary uranium sector.

Paladin held an 85% interest in the Kayelekera Project through its subsidiary company Paladin (Africa) Limited. The remaining 15% is held by the Republic of Malawi according to terms of the Development Agreement signed in 2007. Paladin had supplemented ongoing mining with extensive exploration activities aimed at growing its resource base in Malawi. However, in June 2019 Paladin Energy agreed to sell its 85% interest in the mine to Hylea Metals subsidiary Lotus

Resources Ltd (65%) and to Chichewa Resources (20%) for AUD 5 million. Paladin will receive a 3.5% royalty based on revenues derived from future production at Kayelekera, capped at AUD 5 million.

In 2010, Resource Star signed a joint venture agreement with Globe Metals and Mining over their Livingstonia Project, with Resource Star managing work and earning up to 80% equity. In May 2012, Resource Star announced that it would acquire 100% of the Livingstonia Project from Globe. The Malawi authorities approved the transfer of the exploration licence to Resource Star in November 2012 at which time Resource Star applied to the Malawi authorities for a two-year extension to the term of the Livingstonia tenement.Global Metals is also involved in rare earth exploration with significant uranium by-product potential.

Uranium production centre technical details

(as of 1 January 2015)

	Centre #1	Centre #2
Name of production centre	Kayelekera	Kanyika
Production centre classification	Care and maintenance	Planned
Date of first production (year)	2009	NA
Source of ore:		
Deposit name(s)	Kayelekera	Kanyika
Deposit type(s)	Sandstone	Intrusive
Recoverable resources (tU)	9 725	2 730
Grade (% U)	0.73	0.08
Mining operation:		
Type (OP/UG/ISL)	OP	OP
Size (tonnes ore/day)	4 000	6 000
Average mining recovery (%)	75	NA
Processing plant:		
Acid/alkaline	Acid	NA
Type (IX/SX)	SX	NA
Average process recovery (%)	80	NA
Nominal production capacity (tU/year)	1 270	60
Plans for expansion (yes/no)	Yes	NA
Other remarks	Ramp up to 1 460 tU/yr	By-product

Employment in the uranium industry

Paladin employed 759 people at the Kayelekera mine in 2012, of which 118 were expatriates and 68, or 9%, were female.

Future production centres

Globe Metals & Mining submitted the environmental impact assessment for the Kanyika Niobium Project for public review in May 2012. According to Globe, the aim of the project is to produce niobium and tantalum products with potential production of uranium and zircon. Uranium would be produced as a by-product at a nominal rate of 80 t $Na_2U_2O_7$ (ammonium di-uranate) per year (60 tU/yr). Mining will involve the extraction of ore from a single open pit at a rate of 1.5 million tonnes per annum using conventional open-pit drill and blast, followed by truck shovel load and haul. The final open-pit dimensions are expected to be in the order of 250 m wide, 2.2 km long (north-south) and 130 m deep. The project will produce approximately 52 million tonnes of solids to tailings over the mine life (estimated in excess of 20 years).

As of January 2019, Globe Metals could not place a timeframe upon when mining and processing at Kanyika could start.

Environmental activities and socio-cultural issues

There are no updates for the current reporting period.

Uranium requirements

Currently Malawi has no plans for nuclear power.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

All mining activities are under the control of the Department of Mines of the Ministry of Natural Resources with environmental matters falling under the Department of Environmental Affairs in the same ministry. However, in common with many developing countries, Malawi has no specific legislation or a regulation relating to uranium, but it is working in co-operation with the IAEA to develop appropriate legislation. In 2011, the National Assembly passed an atomic energy bill, which is the first step of the introduction of comprehensive legislation to provide for adequate protection of people as well as the environment against harmful effects of radiation, nuclear material and radioactive materials.

The government is committed to putting in place policies that will attract private sector participation in the exploration, exploitation, processing and utilisation of Malawi's mineral resources. To this end, in March 2013, the Mines and Mineral Policy of Malawi was developed by the Malawi government. The government recognises that the minerals sector has significant potential to contribute towards the rapid economic growth and development of the country. The policy seeks to stimulate and guide private mining investment by administering, regulating and facilitating the growth of the sector through a well-organised and efficient institutional framework. The government will also intensify provision of extension services to the artisanal and small-scale miners and women miners. The goal of the Mines and Minerals Policy is to enhance the contribution of mineral resources to the economy of the country so as to move from being an agro-based to mineral-based economy.

On 14 December 2018, the National Parliament of Malawi passed a new bill (Mines and Minerals Bill 2018) which legislation is intended to replace the current legislation. For the New Act to come into force it must receive presidential assent, which has not yet occurred.

Reasonably assured conventional resources by production method

(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)			4 420	7 464	80
Co-product and by-product				2 205	60
Total			4 420	9 669	

Reasonably assured conventional resources by processing method
(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from OP			4 420	7 464	80
Other				2 205	60
Total			4 420	9 669	

Reasonably assured conventional resources by deposit type
(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone			4 420	7 464
Intrusive				2 205
Total			4 420	9 669

Inferred conventional resources by production method
(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)			1 822	4 083	80
Co-product and by-product				525	60
Total			1 822	4 608	

Inferred conventional resources by deposit type
(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone			1 822	4 083
Intrusive				525
Total			1 822	4 608

Historical uranium production by deposit type
(tonnes U in concentrates)

Deposit type	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Sandstone	4 217	0	0	0	4 217	0
Total	4 217	0	0	0	4 217	0

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Open-pit mining	4 217	0	0	0	4 217	0
Total	4 217	0	0	0	4 217	0

Historical uranium production by processing method

(tonnes U in concentrates)

Processing method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Conventional OP	4 217	0	0	0	4 217	0
Total	4 217	0	0	0	4 217	0

Short-term production capability

(tonnes U/year)

2020				2025				2030			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
0	0	0	0	0	0	NA	NA	0	0	NA	NA

2035				2040			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
0	0	NA	NA	0	0	NA	NA

Mali*

Uranium exploration and mine development

Historical review

Exploration for uranium in Mali was completed along the border with Senegal between 1954 and 1956 by the French Atomic Energy Commission in the Adrar des Iforas region. Indications of uranothorianite and thorianite were discovered in large pegmatite lenses enclosed in highly metamorphosed hornblende- and pyroxene-schists of the Suggarian sequence. Numerous granites were also studied in the area but only younger granites showed anomalous radioactivity, probably because of the presence of monazite as an accessory mineral.

Under an agreement with the government of Mali, Krupp carried out a reconnaissance survey in the eastern part of Mali in 1970 with no positive results. In 1971, the Institute for Geosciences and Natural Resources (BGR) carried out a hydrogeochemical and radiometric reconnaissance survey in the western Kayes region of the country. Some anomalies were found but their character did not encourage further activities. In 1974, Japan's Power Reactor and Nuclear Fuel Development Corporation (PNC) initiated an exploration project in the Adrar des Iforas covering parts of the Taoudeni sedimentary basin.

In 1976, the Compagnie Générale des Matières Nucléaires (COGEMA) started exploration in the areas of Kenieba, Kayes, Bamako, Sikasso, Hombori, Douentza, and Taoudenni. This work included airborne radiometric surveys in Kenieba and Taoudenni, and geophysical exploration (including drilling) in Kenieba (Faléa and Dabora). COGEMA ended its exploration project in 1983 and PNC limited its activities to a small area of 20 km^2. PNC continued work through the first quarter of 1985, using radon emanometry and very low-frequency electromagnetic survey methods over an area of 14 km^2, and then ended its activities in the second quarter of 1985. From 2007-2008, several other companies conducted uranium exploration in Mali.

In 2007-2008, Australia's Oklo Uranium Ltd. conducted uranium exploration over the Kidal area, part of the underexplored north-eastern part of Mali. Exploration covered a large crystalline geological province known as the Adrar des Iforas that is considered prospective for surficial palaeo-channel-hosted uranium, alaskite/pegmatite and vein-hosted uranium, and contains occurrences of uranium, gold, copper-lead-zinc, and manganese. Target identification has been undertaken in the project area with 47% of an airborne geophysical survey completed in 2007. In 2008, potential uranium anomalies were located and tested with ground spectrometry, geochemical sampling, and drilling.

At Faléa, substantial uranium and copper values were first discovered by COGEMA in the late 1970s, but the project has not advanced because of the prevailing low commodity prices. Exploration conducted since 2008 by Rockgate and Delta had focused on defining and expanding these initial results.

The mineralisation at the Faléa Project occurs within the Neoproterozic to Carboniferous sedimentary sequence of the Taoudeni Basin, a shallow interior sag basin with flat to very shallow dips. Faléa is located along the southern edge of the western province of the Taoudeni Basin. In the previous editions of the Red Book, the Faléa deposit was classified as a sandstone type deposit. Now it is classified as unconformity type deposit. With a few exceptions, mineralisation has been confined to the flat-lying Kania Sandstones unit, as well as within the units immediately above and below it. The distance from the surface to the mineralised horizon varies between 31.5 m to more than 350 m below surface. The first mineralising event related to

* Report prepared by the NEA/IAEA, based on previous Red Books and company reports.

ore genesis is believed to have deposited copper (mostly in the form of chalcopyrite) and silver. The copper mineralisation occurs as disseminations, primarily within the Kania Sandstones, around which halos of uranium minerals precipitated (mostly as pitchblende and coffinite), thus acting as a chemical trap (reductant) for uranium mineralisation.

From January to August 2011, 160 diamond drill holes totalling 45 691 m focused on resource definition in the North Zone and initial exploration drilling at Bala, south of Central Zone, East Zone, and Road Fault. The programme resumed in October 2011 continuing through July 2012 and comprised 398 diamond drill holes totalling 88 350 m. Drilling continued to infill and step-out on the North Zone, and expanded north into the Bodi Zone. An additional 44 diamond drill holes were completed at the East Zone and 19 more at the Central Zone as part of an expanded resource definition programme.

In October and November 2012, a total of 15 936 m was completed in 66 diamond drill holes located in the Bodi and North Zone areas. Almost all work to date has been completed on the Faléa Permit.

Recent and ongoing uranium exploration and mine development activities

In January 2014, Denison concluded the purchase of Rockgate and commenced work on the Faléa project including a detailed project review and re-interpretation of existing exploration data and comprehensive internal economic study. Results have shown the project to be uneconomic under current metal prices, however, the potential could improve if additional resources are discovered.

A versatile time-domain electromagnetic (VTEM) survey, including magnetic and radiometric surveys, was completed in March 2015. A small ground follow-up programme was completed in June 2015, including soil sampling and radiometric prospecting.

In June 2016, GoviEx Exploration (Canada) acquired the Faléa project from Denison Mines. The project includes three exploration licences, Bala, Faléa and Madini.

In 2017, GoviEx conducted a geophysical survey over the Faléa area. Radon measurements were carried out by Radon Ex. Ltd. New targets have been defined, which have to be developed and are likely to increase the resources. No drilling was completed in 2017-2018.

In 2018, GoviEx applied for new exploration licences for the Bala and Madini areas, and renewed the Faléa licence for a second term.

As of 1 January 2019, nine uranium exploration permits had been granted to six exploration companies in Mali. However, because of the rebellion in the north-eastern part of the country, exploration activities are only being undertaken in the western part of the country.

Exploration permits

Eastern part of Mali

Arafat	1 750 km^2	Earthshore Resources Mali Ltd
Diarindi	150 km^2	Merrex Gold
Dombia	254 km^2	Tropical Gold of Mali Sarl
Kidal	3 980 km^2	Oklo Uranium Ltd Mali Sarl
Tessalit	4 000 km^2	Oklo Uranium Ltd Mali Sarl
South Arafat	4 00 km^2	Singkind Mines Mali Sarl

Western part of Mali

Bala	125 km^2	Delta Exploration Mali Sarl
Madini	67 km^2	Delta Exploration Mali Sarl
Faléa	75 km^2	Delta Exploration Mali Sarl

Uranium resources

Identified conventional resources

An updated NI43-101 compliant resource estimate was reported for the Faléa project in October 2015 using a cut-off grade of 0.03% U_3O_8 (0.025% U) resulting in a total indicated resource of 6.88 Mt at an average grade of 0.098% U, 0.161% Cu, 72.8 g/t Ag and an inferred resource of 8.78 Mt at an average grade of 0.059% U, 0.20% Cu, 17.3 g/t Ag. Total in situ identified resources amount to 11 846 tU, which includes 6 692 tU indicated and 5 154 tU inferred (no change compared to the 2018 edition of the Red Book).

Recent metallurgical test work and engineering have confirmed recoveries of uranium, silver, and copper consistently, and hence all of these metals that may be expected from mining. A pre-feasibility study has been initiated based upon the results above, together with an enhanced understanding of the orebody and possible mining and metallurgical solutions.

Environmental activities and socio-cultural issues

On 26 April 2010, Rockgate Capital Corp. announced that it had commissioned Golder Associates to conduct environmental and social baseline studies on the Faléa Project. In January 2014, Denison Mines of Canada took over Rockgate Capital Corp.

Uranium exploration and development expenditures and drilling effort – domestic

(USD)

	2015	2016	2017	2018
Industry exploration expenditures	773 514	386 942	390 000	354 000
Total expenditures	773 514	386 942	390 000	354 000

Reasonably assured conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified	0	0	6 692	6 692	NA
Total	0	0	6 692	6 692	NA

Reasonably assured conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Unconformity*	0	0	6 692	6 692
Total	0	0	6 692	6 692

* Previously classified as sandstone type deposit.

Inferred conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified	0	0	5 154	5 154	NA
Total	0	0	5 154	5 154	NA

Inferred conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Unconformity*	0	0	5 154	5 154
Total	0	0	5 154	5 154

* Previously classified as sandstone type deposit.

Mauritania*

Uranium exploration and mine development

Historical review

The first uranium exploration project in Mauritania was carried out in 1959 by France's Atomic Energy Commission in the area of the Ogmane anticline.

In 1972, following the discovery of surficial-type uranium deposits in Western Australia, uranium exploration was initiated in the Regueibat Range by Total Compagnie Française de Pétrole (in a joint venture with the Société Mauritanienne de Recherches Minières, the French Atomic Energy Commission and Tokyo Uranium Development Company). The two exploration permits covered a total area of 164 000 km², divided into four blocks (Chami, Bir Hoghrein, Nouadhibou, and Ghallamane). In 1975, the total area was reduced to five blocks totalling 41 000 km², and these joint ventures were modified after the founding of French Minatome SA and Compagnie Générale des Matières Nucléaires.

These joint ventures held the areas up to 1983. Work on the permits was carried out between 1972 and 1975 and again in 1981 and targeted the evaluation of surficial-type deposits (Reguibat Range), as well as occurrences in the Precambrian basement, where radioactive anomalies were found associated with syenites and granites (Bir En Nar, Tigismat, Tenebdar). In 1983, all uranium exploration activities were suspended.

In December 2007, Australia's Forte Energy NL completed its first drilling programme in Mauritania, a 4 006 m reverse circulation programme of 41 holes of 50-150 m depth. The drilling was carried out in the Bir En Nar area of the Zednes region and followed up on high-grade results previously obtained. Downhole radiometric logging results indicated numerous high-grade uranium intersections, including 1.55 m at 18 280 ppm U (1.83% U). The results of drilling a second group of 21 holes yielded up to 6 310 ppm U (0.63% U) over 1 m, and 576 ppm U (0.058% U) over 19 m.

In November 2006, the United Kingdom's Alba Mineral Resources, along with Mauritania Ventures Limited, started to investigate the uranium potential of areas located in north-east Mauritania. The area is considered to be prospective for unconformity-type uranium mineralisation. The permits cover significant areas of an unconformable contact between Early Proterozoic reworked granitic terrain and overlying sediments of Late Proterozoic-Carboniferous age. Airborne geophysics, flown on behalf of the Mauritanian government, revealed radiometric anomalies within a mapped, organic-rich unit near the base of this sedimentary sequence, and coincident with its intersection with large, deep penetrating crustal shear structures. Uranium mineralisation is known in the north and north-west part of the permit area, hosted in granites and rhyolites cut by these shear structures. On 3 November 2010, Alba Mineral Resources was notified that the mining authorities in Mauritania had withdrawn the licence, citing a lack of additional exploration activity.

Started in 2006 and published in 2013, the Mauritania's Ministry of Petroleum, Energy, and Mines implemented a project "*Projet de Renforcement Institutionnel du Secteur Minier (PRISM-II)*" with the US Geological Survey to define the mineral resource potential of the country, which included delineation of areas permissive for calcrete-hosted, granite-hosted vein/shear, alkaline intrusive-hosted, unconformity-related, quartz pebble conglomerate-hosted, phosphate, sandstone-hosted, and red bed-type uranium deposits.

* Report prepared by the NEA/IAEA, based on previous Red Books and company reports.

Recent and ongoing uranium exploration and mine development activities

Forte Energy NL, based in Australia, holds several uranium exploration licences in Mauritania, including the A 238 and Bir En Ar areas.

The A 238 and Bir En Ar uranium prospects are associated with granites near Bir Moghrein in the north of Mauritania. At the A 238 prospect, the main zone of mineralisation extends over a strike length of 1.75 km with mineralisation extending down to over 250 m from the surface with widths of over 60 m within 50 m of the surface.

Following the positive results of the 2009/10 reverse circulation (RC) drilling, a further RC drilling programme of around 11 300 m commenced in October 2010, focusing initially on anomaly A 238. Preliminary results from A 238 indicated the potential for a shallow, large volume medium-grade deposit. A total of approximately 10 450 m of RC and diamond core drilling has been carried out, resulting in an announcement in June 2011 of an initial JORC code compliant U resource for A 238 of 26.5 Mt at 217 ppm U (0.0217% U) for 5 730 tU (85 ppm U cut-off; 0.0085% U).

After completing a further 63 holes (8 567 m) of RC drilling in 2011/12, an updated JORC resource was announced in April 2012 for A 238. The deposit remains open along strike.

Deposit	Resource category	Average grade (ppm U)	Tonnes of U
A 328	Inferred	199 (0.02% U)	9 000
Bir En Nar	Indicated Inferred	751 (0.0751% U) 488 (0.0488% U)	385 385
Total	Indicated Inferred	751 (0.0751% U)* 204 (0.0204% U)*	385 9 385

* Weighted average grade by proportional amount of tU.

In 2015, Forte Energy was delisted and its leases in Mauritania expired.

Australia's Aura Energy owns the Tiris Project (previously known as the Reguibat project) which comprises several, laterally extensive developments of calcrete uranium mineralisation in northern Mauritania. Between November 2010 and February 2011, Aura Energy completed a drilling programme which covered all of Aura's wholly-owned permits, as well as its joint venture permits, that totalled over 9 100 m in 2 022 holes.

A JORC code compliant uranium resource, based on these drilling results, was released in 2012 (85 ppm U cut-off):

Deposit	Resource category	Average grade (ppmU)	Tonnes of U
Reguibat	Indicated Inferred	254 (0.0254% U) 284 (0.0284% U)	770 18 077
Total	Indicated + inferred	283 (0.0283% U)*	18 847

* Weighted average grade by proportional amount of tU.

In 2014, Aura Energy conducted a scoping study that confirmed that Reguibat could be a robust project with shallow mineralisation that could be upgraded through simple beneficiation to high-grade leach feed. The study indicated that some 4 200 tU could be produced over an initial mine life of 15 years, using only 20% of the project's known total mineral resource. The project would require a capital investment of about USD 50 million and would have an operating cost of USD 30/lbU_3O_8 (USD 11.50/kgU), and with a mine-life average production of 290 tU/yr.

Additionally, extensive radiometric surveys allowed Aura Energy to estimate an exploration target of an additional 19 000 tU, inferring a total mineral resource target of around 38 000 tU at Reguibat.

In 2015 the project progressed to the Definitive Feasibility Study (DFS) stage. The Tiris Uranium Project has an initial production profile up to 1 million lb U_3O_8 (385 tU) per annum with the Scoping Study indicating an average life of mine over 15 years.

In 2015-2016, Aura Energy continued to conduct test-work and validation work aimed at defining optimal methods for the recovery of uranium. Additional verification/validation programmes were completed, including downhole gamma logging, disequilibrium test-work, trenching of the mineralisation, and detailed ground radiometric surveying.

Aura Energy highlighted the very fine nature of the uranium-bearing mineral, carnotite. However, this fine-grained character, together with the high, short-range grade presents challenges in sampling. The carnotite tends to occur as small lenses, nuggets, and coatings in or on the calcrete. Their distribution varies from deposit to deposit. Calcrete uranium deposits are typically lens-like in section, and hundreds of square meters in plan view. This variability requires understanding and management in upgrading resources to measured and indicated status. In general, variability reduces as sample size increases, and for that reason, the 2015 drilling employed a larger diameter drill bit to that used in the earlier resource drilling programmes, resulting in a 50% greater sample size. However, even with the larger sample size grade variability has still been relatively high. To test the effectiveness of gamma logging at Tiris, 63 holes that had been drilled and cased in 2015, were gamma logged. Results of this work were positive and Aura is now using down gamma logging for its resource upgrade work.

In 2016, the Tiris project progressed to the Feasibility Study stage. In 2017, Aura continued the Tiris Feasibility Study, including the following activities: mining lease application, resource definition, geophysics for the definition of water resources and drilling, metallurgical progress on test work, simulation and flowsheet development, early-stage engineering, completion of an Environment and Social Impact Assessment (ESIA), and a community consultation process.

In 2017, a programme of ground radiometric surveying was carried out over all Tiris uranium resource zones as well as priority exploration targets such as Hippolyte South which have to be drilled. The surveys were conducted on lines spaced 20 m apart. A programme to increase the proportion of Measured and Indicated Resources commenced in May 2017. This involved an extensive drilling programme on a 50 m x 50 m pattern with each hole being gamma logged. A proportion of the holes have been drilled by large diameter triple tube diamond drilling and the core was chemically assayed to validate the downhole gamma logging and to obtain density data throughout the zones drilled.

The Environmental and Social Impact Assessment (ESIA) was completed in 2017 by Earth Systems. The ESIA pays attention to issues of radiation exposure and the security of the yellowcake product. Best practice guidelines from the International Atomic Energy Agency (IAEA) and the International Commission on Radiological Protection (ICRP) have been used, complementing the applicable Mauritanian regulations and guidelines. The ESIA was approved by the Mauritanian Government on 5 October 2017.

In 2018, field activities focused on the Tiris project where an extensive drilling programme was conducted to upgrade a substantial part of the Inferred uranium resource to the Measured and Indicated Resource categories, in particular within the Hippolyte and Lazare deposits, where mining could commence. In addition, new resource zones were discovered at Hippolyte South. The programme involved 7 900 m of air-core drilling in 1 428 drill holes. Fifty-two diamond drill holes were completed to provide validation of downhole gamma logging results and to provide density information. All drill holes were logged to estimate uranium grade. The data from these programmes were used to provide a new JORC code compliant resource estimate (30 April 2018). This was carried out by resource consultants H&S Consultants Pty Ltd and resulted in the delineation of 6 538 tU of measured and indicated resources within a total resource of 19 922 tU (at a 85 ppm U cut-off; 0.0085% U).

Cut-off U ppm	Category	Ore (Mt)	Grade U ppm	U (tU)
85 (0.0085% U)	Measured	10.2	200 (0.02% U)	2 038
	Indicated	24.5	185 (0.0185% U)	4 438
	Total M + I	34.7	190 (0.019% U)	6 576
	Inferred	57.4	232 (0.0232% U)	13 346

* Weighted average grade by proportional amount of tU.

A programme of trenching was undertaken within the Lazare North and Lazare South deposits in April 2018. A total of 11 trenches were completed, with 8 in the Lazare South and 3 in the Lazare North deposits. Trenches were dug to a depth of 4 m. The focus of this programme was to collect representative samples for detailed test work.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

In 2012, Forte Energy NL released a JORC code compliant U resource for the A 328 and Bin En Ar deposits. Based on an 85 ppm U cut-off (0.0085% U), global resources for the A 328 and Bin Ar deposits totalled 385 tU in the indicated category, and 9 385 tU in the inferred category (in situ resources).

Following the 2017 drilling campaign, Aura Energy released a new JORC code compliant resource estimation dated 30 April 2018. Based on an 85 ppm U cut-off (0.0085% U), global resources of for the Tiris project total 6 576 tU in the measured + indicated categories, and 13 346 tU in the inferred category (in situ resources).

Undiscovered conventional resources (prognosticated and speculative resources)

Strong radiometric anomalies exist in Mauritania, similar to anomalies occurring with the known resources at Tiris. Aura Energy's exploration has largely focused on radiometric anomalies defined by regional airborne radiometric surveys. In 2016 Aura Energy estimated an additional potential of 19 000 tU in the Reguibat area.

Uranium production

In 2014, Aura Energy completed the Reguibat Scoping Study.

Mineralisation occurs largely within 3-4 m of the land surface, in gravels and weathered granite. Most of the mineralisation occurs as single sheets with little or no cover. The material is largely unconsolidated and can be readily excavated by diggers or scrapers without blasting. The overlying waste consists of loose windblown sand. The strip ratio is anticipated to be approximately 0.25:1.

Simple washing and screening tests on the ore yielded encouraging results. Wet screening at 75 µm resulted in the rejection of 80% by weight with the retention of 91% of the uranium into the screen undersize. This represents a sevenfold upgrade factor from the 334 ppm U (0.0334% U) resource grade. These results may be explained by the extremely fine size and ready liberation of the uranium mineral, carnotite, and the large difference in particle size distribution between the carnotite and the bulk of the host rock minerals.

Following a series of encouraging small-scale preliminary tests, a standard leach test on -300 µm beneficiated material confirmed earlier results, with 92% uranium extraction within 4 hours and 95% after 8 hours.

The total estimated initial capital cost for engineering, procurement, construction, commissioning, start-up, and the owner's activities for the project is AUD 50 million.

The life of mine unit operating cost estimate for the Reguibat Project is estimated to be USD 30.3/lb U_3O_8 (USD 11.65/kgU).

The planned operation will produce approximately 385 tU per year in years 2 and 3, followed by 250 tU for years 4-11, and 270 tU in years 12-15. The total uranium produced under these assumptions is approximately 3 850 tU over the 15-year mine life.

A feasibility study was undertaken in 2015, with a view to a simple truck and shovel mine on the eastern deposit, feeding an AUD 50 million plant, and production at about 400 tU/yr.

On 29 July 2019 Aura released the results of the Definitive Feasibility Study which confirmed that the Tiris Uranium Project is a low cost and low operating cost development. The project is designed to support an open-pit mine, a 1.25 million tonnes of ore processing plant and supporting infrastructure. The uranium mineralisation lies largely within 3 to 5 m of the surface in a relatively soft, free digging material containing patchy calcrete. Based on trenching and metallurgical test work to date, the mineralisation does not require blasting before mining or crushing prior to beneficiation.

Three mining areas can be developed in a practical sequence to produce 310-425 tU per year through the processing plant for over 15 years. The processing facility will consist of three main sections: the beneficiation circuit, the uranium extraction circuit (alkaline leach – solid liquid separation – ion exchange), and the uranium purification and precipitation circuit. Uranium recovery is expected to be 86.1%. Vanadium could be recovered as vanadium pentoxide (V_2O_5) through a standard precipitation and purification process. Target production is 250 000 lb V_2O_5 per year. The cost to develop and operate the mine for ten years has been estimated at USD 66 million or USD 2.24 per tonne of material mined.

Two exploitation licences covering 390 km^2 were granted to Tiris Ressources SA, a Mauritanian registered subsidiary of Aura Energy, on 8 February 2019. The two licences cover the Eastern Tiris resources at Oued El Foule and Ain Sder. An application for a 38 km^2 exploitation licence remains pending over the smaller Western Tiris resource at Oum Ferkik.

Uranium production centre technical details

(as of 1 January 2019)

	Centre #1
Name of production centre	Tiris
Production centre classification	Prospective
Date of first production (year)	NA
Source of ore:	
Deposit name(s)	Lazare N and S, Hippolyte
Deposit type(s)	Calcrete
Recoverable resources (tU)	3 105
Grade (% U)	0.0285
Mining operation:	
Type (OP/UG/ISL)	OP
Size (tonnes ore/year)	1.25 Mtpa
Average mining recovery (%)	NA
Processing plant:	
Acid/alkaline	Alkaline
Type (IX/SX)	IX
Size (tonnes ore/day)	NA
Average process recovery (%)	86.1
Nominal production capacity (tU/year)	315

Reasonably assured conventional resources by production method

(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	0	0	5 655	5 655	86
Unknown	0	0	0	289	75
Total	0	0	5 655	5 944	85

Reasonably assured conventional resources by processing method

(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from OP	0	0	5 655	5 655	86
Unknown	0	0	0	289	75
Total	0	0	5 655	5 944	85

Reasonably assured conventional resources by deposit type

(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Granite-related	0	0	0	289
Calcrete	0	0	5 655	5 655
Total	0	0	5 655	5 944

Inferred conventional resources by production method

(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	0	0	11 478	11 478	86
Unknown	0	0	0	7 039	75
Total	0	0	11 478	18 517	85

Inferred conventional resources by processing method

(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from OP	0	0	11 478	11 478	86
Unknown	0	0	0	7 039	75
Total	0	0	11 478	18 517	85

Inferred conventional resources by deposit type

(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Granite-related	0	0	0	7 039
Calcrete	0	0	11 478	11 478
Total	0	0	11 478	18 517

Speculative conventional resources

(tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
NA	NA	19 000

Mexico

Uranium exploration and mine development

Historical review

Uranium exploration began in 1957, using both ground and aerial prospecting with geological and radiometric methods. Limited technical and financial resources initially hampered national exploration efforts, but these problems were alleviated by government support, particularly from 1972 to 1980.

Until 1979, exploration was performed by the National Institute of Nuclear Energy. In 1979, the responsibility for exploration was vested in Uranio Mexicano (URAMEX). The areas explored, in order of importance, were in the states of Chihuahua, Nuevo León, Tamaulipas, Coahuila, Zacatecas, Queretaro and Puebla. Uranium exploration was stopped in May 1983 and URAMEX was dissolved in February 1985.

In 2009, the Mexican Geological Survey reactivated radioactive exploration in Mexico, in order to validate and re-evaluate the resources reported by URAMEX according to international standards. This involves the analysis of the preliminary information available, as well as complementary studies of geology, geochemistry, geophysics and drilling, simultaneously exploring new locations with uranium potential.

In order to gain a better knowledge of the uranium resources located in Peña Blanca (Chihuahua State), Los Amoles (Sonora State) and La Coma area (Nuevo León State), exploration and assessment works were continued through drilling programmes.

During the period 2013-2016, a total of 16 442 metres were drilled in 144 holes.

Recent and ongoing uranium exploration and mine development activities

Within the period 2017-2018, a total of 5 164 metres were drilled in 47 holes with core recovery. All drill holes were logged using probes for dimensions (calliper), long and short resistivity, spontaneous potential, sonic wave and gamma-ray spectrometry measurements.

Other areas under study were Buenavista, Chapote, La Diana, Peñoles, La Presita, Trancas, Dos Estados and Santa Fe in Nuevo León State using geological and radiometric prospecting methods, which was done in order to develop a base map URAMEX drill holes made in the 1980s, and to assess the uranium mineralisation and geometry of the ore bodies.

In Durango State, the main exploration activities have focused on Santiago Papasquiaro, where anomalies and evidence of surface and underground uranium minerals were defined.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

Past evaluation of these projects by URAMEX did not fulfil the international standards of evaluation. Potential was demonstrated, however, and the Mexican Geological Survey began a programme to evaluate resources following international standards. The first results of this programme are presented here.

Projects	Tonnes U (in situ)
Las Margaritas, Chihuahua State	597
El Puerto III, Chihuahua State	180
El Nopal I, Chihuahua State	422
Los Amoles, Sonora State	399
La Coma, Nuevo León State	852
Buenavista, Nuevo León State	1 455
El Chapote, Nuevo León State	1 104
La Diana, Nuevo León State	940
Peñoles, Nuevo León State	191
La Presita, Nuevo León State	185
Trancas, Nuevo León State	130
Dos Estados, Nuevo León State	169
Santa Fe, Nuevo León State	90

Undiscovered conventional resources (prognosticated and speculative resources)

There are 53 uranium occurrences in Mexico that will be evaluated by the Mexican Geological Survey.

Unconventional resources and other materials

The San Juan de la Costa phosphorite deposit is estimated to contain significant uranium resources.

Uranium production

Historical review

From 1969 to 1971, the Mining Development Commission operated a plant in Villa Aldama, Chihuahua State. The facility recovered molybdenum and by-product uranium from ores mined in the Sierra de Gomez, Domitilia (Peña Blanca) deposits and other occurrences. A total of 49 tU was produced. At present, there are no plans for additional uranium production.

Uranium requirements

As of 1 January 2019, two boiling water reactors with a total installed capacity of 1.4 GW net were in operation at the Laguna Verde NPP. These two units have been in operation since 1990 and 1995. The two units supply about 4-5% of the country's electricity. In 2015, an application for a licence renewal of both Laguna Verde units was submitted to the Mexican regulatory authority, in order to allow their operation for 30 more years. The unit 1 licence expires on July 2020 and the unit 2 licence expires on May 2025.

Supply and procurement strategy

Uranium purchase open bid is under study for three reloads (2022-2025).

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

The 1984 Act on Nuclear activities, adopted pursuant to Article 27 of the Constitution, entered in force on 5 February 1985. It specifies that the exploration, exploitation and the benefit of radioactive minerals are the exclusive domain of the government of Mexico. Exploration activities are exclusively delegated to the Mexican Geological Survey.

Uranium stocks

Uranium stocks are maintained at minimum levels in order to reduce costs.

Uranium exploration and development expenditures and drilling effort – domestic

(USD)

	2016	2017	2018	2019 (preliminary)
Government exploration expenditures	1 236 842	886 179	1 203 590	NA
Total expenditures	1 236 842	886 179	1 203 590	NA

Reasonably assured conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	852	852
Volcanic-related	0	0	1 598	1 598
Total	0	0	2 450	2 450

Inferred conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	2 450	4 264
Total	0	0	2 450	4 264

Net nuclear electricity generation*

	2017	2018
Nuclear electricity generated (TWh net)	10.6	13.2

* Data based on NEA *Nuclear Energy Data* reports.

Installed nuclear generating capacity to 2040*

(MWe net)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
1 552	1 552	1 552	1 552	1 552	1 552	1 552	4 300	1 552	5 700	1 552	5 700

* Data based on NEA *Nuclear Energy Data* reports.

Annual reactor-related uranium requirements* to 2040 (excluding MOX)**

(tonnes U)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
0	416	419	NA	532	NA	282	NA	555	NA	282	NA

* Refers to natural uranium acquisitions, not necessarily consumption during the calendar year.

** Data based on NEA *Nuclear Energy Data* reports.

Mongolia

Uranium exploration and mine development

Historical review

The history of uranium exploration in Mongolia can be divided into three phases. The first phase started immediately after World War II, with investigations directed at the search for uranium contained in other, non-uranium deposits. During the period 1945-1960, numerous uranium occurrences were discovered in the brown coal deposits of eastern Mongolia.

The second phase of exploration covered the period between 1970 and 1990. Under a bilateral agreement between Mongolia and the former Soviet Union, specialised geological surveys were conducted by the Geological Reconnaissance Expedition of the Soviet Ministry of Geology with a result of 1 600 radioactive anomalies and hundreds of radioactive occurrences identified by the joint expedition. Full airborne gamma-ray spectrometric surveys at a scale of 1:25 000 and 1:50 000 were conducted over 420 000 km^2, covering about 27% of Mongolian territory; at a scale of 1:200 000 over 450 000 km^2, covering about 28% of the territory; and at a scale of 1:1 000 000 over 224 000 km2 in the Altai, Khangai mountains and Gobi Desert, covering about 14% of the Mongolian territory. The territory along the border with the People's Republic of China and the central Mongolian mountain area, about 30% of the country, was not included in these surveys.

Metallogenic investigations at the scale of 1:500 000 over a 500 000 km^2 area, and more detailed geological mapping and exploration at the scale of 1:200 000-1:50 000 over 50 000 km^2 of territory in Mongolia, were also completed. This work included 2 684 000 m of surface drilling, 3 179 000 m^3 of surface trenching and 20 800 m of underground exploration.

The third phase of exploration started in the 1990s with private stakeholder engagements including local and foreign entities. As a result of the depressed uranium market, exploration strategies changed globally toward the exploration for low-cost uranium deposits, especially sandstone type deposits. Uranium exploration was focused on Mesozoic and Cenozoic basins in south-east Mongolia. The "uranium" state-owned manufacturing enterprise, in co-operation with the IAEA, assessed the uranium potential of Mongolia in two phases between 1993 and 2001. The studies that were completed focused on identifying the potential for uranium mineralisation in sedimentary and metasomatised settings.

Based on these surveys, the territory of Mongolia was classified into four uranium-bearing metallogenic provinces: Mongol-Priargun, Gobi-Tamsag, Khentei-Daur and Northern Mongolia. Each of these provinces has a different geology and hosts different deposit types. Mineral associations and ages of mineralisation also vary. Within these provinces, 13 uranium deposits, and about 100 uranium occurrences and 1 400 showings and radioactive anomalies were identified.

The Mongol-Priargun metallogenic province is located in eastern Mongolia, coinciding with a 70 to 250 km wide continental volcanic belt that can be traced over some 1 200 km, from the Mongolian Altai to the Lower-Priargun region. This territory includes deposits and occurrences with fluorite-molybdenum-uranium associations resulting from volcano-tectonic events. Distinct uranium mineralisation districts of the Northern Choibalsan, Berkh, eastern and central Gobi are included in this area. The Dornod ore field of Northern Choibalsan includes the uranium deposits of Dornod, Gurvanbulag, Mardaingol, Nemer, and Ulaan, as well as other polymetallic and fluorite associations. The Choir and Gurvansaikhan Basins of the eastern and central Gobi uranium mineralisation district include the Kharaat and Khairkhan uranium deposits, among others.

The Gobi-Tamsag metallogenic province covers a territory 1 400 km long by 60 to 180 km wide in southern Mongolia. It is characterised by numerous uranium occurrences in terrigenous sediments. The district includes a prospective uranium deposit in the south, near the Dulaanuul and Nars deposits, and numerous other occurrences, as well as other prospective uranium-bearing sedimentary basins, such as the Tamsag, Sainshand, and Zuunbayan Basins, among others.

The Henter-Daur metallogenic province (700 km long by 250 km wide) includes the Khangai and Khentii mountains. In this area, uranium occurrences in granite can be found, such as the Janchivlan ore field, which shows some promise of becoming a deposit of economic interest.

The Northern Mongolian metallogenic province is the largest (1 500 km long by 450 km wide) of the four metallogenic provinces. The north-western part of Mongolia is characterised by a variety of minerals such as uranium, thorium and rare earth elements related to alkaline mineralisation, and uranium and thorium in metasomatites, pegmatite, magmatic and quartz schist host rocks.

Recent and ongoing uranium exploration and mine development activities

At present ten national and foreign investment companies are carrying out intensive exploration activities across the country.

There are two types of uranium exploration activities in Mongolia. They are prospecting aimed at the discovery of new deposits and the exploration of previously discovered deposits to increase resource endowments.

From 2017 to 2018, the majority of the uranium prospecting was performed in the south Mongolian sedimentary basins to identify sandstone-type uranium mineralisation that is amenable to ISL mining.

There are currently eight deposits on which mining feasibility studies have been completed and approved by the Mongolian Professional Committee of Resources. One of the potential projects is the Zuuvch Ovoo and Dulaan uul uranium project in Dornogobi province in the southeast region of Mongolia. The deposit will be mined by ISL using sulphuric acid.

Uranium exploration expenditures were MNT 16 855 million in 2017 (Mongolian tugrug), and MNT 11 960 million in 2018. Exploration drilling totaled 14 222 m in 2018, compared with 23 665 m reported in 2017.

Identified conventional resources (reasonably assured and inferred resources)

As of 1 January 2019, Mongolia's total identified conventional RAR recoverable at a cost of <USD 80/kgU amounted to 33 255.2 tU. Total conventional RAR recoverable at a cost of <USD 130/kgU totalled 60 547.6 tU. Inferred conventional resources recoverable at a cost of <USD 80/kgU amounted to 26 699.6 tU. Total conventional inferred resources recoverable at a cost of <130/kgU totalled 82 907.3 tU.

Undiscovered conventional resources (prognosticated and speculative resources)

As of 1 January 2019, prognosticated resources amounted to 13 300 tU and speculative resources totalled 1 319 000 tU.

Unconventional resources and other materials

No unconventional resources have been identified.

Uranium production

Historical review

Uranium production in Mongolia started with the operation of the Dornod open-pit mine in the Mardai-gol district in 1989, based on the known uranium resources at the Dornod and Gurvanbulag deposits. With an ore grade of 0.12% U, mining production was 2 400 tU/year.

Mongolia has no processing facilities. The ores mined in the Mardai-gol district were transported by rail 484 km to the Priargunsky mining and processing facility in Krasnokamensk, Russia, for processing. Because of political and economic changes in Mongolia and neighbouring areas of Russia, uranium production at Erdes was terminated in 1995.

Status of production facilities, production capability, recent and ongoing activities and other issues

Currently, no uranium is being produced in Mongolia. However, several mines are in the planning stage of development

Uranium production centre technical details

(as of 1 January 2019)

	Centre #1	Centre #2				Centre #3	
Name of production centre	Emeelt mines	Gurvansaihan				Orano mines	
Production centre classification	Planned	Planned				Planned	
Date of first production (year)	NA	NA				NA	
Source of ore:							
Deposit name(s)	Gurvanbulag	Kharaat	Khairkhan	Gurvansaikhan	Ulziit	Dulaan uul	Zuuvch ovoo
Deposit type(s)	Volcanic	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone
Recoverable resources (tU)	8 580	7 288	8 406	4 250	3 075	11 006	54 639
Grade (% U)	0.152	0.026	0.071	0.034	0.036	0.022	0.022
Mining operation:							
Type (OP/UG/ISL)	UG	ISL	ISL	ISL	ISL	ISL	ISL
Size (tonnes ore/day)	NA	NA	NA	NA	NA	NA	NA
Average mining recovery (%)	NA	NA	NA	NA	NA	NA	NA
Processing plan							
Acid/alkaline	Acid	Acid	Acid	Acid	Acid	Acid	Acid
Type (IX/SX)	IX	IX	IX	IX	IX	IX	IX
Size (tonnes ore/day)	NA	NA	NA	NA	NA	NA	NA
Average process recovery (%)	NA	NA	NA	NA	NA	NA	NA
Nominal production capacity (tU/year)	NA	NA	NA	NA	NA	NA	NA
Plans for expansion	No	No	No	No	No	No	No

Secondary sources of uranium

Production and/or use of mixed oxide fuels

Mongolia has not produced or used mixed oxide fuels.

Production and/or use of re-enriched tails

Mongolia currently does not have a uranium enrichment industry. Re-enriched tails are not used or produced.

Production and/or use of reprocessed uranium

There is no production or use of reprocessed uranium.

Status of production facilities, production capability, recent and ongoing activities and other issues (including information on uranium recovery methods)

Currently, no uranium is being produced in Mongolia.

Ownership structure of the uranium industry

The Nuclear Energy Law of Mongolia defines the ownership of radioactive minerals and state participation in the exploitation of radioactive minerals. Article 5 states that:

- 5.1: Radioactive minerals occurring in the subsoil of Mongolia shall be the property of the state.
- 5.2: Provided that the radioactive mineral deposit, for which exploration and reserves determination was conducted by state budget financing, and is jointly exploited with others, the state shall directly possess free of charge no less than 51% of shares of the company that will be set up jointly.
- 5.3: The state shall directly possess free of charge no less than 34% of shares of the company holding a special licence for exploitation of the radioactive mineral deposit, for which exploration and reserves determination were conducted without state budget involvement, and was recorded in the state integrated register.
- 5.4: Provided the state owns shares exceeding the percentages specified in the clauses 5.2 and 5.3 of this law, the State Great Khural shall fix this share by presentation of the government in view of the size of investment made or to be made by the state.

National policies relating to uranium

The Mongolian government considers the mining of uranium deposits an important national interest as it would positively influence and improve the national economy. As a result, the government has developed a special programme on uranium and is committed to implementing it.

The programme covers the following policies and guidelines:

- Geological exploration and mining of uranium deposits, processing, and marketing of uranium ores in Mongolia. The purpose is to reduce Mongolian government investment and to encourage foreign investment.
- Developing intensive and effective co-operation with international organisations involved in the prospecting, mining, and sale of uranium and other raw materials for nuclear energy.
- Developing all of the necessary regulations, instructions, and recommendations for activities related to uranium mining.
- Studying possibilities of recovering uranium from phosphate and brown coal deposits and developing alternative extraction techniques.
- Training national personnel for uranium studies and production and introducing advanced technology, instruments, and tools of high precision.
- Setting up a government enterprise responsible for monitoring and co-ordinating uranium exploration and production, as well as developing and implementing government policy and strategies in the field of uranium exploration based on mobilising efforts of national uranium specialists.

Uranium exploration and development expenditures and drilling effort – domestic

(Mongolia tögrög millions)

	2016	2017	2018	2019 (expected)
Industry* exploration expenditures	13 058	16 855	11 960	4 592
Government development expenditures	0	0	0	0
Total expenditures	13 058	16 855	11 960	4 592
Industry* exploration drilling (m)	12 128	23 665	14 222	5 925
Subtotal exploration drilling (m)	12 128	23 665	14 222	5 925
Total drilling (m)	12 128	23 665	14 222	5 925

* Non-government.

Reasonably assured conventional resources by production method

(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)		20 956.0	27 929.0	27 929.0	75
Open-pit mining (OP)		2 202.7	2 202.7	2 202.7	80
In situ leaching acid		10 096.5	30 415.9	30 415.9	75
Total		33 255.2	60 547.6	60 547.6	

Reasonably assured conventional resources by processing method

(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG		20 956.0	27 929.0	27 929.0	75
Conventional from OP		2 202.7	2 202.7	2 202.7	80
In situ leaching acid		10 096.5	30 415.9	30 415.9	75
Total		33 255.2	60 547.6	60 547.6	

Reasonably assured conventional resources by deposit type

(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone		20 956.0	27 929.0	27 929.0
Volcanic-related		12 299.2	32 618.6	32 618.6
Total		33 255.2	60 547.6	60 547.6

Inferred conventional resources by production method
(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)		7 705.6	11 261.0	11 261.0	75
Open-pit mining (OP)		6 578.7	6 578.7	6 578.7	80
In situ leaching acid		12 415.3	65 067.6	65 067.6	75
Total		26 699.6	82 907.3	82 907.3	

Inferred conventional resources by processing method
(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG		7 705.6	11 261.0	11 261.0	75
Conventional from OP		6 578.7	6 578.7	6 578.7	80
In situ leaching acid		12 415.3	65 067.6	65 067.6	75
Total		26 699.6	82 907.3	82 907.3	

Inferred conventional resources by deposit type
(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone		7 705.6	11 261.0	11 261.0
Volcanic-related		18 994.0	71 646.3	71 646.3
Total		26 699.6	82 907.3	82 907.3

Prognosticated conventional resources
(tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
13 300	13 300	13 300

Speculative conventional resources
(tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
1 319 000	1 319 000	

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Open-pit mining	535	0	0	0	535	0
Total	535	0	0	0	535	0

Historical uranium production by deposit type

(tonnes U in concentrates)

Deposit type	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Volcanic-related	535	0	0	0	535	0
Total	535	0	0	0	535	0

Short-term production capability

(tonnes U/year)

2017				2020				2025			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

2030				2035			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
NA	NA	NA	NA	NA	NA	NA	NA

Namibia*

Uranium exploration and mine development

Historical review

Uranium was first discovered in the Namib Desert in 1928 in the vicinity of the Rössing Mountains, but it was not until the late 1950s that the Anglo American Corporation of South Africa prospected the area by drilling and limited underground exploration. As a result of erratic uranium prices, lack of demand, and limited economic prospects for uranium at that time, Anglo American abandoned its work.

With the upswing in the uranium market demand and prices, extensive uranium exploration started in Namibia in the late 1960s. Several airborne radiometric surveys were conducted and numerous anomalies were identified. In 1966, after discovering uranium occurrences, Rio Tinto acquired the rights to the low-grade Rössing deposit, located 65 km inland from the town of Swakopmund on the Atlantic coast. Trekkopje, a near-surface calcrete deposit just north of Rössing and Langer Heinrich, another calcrete deposit situated 50 km southeast of Rössing, were also discovered during this period.

Mining commenced in 1976 at Rössing and exploration intensified as uranium prices increased sharply. However, in the early 1980s, the sharp decline in uranium prices caused rapid curtailment of exploration and mine development efforts. This was untimely as refined and proven exploration techniques appeared poised to discover new deposits.

Beginning in 2003, rising uranium prices once again stimulated extensive exploration activity, mainly in the Namib Desert. Based on earlier successes, two major types of deposits were targeted: intrusive-type associated with alaskite, as at Rössing, and surficial, calcrete-type deposits, as at Langer Heinrich. In 2002, Paladin Energy bought the Langer Heinrich tenement and in 2005 started construction of the Langer Heinrich mine that officially opened five years later. That same year, French state-owned Orano (at that time Areva) purchased Trekkopje from the Canadian company UraMin and began construction of an alkaline heap leach mine in 2008, as well as an associated seawater desalination plant. Production of 3 000 tU was initially expected to start in early 2010, but decreased demand following the financial crisis and lower uranium prices after the Fukushima Daiichi accident in Japan led Orano to place Trekkopje on care and maintenance in 2013, following completion of the Phase 2 pilot tests. Other uranium projects that were issued mining licences at the time but have not commenced construction are the Norasa (original name Valencia) and the Zhonge Projects.

Discovery holes for the Husab (initially known as Rössing South) uranium deposit were drilled in late 2007 and chemical assay results were released in February 2008. Swakop Uranium had in total completed over 800 000 m of combined reverse circulation and diamond core drilling since the drilling programme began in 2006. In 2008, Extract Resources discovered the Husab uranium deposit. In March 2012, Chinese government owned China Guandong Nuclear Power Corporation (CGNPC) acquired the project in a takeover bid of USD 2.4 billion. An environmental clearance certificate was awarded in December 2011, construction commenced in October 2012 and the first uranium oxide was drummed in December 2016.

* Report prepared by the NEA/IAEA, based on previous Red Books, government data and company reports.

Exploration efforts continued, but low uranium prices since 2011, partly as a result of the Fukushima Daiichi accident, slowed activity. Nonetheless, substantial growth in uranium exploration took place in the Erongo area of west-central Namibia, focused mainly on previously known deposits with considerable historical data. For example, Bannerman Mining Resources Pty Ltd progressed the Etango Project from an initial scoping study (2007) and pre-feasibility study (2009) to a definitive feasibility study in 2012. It then built a heap leach demonstration plant in 2015 to test the proposed metallurgical process. In total, over 300 000 m of exploration drilling has been completed in the Etango Project area.

For the Rössing mine a positive evaluation of extending the mine life led to the expansion of the existing pit to expose more of the steeply dipping SJ orebody. Between 2007 and 2010, exploration focused on extensions of the main SJ ore body, as well as the adjacent SK and SH ore bodies. However, the SK body contains largely refractory mineralisation (betafite) for which the existing process plant is not suited. The official life of mine for the SJ ore body is to 2025.

Other uranium exploration companies that continued work include Marenica Energy and Reptile Mineral Resources and Exploration (Pty) Ltd (RMRE). RMRE is a wholly owned Namibian registered subsidiary of the Australian public company Deep Yellow Limited (DYL). Active in Namibia since 2007, RMRE holds three exclusive prospecting licences including the Omahola, Tubas, Tumas and Aussinanis deposits, which are situated in the Namib Naukluft National Park. Deposits are hosted in alaskite granites and in surficial paleochannel calcrete and sand sediments.

Metals Australia Ltd owns 100% of the Mile 72 uranium project, located near Henties Bay on the west coast of Namibia. The project is considered prospective for calcrete and gypcrete hosted uranium as well as alaskite hosted uranium. A high-resolution airborne geophysical survey, radon cup, surface trenching and drilling exploration activities have been conducted. Activity during 2015 and 2016 was restricted to geological and economic assessments.

Over 60 exploration licences were issued until early 2007, when a moratorium on new licences was imposed by the Namibian government pending development of new policies and legislation, primarily in response to concerns about water and energy requirements of uranium mining.

Recent and ongoing uranium exploration and mine development activities

In January 2017, the Namibian government lifted the 10-year moratorium on new applications for exploration licences for nuclear fuel minerals, and since then, 52 new licences have been granted up to the end of 2019.

Rössing Uranium Limited

Since 2010, the main exploration focus has been on the southernmost Z20 deposit that extends across the lease boundary into the adjacent lease held by Husab. A total of 24 000 m of drilling was completed on Z20 to determine inferred resources by the end of 2012, and a third phase of drilling on the Z20 ore body was completed during 2013. Data indicated in situ resources of over 46 000 tU at higher grades (0.023% U) than in the main orebody.

A revision of the pricing outlook resulted in the removal of the Z20 and Phase 4 mineralised zone from the 2018 JORC compliant resource declaration. This decision was taken as a result of a financial analysis, which demonstrated that with the revised downward pricing outlook, the Z20 deposit would not contribute any additional value to the existing SJ Pit operations. However, the resources contained within the Phase 4 pushback, as well as the inferred resources within the Phase 2 and 3 pushbacks, continue to demonstrate value.

Once the higher grade material was reached, production steadily increased from 1 057 tU in 2015 to 1 788 tU in 2017 and 2 100 tU in 2018. The higher grade material does, however, come with increased calcium content, thereby limiting processing plant throughput. A situation that is expected to persist for the next few years.

In 2019 Rio Tinto plc sold its 69% share to the China National Uranium Corporation (CNUC), a wholly owned subsidiary of government owned China National Nuclear Corporation (CNNC). CNNC is a significant player throughout the entire nuclear fuel cycle, and the ownership change should assist in keeping the Rössing operation in production.

Langer Heinrich

Langer Heinrich (owned by Paladin Energy Ltd) is a surficial, calcrete-type uranium deposit located in the Namib Desert, 80 km from the major seaport of Walvis Bay. The ore occurs over 15 km in a paleochannel system approximately 50 m deep, and an exploration prospecting licence covers the western extension of the mineralised Langer Heinrich paleochannel. In 2015, this prospecting licence was converted to a mining licence. Originally identified in situ resources amounted to 49 179 tU at an average grade of 0.040% U.

There has been no recent exploration activity due to continued low uranium prices. Instead, the focus has been on improving operating efficiencies to increase production and reduce costs.

Due to sustained low uranium prices, Langer Heinrich was placed in care and maintenance in August 2018. The mine is expected to remain idle until the uranium spot price makes it economical to restart the facility on a sustainable basis. In the interim, Paladin has begun studies to optimise the Langer Heinrich operation in preparation for restart. Examining opportunities to improve mining and processing in order to decrease costs, increase throughput and productivity, as well as the potential for producing vanadium as a by-product. The prefeasibility study is expected to be completed in 2020.

Trekkopje

The Trekkopje Project, located approximately 65 km northeast of the coastal town of Swakopmund, embodies the Klein Trekkopje and Trekkopje surficial uranium deposits, with 80% of the mineralisation contained in the top 15 m of strata below the surface. Hosted in calcium carbonate cemented (calcrete) conglomerates of Cenozoic age, the basal channels in the Trekkopje area follow the northeast trending structural grain of the underlying basement rocks.

Exploitation at Trekkopje is technically challenging due to the low uranium content and the use of alkaline heap leaching. The mine was developed in a staged process, with Phase 1 ("Mini"), designed to validate the chemistry of the heap leach process successfully completed in 2009. Phase 2 ("Midi") treated 3 million tons of ore to prove the commercial process before scaling up to full production. Phase 3 ("Maxi") represented the full production stage of the mine, which was expected to produce about 3 000 tU per annum. However, due to the depressed uranium market, the mine was put on care and maintenance at the end of 2012. As of 1 January 2013, known resources for Klein Trekkopje and Trekkopje amounted to over 45 000 tU at 0.013% U.

While in the operation is in care and maintenance, Orano has conducted research to improve uranium recovery. An optimised process was developed that enhances permeability in the heap by adding cement at the agglomeration stage and recovery of a substantial part of the reagents used is accomplished through membrane technology.

The desalination plant built in association with the mine continued to supply sufficient water to meet the demand of other uranium mines and other users in the coastal area. Production capacity was boosted to 1 million m^3/month to meet increased demand when the Husab mine began production.

Husab

The main part of the Husab orebody lies approximately 5 km south of the Rössing mine. The 8-km long uranium deposit lies under a cover of shallow alluvial sand. Estimated in situ identified resources for all deposits currently licensed to Swakop Uranium, as reported by the Mineral Resource Department, amount to over 240 000 tU grading at about 0.03% U.

Etango

Bannerman Resources' Etango Project consists of three prospects: Anomaly A, Oshiveli and Onkelo. These prospects contain uraniferous sheeted leucogranite bodies, or alaskites, very similar to those at Rössing. Although extensions continue to 400 m below the surface, two-thirds of the resource base is located less than 200 m below the surface.

Bannerman is also investigating potential satellite pit opportunities at Ondjamba and Hyena deposits. These in situ resources amount to about 16 700 tU.

Reptile Mineral Resources & Exploration (RMRE)

RMRE holds three uranium prospecting licences south of the Husab mine covering areas of Rössing-type alaskite (Omahola), surficial Langer Heinrich-type mineralisation in the Tubas Sand and Tubas/Tumas paleochannel, as well as Aussinanis calcrete type deposits. Total identified in situ resources amount to 59 850 tU, while 17 350 tU occur in Omahola alaskite deposit and 42 500 tU in surficial sandstone and calcrete deposits.

The Omahola Project consists of the Ongolo and MS7 alaskite deposits and the Inca uraniferous magnetite deposit. It is envisaged that the Project would consist of a processing plant located close to the Ongolo deposit, treating a blend of primary ore from these three deposits. Ongolo's JORC 2004 compliant in situ mineral resources amount to 9 638 tU at 0.021% U.

The majority of the Omahola resources are mineable by open-pit methods. Originally predicated on open-pit mining and conventional tank acid leach extraction, further test work and analyses indicated that the project is more economically viable as a heap leach process.

In 2018, work continued on expanding the calcrete associated uranium mineralisation in the Tumas 1, 2 and 3 areas, including the Tubas zones. Evaluation of all calcrete-associated uranium mineralisation was undertaken and is estimated to contain 28 300 tU grading about 0.03% U.

The Tubas deposit was discovered and explored in the 1970s and 1980s. It consists primarily of low-grade secondary uranium mineralisation (carnotite) in well-sorted aeolian sediments. Since 2006, RMRE has conducted two infill drilling campaigns, which led to a resource update in early 2014, with in situ JORC compliant resource totals of 4 920 tU at an average grade of about 0.014% U). Preliminary economic analysis shows that the Tubas Project is not viable as a standalone production facility and efforts to secure an interested party for the concentrate or a toll-treat arrangement at a nearby processing plant are ongoing.

The Aussinanis Project is a paleochannel deposit with uranium mineralisation (carnotite hosted in sediments and calcrete) present from the surface to an average depth of 6 metres. It has 6 955 tU of indicated and inferred in situ resources grading at about 0.02% U. In 2013 Deep Yellow agreed to transfer the Aussinanis Project into a new company, the Yellow Dune Joint Venture, composed of Yellow Dune Uranium Resources (Pty) Ltd, a wholly owned subsidiary of Reptile Uranium Namibia (Pty) Ltd (85%), Oponona Investments (Pty) Ltd (10%) and Epangelo Mining Company Pty Ltd (5%).

Marenica

Marenica Energy Ltd has a 75% interest in the project, while the other partners are Xanthos Mining Limited (20%) and Millennium Minerals (5%). The Marenica Project is situated in a paleochannel structure approximately 40 km north of Trekkopje Project. Carnotite uranium mineralisation occurs in both paleochannel sediments and in weathered basement rock. In November 2011, Marenica Energy reported a resource estimate totalling 23 577 tU at an average grade of 0.008% U.

With continued depressed market conditions, Marenica Energy suspended all drilling activities to focus on metallurgical testing and beneficiation for the so-called "U-pgrade™" processes to increase the grade of mined ore prior to leaching. Calcite rejection has also enabled the proposed leach circuit to be changed from an alkali leach (with higher operating temperatures and slower kinetics) to acid (at ambient temperature and rapid kinetics), thereby reducing expected capital expenses and operating costs.

During 2015 and 2016, Marenica Energy continued to do test work with various types of ores using U-pgrade™, Marenica Energy's patented disruptive beneficiation process. The process reportedly increases the plant feed grade from 80 ppm U (94 ppm U_3O_8) to 4 600 ppm U (5 500 ppm U_3O_8), and removes the clay and carbonate minerals. Marenica believes U-pgrade™ can revolutionise surficial uranium processing by reducing processing capital and operating costs by approximately 50%, thereby improving the economics of all uranium projects that process surficial uranium, and specifically making lower-grade projects much more competitive and financially viable.

Happy Valley

Located approximately 110 km northeast of Swakopmund and east of Rössing, the Happy Valley Project area was granted to Zhonghe Resources on 1 August 2006. It is a Namibian registered company founded in 2008 by CNUC (58%), a wholly owned subsidiary of CNNC, and co-owned by two private companies, China Mineral Resources Investment and Development P/L Nam-China (21%), and Springbok Investment Ltd (21%).

Exploration work was started in the area in 2007 and JORC compliant in situ resources amounting to 40 730 tU at 0.016% U were defined. A feasibility study was undertaken from 2013 to 2018 while Zhonge Resources continued to focus on resource evaluation and economic reassessment. Since CNUC has taken over Rössing Uranium Limited, the Zhonge Resources project could serve as a backup resource for Rössing Uranium Ltd. Since the deposit is not economically viable at current prices, CNUC is also reportedly looking to conclude partnerships with other Namibian uranium mining companies.

Nova Project

The Nova Joint Venture is owned by the Deep Yellow Ltd and JOGMEC (a Japanese Government Agency). The JV includes two prospecting licences for both basement-related alaskite-associated uranium targets (e.g. Rössing/Husab), skarn-type (e.g. Inca), and paleochannel-related surficial calcrete uranium targets (e.g. Langer Heinrich).

In 2017 and 2018, ground geological and geophysical follow-up of the anomalous zones were undertaken to define the drill target locations for the drilling programme. Following extensive ground verification work involving geological mapping and application of various geophysical surveys, a reconnaissance exploration drilling campaign of 82 reverse-circulation and diamond drill holes totalling 7 490 m was completed in December 2017. Targets included surficial calcrete type uranium mineralisation within paleochannels, and alaskite and skarn type mineralisation in basement rocks. This work identified greater than 100 ppm eU_3O_8 calcrete uranium mineralisation in a newly delineated paleochannel. The mineralisation has no surface expression.

Engo Valley

The Engo Valley Project consists of a series of uranium anomalies exposed in and adjacent to Karoo sedimentary rocks. The project is located 600 km north of Swakopmund, on the Skeleton Coast of northern Namibia. The licence was relinquished in 2014 following a review of the project considering its remote location.

Headspring

In south-eastern Namibia, Russian owned Uranium One, through its daughter company Headspring, conducted ground geophysical and geochemical surveys during 2016-2017, carried out metallurgical test studies of core with uranium mineralisation in 2018, and began exploration drilling in 2019. Based on these results, sandstone-type uranium resources potentially suitable for development by ISL have been identified.

Identified conventional resources (reasonably assured and inferred resources)

Total identified in situ conventional resources in Namibia amounted to 630 280 tU as of the end of 2018. Recoverable known resources amounted to 504 224 tU, including 320 714 tU in the reasonably assured and 183 510 tU in the inferred resources categories. The average overall recovery factor is 80%. Deposits in Namibia are typically large and low grade. About 89% of the recoverable identified uranium resources are classified in the <USD 130/kgU cost category, with the remainder reported in the <USD 130 and <USD 260 kg/U categories. Compared with data as of 1 January 2017, there has been a decrease of 37 122 tU in total recoverable resources, with a decrease of 47 775 tU in the reasonably assured resource category and a 10 653 tU increase in the inferred category. The decrease is a result of 2017 and 2018 mining depletion and of the reclassification and removal of non-minable Rössing mine resources, as reported in the Rio Tinto 2018 JORC compliant resource statement.

Undiscovered conventional resources (prognosticated and speculative resources)

Undiscovered resources are estimated in areas adjacent to deposits with identified resources in Happy Valley, Etango, Tumas and Husab. As of 1 January 2019, prognosticated resources amounted to 57 000 tU and speculative resources totalled 110 700 tU (unchanged from 1 January 2017).

Uranium production

Historical review

Rössing Uranium Limited was formed in 1970 to develop the Rössing deposit. Rio Tinto was the leading shareholder with 51.3% of the equity when the company was formed. Rio Tinto subsequently increased its stake to 69% of the project. In 2019, Rio Tinto sold its majority stake in Rössing to Chinese state company CNUC/CNNC.

Mine development commenced in 1974 and initial production began in July 1976, but full design capacity of 3 845 tU/yr (5 000 short tons of U_3O_8/yr) was not achieved because of the highly abrasive nature of the ore, an aspect not identified during the pilot plant testing stage. The production target was reached in 1979 after plant design changes were implemented. From the date of first production in July 1976 to the end of 2018, a cumulative total of over 116 000 tU had been produced at Rössing.

Full-scale development of the Langer Heinrich mine proceeded after licensing and commissioning in late 2006. Open-pit mining with a minimum mine life of 11 years and a process plant life of 15 years was planned when production began in 2007. The Langer Heinrich Project has been expanded three times since opening to achieve a production capacity of just over 2 000 tU/yr. In early 2014, CNNC subsidiary CNNC Overseas Uranium Holding Company bought a share of the Langer Heinrich Project, which entitled it to 25% share of mine production.

Swakop Uranium developed and constructed the Husab mine approximately 5 km south of the Rössing mine and 45 km northeast of Walvis Bay port. The project received environmental clearance in January 2011 and a mining licence later that same year. Construction began in February 2013 and first uranium production occurred at the end of 2016, with ramp up to full production capacity of 5 700 tU/yr planned by the end of 2020. Construction of Husab created more than 6 000 temporary jobs.

Until April 2012, Swakop Uranium was a 100% subsidiary of Extract Resources, an Australian company listed on the Australian, Canadian and Namibian stock exchanges. During April 2012, Taurus Minerals Ltd of Hong Kong became the new owner following a successful takeover of Extract Resources. Taurus is owned by the Chinese CGNPC Uranium Resources Co. Ltd and the China-Africa Development Fund. In November 2012, Epangelo, the Namibian state-owned mining company, finalised an agreement with Swakop Uranium under which Namibian state company Epangelo obtained a 10% stake in Swakop Uranium.

Status of production facilities, production capability, recent and ongoing activities and other issues

Total uranium production in Namibia declined from 3 246 tU in 2014 to 2 992 tU in 2015, but rebounded to 3 593 tU in 2016. Production continued to increase to 4 221 tU in 2017 and 5 520 tU in 2018. Start-up of the Husab mine was the main reason for production increases since 2016.

Rössing

Production at Rössing Uranium has steadily increased over the last few years as the mine has gradually accessed higher grade ore after the Phase 2 and 3 pushbacks: 1 761 tU in 2016, 1 788 tU in 2017, and 2 100 tU in 2018. Current mine plans foresee a cessation of Rössing production at the end of 2025.

Langer Heinrich

Following three successive mine expansions, a stage four expansion feasibility study (aimed at achieving a production level of 3 850 tU/yr) and an environmental impact assessment were submitted to government, but the expansion project was put on hold in 2014 because of low uranium prices.

Production has declined since due to lower grades and process recovery from 1 937 tU in 2015, 1 832 tU in 2016, and 1 293 tU in 2017. In August 2018, the mine was placed in care and maintenance due to the sustained low uranium spot prices, and only 394 tU was produced in 2018.

A concept study was subsequently undertaken to optimise Langer Heinrich mining and processing and to examine the potential for the recovery of vanadium as a by-product. The concept study and a prefeasibility study established the opportunity for restarting the mine at a sustainable USD 30/lb U_3O_8 production cost pending USD 80 million in capital investment.

Trekkopje

Following Phase 1 trial mining with 250 000 t of ore and processing operations, Phase 2 pilot tests, heap leach trials (using a sodium carbonate/bicarbonate leach process) and construction of the main production pad in 2010, a final production level of 2 545 tU/yr (3 000 t U_3O_8/yr) was envisaged. Production, limited to 251 tU and 186 tU in 2012 and 2013 respectively, demonstrated the feasibility of the technical process and confirmed production costs. However, as a direct consequence of low uranium prices, the project was placed in care and maintenance in mid-2013.

Husab

With a conventional, large-scale open-pit mine and a conventional agitated acid leach process plant, Husab has a nameplate capacity of 5 700 tU/yr (15 Mlbs U_3O_8/yr). Mining began in May 2015 and uranium production reached 1 140 tU in 2017, then was ramped up to 3 026 tU in 2018 and maintained at that level in 2019. The feasibility study showed a production cost of USD 83/kgU (USD 32/lb U_3O_8), including royalties, marketing and transport, and a capital cost of USD 1.66 billion. The mining fleet is expected to move 15 million tonnes of ore per year from two separate open pits to feed a processing plant producing 5 700 tU per year. Total mining fleet design capacity for ore and waste rock transportation is 120 million tons per annum.

Future production centres

Etango

After receiving environmental approvals to proceed with development of the Etango mine, completing a scoping study in September 2007 and a preliminary feasibility study, Bannerman Resources confirmed the viability of the project with a long-term uranium price of about USD 159/kgU (USD 61/lb U_3O_8) with pre-production capital costs estimated at USD 870 million. Additional work produced a reduction in break-even costs to USD 135/kgU (USD 52/lb U_3O_8) and reduced capital costs to USD 793 million for 16 years of operation, producing 2 770 tU/yr from a conventional open-pit mine. Subsequent work further reduced the pre-production capital cost estimate to USD 720 million.

Norasa

With estimated annual production of about 2 000 tU over a 15-year mine life, at costs of USD 86/kgU (USD 32.96/lb U_3O_8) over the first 5 years of production, and USD 90/kgU (34.72/lb U_3O_8) over the mine life, the project is expected to start when uranium prices recover. Environmental approval for an open-pit mine was granted in June 2008 and a 25-year mining licence was granted in August 2008 to Valencia Uranium P/L (a wholly owned subsidiary of Forsys). In situ indicated resources of 44 200 tU and inferred resources of 6 538 tU at a cut-off grade of 0.01% U have been delineated.

Uranium production centre technical details

(as of 1 January 2019)

	Centre #1	Centre #2	Centre #3	Centre #4	Centre #5	Centre #6
Name of production centre	Rössing	Langer Heinrich	Husab	Trekkopje	Norasa	Etango
Production centre classification	Existing	Care and maintenance	Existing	Care and maintenance	Prospective	Prospective
Date of first production (year)	1976	2006	2016	2013	NA	NA
Source of ore:						
Deposit name(s)	SJ, SK, SH	Langer Heinrich	Husab Zones 1 and 2	Trekkopje, Klein Trekkopje	Valencia and Namibplaas	Etango
Deposit type(s)	Intrusive	Calcrete	Intrusive	Calcrete	Intrusive	Intrusive
Recoverable resources (tU)	31 713	36 831	181 455	36 445	40 590	65 416
Grade (% U)	0.025	0.045	0.033	0.012	0.017	0.016
Mining operation:						
Type (OP/UG/ISL)	OP	OP	OP	OP	OP	OP
Size (tonnes ore/day)	40 000	20 000	42 000	30 800	33 000	55 000
Average mining recovery (%)	85	90	88	90	77	90
Processing plant:						
Acid/alkaline	Acid	Alkaline	Acid	Alkaline	Acid	Acid
Type (IX/SX)	IX/SX	IX	IX/SX	HL/IX	IX/SX	HL/IX/NF
Size (tonnes ore/day)	40 000	15 000	40 000	100 000	30 000	55 000
Average process recovery (%)	85	85	88	80	89	87
Nominal production capacity (tU/year)	4 000	2 030	5 700	3 000	2 000	2 770
Plans for expansion (yes/no)	No	No	Yes	No	No	No

Employment in the uranium industry

Rössing employment increased from 949 employees in 2016 to 967 employees at the end of 2018. The average number of contractors at the mine was 938.

At Langer Heinrich, the number of employees decreased from 309 in 2016 to 282 in 2017, and then to 19 by the end of 2018 when the operation was put in care and maintenance.

Recruitment intensified at Husab from 2016, and in 2019, Swakop Uranium had 1 650 permanent employees.

At Trekkopje, 20 workers are employed for care and maintenance activities.

Environmental activities and socio-cultural issues

Namibia's "Vision 2030" spells out the country's development programmes and strategies to achieve national objectives. It focuses on eight themes to realise the country's long-term vision. Uranium mine and exploration companies actively support these government objectives.

The Namibian Uranium Association

The Namibian Uranium Association (NUA) is an advocacy body for the uranium industry, assisting senior executives in shaping the context in which their industry operates. It supports policies that allow uranium to compete on its merits as a low-carbon energy source appropriate for modern society through research, information and advocacy. Members of NUA span all Namibian uranium mining operations, most of Namibia's leading uranium exploration companies, and associated contractors.

NUA is the leading point of contact for government, media, stakeholders, and the general public interested in the position and policies of the Namibian uranium industry. NUA promotes industry adherence to sustainable development performance, product stewardship and compliance within the Namibian legislative framework.

A key mission of the association's Uranium Stewardship programme is to "earn public trust for the global nuclear fuel cycle through the continued replacement of standard practice with best practice".

As part of its stewardship mission, NUA established the Namibian Uranium Institute (NUI). NUI is guided by respected independent scientists who serve on its Scientific Committee. The main purpose of the NUI is to act as a communication hub for the industry in Namibia, and to promote knowledge and capacity building in specialised skills in the fields of environmental management, radiation safety and health. NUI therefore provides an opportunity for NUA members to collectively improve safety and health performance through the identification of world-class leading practices and their implementation. As such, NUI is working closely with the Namibian government and state agencies, as well as maintaining close ties to the Namibian University of Science and Technology.

Environmental Management Act, Act No. 7 of 2007

Namibia committed itself to sound environmental management, and this is reflected in the Environmental Management Act, Act No. 7 of 2007 and Regulations, gazetted on 6 February 2012. The object of the act is prevention and mitigation, following environmental management principles that:

- ensure that the significant effects of activities on the environment are considered in time and with care;
- ensure that there are opportunities for timely participation of interested and affected parties through the assessment process, and that the findings of an assessment are taken into account before any decision is made with respect to the activities.

The Strategic Environmental Assessment and the Strategic Environmental Management Act

The Erongo Region is characterised by aridity, vast desert landscapes, scenic beauty, high biodiversity and endemism, and heritage resources. It has the second largest economy of all Namibian regions, and mining plays an important part. Walvis Bay and Swakopmund are among Namibia's five largest towns, but at the same time, large parts of the Erongo Region, especially along the coast, are under active conservation as national parks.

Most of the Namibian uranium exploration and mining activities occur in the Central Namib, an ecologically sensitive area containing parts of the Namib Naukluft and Dorob National Parks. Mining and associated developments are vital for Namibian economic growth, and the country strives to reconcile development objectives and mineral exploitation with environmental protection in order to foster long-term socioeconomic growth and stability. An integrated approach is required so that development of one resource will not jeopardise the potential of another.

The need for proper environmental planning in the framework of a comprehensive environmental assessment was therefore realised at an early stage when rising uranium prices in the mid-2000s caused a uranium exploration rush. Apart from forming the uranium stewardship committee, a proposal was made for a strategic environmental assessment (SEA) that was subsequently carried out by the Geological Survey of Namibia. The Uranium-SEA, as it has become known, dealt with a variety of topics, such as water, energy, air quality, radiation, health, transport, tourism, biodiversity, heritage, economics, education and governance. Following an independent assessment by the International Institute for Environment and Development, a Strategic

Environmental Management Plan (SEMP) was created from the SEA findings and is being implemented by the Ministry of Mines and Energy. The Namibian uranium industry has supported the SEA process and is an active partner of government in the implementation of the SEMP.

Positive impacts noted in the SEA include stimulating the Namibian economy, as well as developing skills and infrastructure. Constraints to development, such as possible water shortages, lack of skills, capacity of physical infrastructure and environmental protection, were also identified. The SEA noted that a uranium rush could impact natural physical resources, biodiversity, health, infrastructure and tourism. Good governance will be critical in minimising these impacts.

The SEMP sets out several environmental quality objectives related to socioeconomic development, employment, infrastructure, water, air quality and radiation, health, tourism, ecological integrity, education, governance, heritage and future developments, closure and land use, which are to be continuously monitored as a collective proxy for measuring the degree to which uranium mine development activities are moving the Erongo Region towards a desired future state. An office has been established to administer the SEMP programme.

One of the key aspects identified in the SEMP is water. Since 2010, water has been supplied to Trekkopje from a coastal desalination plant built by Areva (now Orano) capable of supplying 20 million m^3/yr and requiring 16 MWe from the grid. Desalinated water is also supplied via the Namibian Water Corporation to Rössing, Langer Heinrich and Husab. The SEMP stated that uranium mining, mine development and exploration have not compromised community access to water supplies of acceptable quality.

Rössing Uranium completed an environmental impact assessment of a proposal for a second desalination plant and an environmental clearance certificate issued by the Environmental Commissioner's office of the Ministry of Environment and Tourism. Rössing subsequently applied for the water permits as required by the Directorate of Water Resources Management in the Ministry of Agriculture, Water and Forestry in September 2016, but did not receive a reply, likely owing to jurisdictional disputes over water supply. No other environmental impact assessments were carried out by Rössing Uranium in 2017 or 2018.

Environmental monitoring

Uranium mining operations, in co-operation with the Environmental Affairs Department of the Ministry of Environment and Tourism, continue to actively monitor environmental issues of concern. Best practices and shared experiences are encouraged by participatory environmental planning and management to promote effective waste management practices. In addition to the SEMP, Namibian Uranium Association members carry out additional environmental monitoring, verified by the government, to ensure that the mining footprint is as small as possible. Stringent water-saving measures, air quality and biodiversity monitoring, as well as the implementation of mitigation measures for adverse impacts and environmental training of staff are examples of these efforts.

Well-established environmental monitoring programmes approved under the Environmental Clearance Certificate granted by the Ministry of Environment and Tourism continue. Rössing works to continuously improve environmental management programmes to maximise benefits and minimise negative impacts. Key environmental management programmes include energy efficiency and greenhouse gas emissions, air quality control (including emissions of dust and other impurities, as well as noise and vibration), water use, waste management (both mineral and non-mineral), chemical substance management and land use management (including biodiversity, rehabilitation and closure).

The mineral waste generated by Rössing Uranium in 2018 amounted to a total of 20.4 million tonnes (8.9 million tonnes of tailings and 11.5 million tonnes of waste rock). Tailings were deposited on the existing tailings storage facility, mainly in the re-activated deposition areas that had been prepared during 2015. The tailings footprint remained the same as in 2017.

Waste rock was deposited in existing rock dumps close to the open pit with no extension of the footprint. The total mineral waste inventory generated by Rössing over the last 42 years consists of 1.40 billion tonnes covering a total footprint of 1 377 ha.

Since 1980, Rössing has been recycling 60 to 70% of its water. The 2018 Rössing operating plan set and achieved a target for desalinated freshwater usage of 2.9 million m^3 supplied by NamWater. Saline groundwater from the Khan River aquifer used for haul road dust suppression took only 15% of the permitted volume in 2018.

Periodic reports on project-specific issues, such as water, are submitted to government by Paladin Energy, majority owner and operator of the Langer Heinrich mine. An environmental database was established to better evaluate and assess accumulating monitoring data (including a comprehensive surface and groundwater monitoring programme) in order to detect any potential issues as early as possible. Reusing and recycling water practices include water return from the tailings storage, as well as recovery from boreholes, trenches and treated effluent from the sewage treatment plant.

Environmental activities at Husab include finalising, updating and reviewing databases for the bio-physical monitoring network. A greenhouse gas emission inventory and a stack monitoring programme, initiated in 2018 and 2019 respectively, and applications for an on-site nursery for restoration trials were filed. A draft mine rehabilitation, restoration and mine closure plan was finalised in 2018, with a social component of the study expected to be completed in 2020.

Water requirements continue to be met by desalinated water supply through agreements with NamWater and Orano. An application for a permit to allow pit dewatering to be used for dust suppression was made to the relevant authorities. A closed loop circuit in the Husab processing plant facilitates continual water recycling and the final treated effluent from the sewage treatment plant is used for dust suppression.

Continued liaison, meetings and site visits with government agencies continue. Bi-annual compliance reports on mining and exploration activities are verified through external second party and third party audits. Amendments made to Husab environmental impact assessments from 2017 to 2019 were assessed through scoping reports issued for approval by government.

Site rehabilitation

All Namibian uranium operators adhere to the Mine Closure Framework of the Chamber of Mines of Namibia. The Framework provides guidance to the mining industry on developing relevant, practical and cost-effective closure plans and establishes minimum requirements for members bound by the Chamber's Code of Conduct and Ethics.

The Rössing Environmental Rehabilitation Fund, established to provide for the mine's closure costs, complies with statutory obligations and stipulated requirements of the government. The Fund requires an annual contribution by the mining company to provide for the total cost of the eventual closure of the mine, expected in 2025. At the end of December 2018, the fund had a cash balance of NAD 845 million (USD 47 million).

Corporate social responsibility

Members of the NUA have undertaken corporate social responsibility projects for more than three decades, with over 20 ongoing to address themes such as economic advancement, social progression, education and training, hunger and poverty, water supply, sanitation and youth employment.

Rössing also promotes healthy, safe and environmentally responsible lifestyles among neighbouring communities, and makes direct contributions to initiatives targeting biodiversity protection, conservation, health and safety (including HIV/Aids) and waste management. It also provided NAD 28 million (USD 1.5 million) to repair and replace asbestos roofs in the community of Arandis.

The Langer Heinrich mine implemented a Social Performance Management Plan, which is consistent with the ISO 14001 and 26000 and follows the ISO 26000 systems plan. The Husab mine committed to addressing social aspects such as local procurement, recruitment and employment, involvement in social responsibility programmes, training, education and sound environmental management practices.

Orano engages with stakeholders at local, regional and national levels in the areas of economic development, education, culture and sport. Orano fully supports the Harambee Prosperity Plan.

Bannerman Resources, even at an early stage of mine development, has focused on education and tourism as part of its social programme, for example, supporting over 2 000 disadvantaged primary school children in the Erongo and other regions in Namibia.

Atomic Energy and Radiation Protection Act, Act No 5 of 2005

The Atomic Energy and Radiation Protection Act (Act No.5 of 2005) was gazetted on 16 January 2012. Administered by the National Radiation Protection Authority, it provides for the regulation of all activities associated with radiation sources, radioactive or nuclear material.

The primary purposes of the act are to protect people against the harmful effects of radiation, minimise environmental pollution that may be caused by radiological contamination, ensure the safety of facilities and radiation sources, and guarantee that Namibia meets its obligations within the context of international legal instruments in the sector of radiation or nuclear technologies.

Regulatory regime

Namibia has been hosting mining uranium for more than 42 years. The sector is governed by a range of comprehensive legislations for uranium exploration and mining, starting with the Namibian Constitution that provides for the protection of the environment and the welfare of humankind, the Minerals (Prospecting and Mining) Act 1992 (No. 33) that requires every licence holder to conduct environmental impact assessments before the start of exploration, and the Minerals (Prospecting and Mining) Act 33 of 1992 that sets terms and conditions for granting exploration and mining licences. Section 102 of this Act prohibits the processing, import, export or possession of source material without the Minister's approval.

Namibia's Environmental Management Act underlines the importance of consultation with interested and affected parties. It promotes sustainable environmental management and use of natural resources by establishing principles for decision-making and environmental impact assessment regulations.

In 2007, the Government of Namibia imposed a moratorium on exclusive prospecting licence applications for nuclear fuel minerals. This was terminated on 15 December 2016, providing an opportunity for further exploration within the country.

Namibia is party to the Nuclear Non-Proliferation Treaty, has had a comprehensive safeguards agreement in force since 1998, and in 2000 signed and ratified the Additional Protocol. During 2016 a national legislative review mission was undertaken by the IAEA to provide advice on revisions to the Atomic Energy and Radiation Protection Act and discuss steps to enhance the national legal framework and further adherence to the relevant international legal instruments.

In July 2008, the Epangelo Mining Company was established by government to participate in the mining sector, and as per the provisions of the Minerals (Prospecting and Mining) Act, to acquire mining rights and equity by concluding joint ventures with existing companies. The Namibian government is the sole shareholder of Epangelo. Namibia has identified uranium as a strategic mineral and potential source of energy, expressing its desire to enhance economic development through potential local fuel cycle facilities and by considering nuclear power to augment its energy needs.

Uranium requirements

At present, Namibia has no nuclear power generating facilities. More than half of Namibia's annual electricity supply of about 4 400 GWh is being imported from neighbouring states, such as South Africa, Zimbabwe and Zambia.

National policies relating to uranium

The government has designated its uranium resources as strategic and controlled minerals that must be treated differently from other minerals because of, among other reasons, the risk of proliferation, radiological risks and its use as fuel for generating electricity.

Given its special nature and the radiological and fissile properties of uranium, the government is developing responsive regulatory frameworks to address health, safety, research and development applicable to the nuclear fuel cycle. Because Namibia is considering the development of commercial nuclear power to promote energy security and meet its increasing energy needs without increasing greenhouse gas emissions, it has developed a draft Nuclear Fuel Cycle Policy to examine the potential development of conversion, enrichment and other facilities.

Uranium exploration and development expenditures and drilling effort – domestic

(NAD – Namibian dollars)

	2015	2016	2017	2018	2019 (expected)
Industry* exploration expenditures	40 400 000	40 399 837	38 880 037	39 699 026	14 482 000
Industry* development expenditures	81 138 309	84 465 924	4 145 042	11 767 531	9 340 000
Total expenditures	121 538 309	124 865 761	43 025 079	51 466 557	23 822 000
Industry* exploration drilling (m)	9 845	8 390	21 428	18 756	2 500
Industry* exploration holes drilled	377	40	548	794	9
Industry* development drilling (m)	378 497	47 777	7 044	14 511	16 000
Industry* development holes drilled	380	108	128	154	165
Subtotal exploration drilling (m)	9 845	8 390	21 428	18 756	2 500
Subtotal exploration holes drilled	377	40	548	794	9
Subtotal development drilling (m)	378 497	47 777	7 044	14 511	16 000
Subtotal development holes drilled	380	108	128	154	165
Total drilling (m)	388 342	56 167	28 472	33 267	18 500
Total number of holes drilled	757	148	676	948	174

* Non-governmental expenditure.

Reasonably assured conventional resources by production method

(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	0	0	279 423	320 714	80
Total	0	0	279 423	320 714	80

Reasonably assured conventional resources by processing method

(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from OP	0	0	233 669	240 992	80
Heap leaching* from OP	0	0	45 754	79 722	80
Total	0	0	279 423	320 714	80

* A subset of open-pit and underground mining, since it is used in conjunction with them.

Reasonably assured conventional resources by deposit type

(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Intrusive	0	0	236 284	243 606
Surficial	0	0	43 139	77 107
Total	0	0	279 423	320 714

Inferred conventional resources by production method

(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	0	0	168 922	183 510	80
Total	0	0	168 922	183 510	80

Inferred conventional resources by processing method

(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from OP	0	0	149 260	161 372	80
Heap leaching* from OP	0	0	19 662	22 138	80
Total	0	0	168 922	183 510	

* A subset of open-pit and underground mining, since it is used in conjunction with them.

Inferred conventional resources by deposit type

(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Intrusive	0	0	122 368	134 479
Surficial	0	0	46 554	49 031
Total	0	0	168 922	183 510

Prognosticated conventional resources

(tonnes U)

Cost ranges		
<USD80/kgU	<USD 130/kgU	<USD 260/kgU
0	0	57 000

Speculative conventional resources

(tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
0	0	110 700

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (preliminary)
Open-pit mining*	123 410	3 593	4 221	5 520	136 744	5 103
Total	123 410	3 593	4 221	5 520	136 744	5 103

* Pre-2015 totals may include uranium recovered by heap and in-place leaching.

Historical uranium production by processing method

(tonnes U in concentrates)

Processing method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (preliminary)
Conventional	122 973	3 593	4 221	5 520	136 007	5 103
Heap leaching	437	0	0	0	437	0
Total	123 410	3 593	4 221	5 520	136 744	5 103

Historical uranium production by deposit type

(tonnes U in concentrate)

Deposit type	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (preliminary)
Intrusive	110 480	1 761	2 928	5 126	120 295	5 103
Surficial	12 930	1 832	1 293	394	16 449	0
Total	123 410	3 593	4 221	5 520	136 744	5 103

Ownership of uranium production in 2018

Domestic				Foreign				Totals	
Government		Private		Government		Private			
(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)
374	7	0	0	3 357	61	1 789	32	5 520	100

Uranium industry employment at existing production centres

(Person-years)

	2017	2018	2019 (preliminary)
Employment directly related to uranium production	2 858	2 585	2 585

Short-term production capability

(tonnes U/year)

2020				2025			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
0	0	6 000	6 000	0	0	7 200	7 200

2030				2035				2040			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
0	0	7 200	7 200	0	0	7 200	9 800	0	0	7 200	9 800

Niger*

Uranium exploration and mine development

Historical review

Uranium exploration began in 1956 in the Arlit area of Niger within the Tim Mersoï sedimentary basin, and uranium was first discovered in sandstone at Azelik in 1957 by the French Bureau de Recherches Géologiques et Minières (BRGM). The French Atomic Energy Commission initiated further studies of the sandstone, which were taken over by the Compagnie Générale des Matières Nucléaires (COGEMA) and resulted in the discoveries of Abokurum (1959), Madaouela (1963), Arlette, Ariege, Artois and Taza (1965), Imouraren (1966) and Akouta (1967).

The Société des Mines de l'Aïr (Somaïr) was created in 1968 and started production from the Arlette deposit in 1971 by shallow (60 m depth) open-pit mining. From 1971 to 1988, acid heap leaching was used at Arlit, producing 200-600 tU/yr, for a total of 5 900 tU over this 17-year period. The uranium recovery rate achieved was low (50% or less) and from 1988 to 2009 more than 10 Mt of low-grade ore (0.08% U average grade) had been stockpiled. In 2009, after conducting tests over several years, Somaïr restarted heap leaching using an improved process to achieve recovery rates above 85%. Since the start of operations in 1971, about 70 000 tU were produced at the Somaïr mine. In 2017, due to tough uranium market conditions, Somaïr entered into a plan to reduce annual production to 1 700 tU.

The Compagnie Minière d'Akouta (Cominak) was set up in 1974 and started production from the Akouta and Akola deposits, near the town of Akokan. This is an underground operation at a depth of about 250 m. Production has now switched to the deposit of Ebba/Afasto, south of Akouta and Akola. Since the start of operations in 1978, more than 70 000 tU were produced at Cominak mine.

In 2004, COGEMA and the government of Niger signed an agreement to undertake a major exploration programme. In subsequent years, both Somaïr and Cominak were involved in exploration solely for the purpose of better evaluating previously discovered deposits. Somaïr delineated the Taza Nord deposit, while Cominak evaluated a mineralised area south-east of the Akola deposit.

Development of the large Imouraren deposit about 80 km south of Arlit was confirmed in January 2008. In 2009, Areva S.A. (now Orano S.A., as of January 2018) was awarded a mining licence and a joint venture agreement was signed to develop Imouraren, but it was shelved because of unfavourable market conditions.

In 2006, the China National Nuclear Corporation (CNNC) signed an agreement to develop the Azelik-Abokurum deposit and a new company, Société des Mines d'Azelik (Somina), was created in 2007 for this purpose. About 670 tU were produced up to 2014 when the mine was put in care and maintenance.

All uranium deposits in Niger are located within the Tim Mersoï Basin, a sub-basin of the Illemmenden Basin. The Tim Mersoï Basin is in close proximity to the main Arlit-In Azaoua fault. Uranium is mined close to the twin mining towns of Arlit and Akokan, 900 km north-east of the capital Niamey (more than 1 200 km by road), near the southern border of the Sahara Desert and the western range of the Aïr Mountains. The concentrates are trucked to ports in Benin and the majority are exported to the Malvési conversion facility in France.

* Report prepared by the NEA/IAEA, based on company reports and government data.

Uranium exploration in Niger was revitalised in 2007 as the price of uranium increased. A total of six new exploration permits were granted that year and by 2011 uranium exploration activities were being carried out on 160 concessions by foreign companies. From 2001 to 2016, 356 uranium exploration permits were registered. However, since 2011, there have been increasing geopolitical tensions in the region, resulting in foreign companies like Paladin and URU Metals ceasing exploration activities in Niger.

Following a 2006 agreement in which Areva agreed to increase royalty payments to the government by 50%, development of the Imouraren deposit, about 80 km south of Arlit and 160 km north of Agadez, was announced in January 2008. In January 2009, Areva was awarded a mining licence. The Imouraren SA mining company was established, with Areva NC Expansion (86.5% Areva, 13.5% KEPCO) holding a 66.65% interest and Sopamin of Niger holding the remaining 33.35%.

The Imouraren project is a EUR 1.9 billion (USD 2.06 billion) investment, and Orano has agreed to spend EUR 6 million per year (USD 6.5 Million) on health, education, training, transport and access to water and energy for local residents. Production is expected to be 5 000 tU/yr for 35 years. The deposit covers 8 km by 2.5 km and Orano reports 213 722 tU of reserves at 0.072% U, plus 62 584 tU indicated resources. Average depth is 110 m and maximum thickness 60 m. At full production, the project's heap leaching facility will process 20 000 tonnes of ore per day with an expected 85% rate of recovery. Excavation of the first pit started in mid-2012.

In May 2014, uranium prices were not sufficient to allow profitable mining of the deposit and the Nigerien government and Areva agreed to set up a joint strategic committee that will determine when mining should start.

GoviEx Uranium in 2008 held two exploration properties of 2 300 km^2: one near the Arlit mine, including the Madaouela deposit, as well as 2 000 km^2 near Agadez. In August 2008, Cameco bought an 11% share in the company for USD 28 million, with an option to increase its share to 48%. The Government of Niger has the right to hold a 10% carried interest and the option to purchase a further 30% share when the Nigerien mining company is incorporated.

The GoviEx drilling programme commenced in August 2008. The work programme was based on three objectives: i) resource delineation drilling of Marianne and Marilyn deposits; ii) exploration and resource definition drilling on the Madaouela South deposit area; and iii) exploratory drilling between the known deposits. As of February 2010, a project-wide total of 584 000 m had been drilled by GoviEx.

Global Atomic Fuels Corp. (GAFC), a private Canadian company, has six exploration permits (728.8 km^2) located in the north of Agadez, four at Tin Negouran (the "TN permits") and two at Adrar Emoles (the "AE Permits"). The Adrar Emoles permit hosts the Dasa deposit, a sandstone basal channel type deposit.

From 2010 to 2014, GAFC drilled 969 holes (867 rotary drill holes and 102 diamond drill holes), for a total of >120 000 m and in January 2014 released an initial inferred resource estimate, which totalled 43 850 tU grading 0.054% U, using an 0.0085% U cut-off. In June 2014, GAFC announced internal resource estimates ranging from 64 600 tU at 0.049% U (0.0085% U cut-off), to 29 600 tU grading 0.29% U (0.127% U cut-off). The base case appeared to be 36 500 tU grading at 0.222% U (0.085% U cut-off).

URU Metals Limited reported a SAMREC (South African Mineral Resource Committee) compliant inferred resource of 1 654 tU on their In Gall deposit and in 2011 continued to drill the Aboye, Akenzigui and Fagochia targets within their Irhazer and In Gall permits. Project commitments elsewhere caused URU Metals to take steps to terminate activities in Niger by 2014.

In December 2010, Paladin completed the takeover of NGM Resources Ltd, the owner of the local company Indo Energy Ltd that held concessions in the Agadez region. NGM Resources had announced an inferred mineral resource of 4 320 tU. In early 2011, Paladin carried out a drilling programme that further defined targets for follow-up and information from the drilling was used to plan a 15 000 m follow-up drilling campaign. However, this was put on hold because of security concerns. All fieldwork has ceased and *Force Majeure* has been requested from the government authorities for an indefinite suspension of further expenditures.

In 2011, GazPromBank Niger Minerals SARL, a Russian company, was granted two uranium licences (Toulouk) located in the Tim Mersoï Basin. On March 2017, the company submitted a pre-feasibility study through which it declared JORC compliant inferred resources of sandstone type tabular mineralisation with 29 630 tU at a grade of 0.0157%, a roll-front type deposit containing 17 000 tU with grades varying from 0.04% to 0.06% and a surficial sandstone type deposit containing 8 237 tU at a grade of 0.0252% U.

On 20 September 2013, Pan-African Minerals Ltd was granted 4 uranium licences (Ouricha 1 and 2, Tegmert 1 and 2) located in the Agadez area. Pan African Minerals planned to invest at least USD 20 million in exploration activities during the next 3 years.

Recent and ongoing uranium exploration and mine development activities

In 2017-2018 Global Atomic Corporation (GAC; formerly GAFC) commenced a new drilling programme targeting various areas of the Dasa project and a total of 59 holes amounting to 26 479 m were completed. This successfully delineated higher-grade mineralisation within 300 m of the surface. The drilling was focused on areas of faulting associated with a graben structure and results improved understanding of the distribution of mineralisation within the deposit and confidence in the geological model. This resulted in an upgraded classification of resources from inferred to indicated

The Dasa Project mineral resources were first estimated and reported by CSA Global in April 2017, then updated in June 2018 and June 2019. Mineral resources were reported in two parts; those that have potential for extraction by open-pit, and the deeper, higher-grade material outside of the open pit that may be amenable to underground mining. The open-pit mineral resources are the parts of the deposit above a cut-off of 320 ppm eU_3O_8. Higher-grade material above a cut-off grade of 1 200 ppm outside of the optimised pit shell was considered for underground mining. Some areas could also be considered for ISL.

Dasa mineral resources as at 1 June 2019

(mineral resources are based on CIM definitions)

Category	Ore (Mt)	Grade (% eU)	Uranium (t)
Indicated OP	25.59	0.145	37 118
Indicated UG	0.71	0.275	1 962
Total indicated	26.30	0.148	39 080
Inferred OP	18.93	0.115	21 771
Inferred UG	3.38	0.352	11 924
Total inferred	22.31	0.151	33 695

In 2018, CSA Global completed a preliminary economica assessment (PEA) based on the 2018 resource estimate. The PEA determined that the most attractive returns were generated from a stand-alone, underground, high-grade mining scenario which would operate for a period of 15 years and produce between 1 540 tU and 2 690 tU annually. The extraction ratio would be 85%, mill recovery 84.3% and the total operating cost would be USD 28.51/lb U_3O_8 (USD 74.12/kgU). Results of the metallurgical testwork show that the mineralogy and metallurgy of the Dasa deposit is amenable to acid leaching with conventional uranium recovery – similar to the Arlit operation. GAC then began a prefeasibility study (PFS) based on the 2019 resource update which is expected in 2020. In 2017, GAC signed an agreement with Orano on ore sales and joint co-operation.

In addition to Dasa, two other deposits are located on the Adrar Emoles permits, Dajy and Isakanan. The Dajy deposit is located along the major NE-SW trending Azouza Fault that hosts the Azelik and Dasa deposits, some 30 km SE of Imouraren. Whereas Dasa can be traced to surface, Dajy occurs at depth. Dajy uranium mineralisation is hosted in three sandstone units over a 3.5 km long and 400 m wide area. The Dajy deposit contains 6 400 tU grading 0.0584% U (inferred resources). The Isakanan deposit, located 15 km south of the Dasa and Dajy deposits, hosts 13 000 tU grading 0.076% U (inferred resources). The Tin Negouran permits host the Tagadamat deposit, where mineralisation occurs within surface paleochannels along a 3-km strike, with potential for open-pit mining and heap leach processing. The Tagadamat deposit hosts 3 500 tU grading 0.015% U (inferred resources). An environmental baseline study was completed in 2009, but the project was put on hold until 2020.

In March 2017, GoviEx began a drilling programme focused on expanding shallow near-surface uranium mineralisation associated with the Miriam Deposit. The 4 000 m drilling programme was conducted on a 100 m grid at Madaouela to an expected average depth of approximately 100 m (40 drill holes). However, the drilling did not result in additional resources. On 15 November 2017, GoviEx was granted the Agaliouk Exploration Permit, which is adjacent to the Madaouela deposit. The Agaliouk Exploration Permit adds 4 488 tU in the measured and indicated categories and 3 596 tU in the inferred category.

GoviEx developed a NI 43-101 Integrated Development Plan for five deposits (Marianne, Marilyn, Miriam, MSNE and Maryvonne). The Plan is based on detailed pre-feasibility geological studies that considered metallurgical testing and processing options, mine design, infrastructure, rock mechanics, tailings and heap leach, hydrogeological and environmental impacts. In November 2017, NI 43-101 compliant resources at Madaouela totalled 42 603 tU of measured and indicated and 10 647 tU of inferred. An open-pit mine on at least part of the deposit, by underground room and pillar mining with conventional processing, is expected to produce 1 030 tU/yr over 21 years, with potential for expanding the resource. Production is expected to begin by 2022. The environmental and social impact assessment for the project was filed with the Nigerien government in March 2015 and a mining licence was obtained in January 2016.

Madaouela mineral resources (cut-off: 0.04% U) as of 13 November 2017

(in accordance with CIM guidelines)

Deposit	Classification	Ore (Mt)	Grade (%U)	U (t)
Marianne/Marilyn	Measured	2.14	0.152	3 252
	Indicated	14.72	0.121	17 808
	Inferred	5.04	0.099	5 012
Miriam	Measured	9.62	0.092	8 817
	Indicated	2.68	0.067	1 791
	Inferred	0.58	0.113	656
MSNE	Indicated	5.05	0.137	6 878
	Inferred	0.10	0.114	111
Maryvonne	Indicated	1.23	0.152	1 861
	Inferred	0.42	0.141	596
MSCE	Inferred	0.72	0.153	1 109
MSEE	Inferred	1.45	0.139	2 012
La Banane	Indicated	1.57	0.139	2 195
	Inferred	1.15	0.110	1 152
	Total Measured	11.76	0.103	12 069
	Total Indicated	25.25	0.121	30 534
	Total Inferred	9.46	0.113	10 647

In 2018, GoviEx reviewed the ore process design of the Madaouela project and determined that the inclusion of membrane separation in the process design could potentially reduce operating and capital costs, which may in turn improve project economics. On 19 September 2018, GoviEx announced the appointment of SRK Consulting (UK) Ltd and SGS Bateman (Pty) Ltd as the consultants to complete a feasibility study for the Madaouela Project.

In 2017-2018, Orano, Cominak and Somair continued exploration and development activities within the mines perimeters and in the Arlit concession. Somaïr drilled 16 240 m in 2017, 8 150 m in 2018, and was planning 11 863 m in 2019. In October 2018, Somair was granted the Artois deposit concession.

In 2018, the government of Niger renewed Pan African Minerals exploration licences (Ouricha 1 and 2, Tegmert 1 and 2). During 2017 and 2018, spending corresponded to field activities and company administrative costs.

Uranium reserves (in situ) as of 31 December 2018

Deposit	Classification	Ore (Mt)	Grade (%U)	U (t)
Cominak	Proven	132	0.373	494
	Probable	249	0.406	1 010
Imouraren	Proven	0	0	0
	Probable	306 048	0.070	213 722
Somair	Proven	221	0.064	141
	Probable	8 879	0.114	10 125
Total	Proven	353	0.180	635
	Probable	315 176	0.071	224 957

Recovery factor: Cominak (93%), Imouraren (82%), Somaïr (83%).

Additional resources (in situ) as of 31 December 2018

Deposit	Classification	Ore (Mt)	Grade (%U)	U (t)
Concession Arlit	Inferred	12 845	0.159	20 403
Cominak	Measured	1 288	0.311	4 001
	Indicated	1 029	0.263	2 711
	Inferred	735	0.313	2 297
Imouraren	Indicated	108 668	0.058	62 584
	Inferred	4 394	0.066	2 879
Somaïr	Indicated	14 520	0.143	20 782
	Inferred	13 877	0.164	22 718
Total	Measured	1 288	0.311	4 001
	Indicated	124 217	0.069	86 087
	Inferred	31 851	0.152	48 297

Recovery factor: Cominak (93%), Concession Arlit (83%), Imouraren (82%), Somaïr (83%).

Uranium exploration and development expenditures (F CFA)

Company	2016	2017	2018	2019 (expected)
Cominak	379 755 928	0	0	NA
Global Atomic Corp.	102 552 290	82 607 469	3 788 995 583	NA
GoviEx	1 387 010 400	45 625 000	53 316 000	NA
Gazprom	533 284 400	0	0	NA
Orano	114 873 839	13 568 097	0	NA
Pan African	153 676 381	43 154 510	87 661 960	NA
Somair	NA	398 000	289 000	430 000
Total	2 671 153 238	185 353 076	3 930 262 543	NA

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

The total recoverable identified conventional resources for Niger, as of 1 January 2019, amounted to 439 388 tU, compared to 425 577 tU as of the end of 2016. The increase of total recoverable resources is mainly associated with an increase of resources at the Dasa deposit and the addition of Toulouk deposit resources. Mining depletion in 2017 and 2018 amounted to 6 362 tU and is taken into consideration in the resource figures.

All uranium deposits in Niger are sandstone-hosted, with average grades of 0.07 to 0.40% U, with 72% of total identified resources in RAR category and 93% of these are amenable to open-pit mining.

Undiscovered conventional resources (prognosticated and speculative resources)

Total speculative and prognosticated resources in Niger, as of 1 January 2019, amounted to 64 900 tU (unchanged from 2017).

Uranium production

Historical review

Uranium has been produced from sandstone deposits in Niger since 1971 by Somaïr at the Arlit mine, 1978 by Cominak at the Akouta mine and 2010 by Somina at the Azelik mine.

The Société des Mines d'Azelik SA (Somina) was established in 2007 to mine the Azelik/Teguidda deposits. Azelik was developed by the China National Nuclear Corporation (CNNC) and came into production at the end of 2010, with the aim of ramping up to 700 tU/yr. It is an open-pit and underground operation using alkaline leach. In August 2014, CNNC announced that Azelik had experienced prolonged project delays, overruns in its construction budget, and low production. In February 2015, CNNC announced that the mine would be closed and put in care and maintenance because of "tight cash flow".

Somaïr and Cominak were licensed to the end of 2013, and in mid-December 2013, both were shut down for maintenance, pending resolution of negotiations on licence renewals. The mines resumed operation at the end of January 2014 under the terms of a government decree. In May 2014, the government and Areva signed a new five-year agreement for the two mines based on the 2006 mining law and expressing what both sides said was a balanced partnership.

In 2015, production recorded for Niger amounted to 4 116 tU, then decreased to 3 478 tU in 2016, 3 484 tU in 2017 and 2 878 tU in 2018. Production in 2019 amounted to 3 053 tU, 1 903 tU of which was produced by Somair at the Arlit open-pit mine and 1 150 tU by Cominak at the Akouta undergound mine.

Status of production facilities, production capability, recent and ongoing activities and other issues

Production at Somair (Arlit) open-pit mine has been lowered by 30% since 2015 due to weak market conditions. Arlit is expected to continue operating for some time, as additional resources have been added to the project over the last few years that should extend its mine life to the late 2020s.In December 2018, the Nigerien government and Orano negotiated and approved a new five-year agreement (2019-2023) for the Cominak and Somaïr mines.

Cominak (Akouta) continued underground mining at a depth of ~250 meters. On 24 October 2019, Orano announced that Cominak will end its uranium production on 31 March 2021 due to the exhaustion of ore and high operating costs.

In 2019, GAC started an optimised preliminary economic assessment for the Dasa Uranium Project, incorporating a high-grade zone for the initial Phase 1 mining plan. It plans to apply for a Dasa uranium project mining permit in the second half of 2020 and continues negotiations with Orano on processing Dasa ore at Orano's mill given the expected closure of the Cominak mine in 2021.

Uranium production centre technical details
(as of 1 January 2019)

	Centre #1		Centre #2	Centre #3	Centre #4	Centre #5	Centre #6
Name of production centre	Arlit (Somaïr)		Akouta (Cominak)	Azelik (Somina)	Imouraren	Madaouela (Comina)	Dasa
Production centre classification	Existing		Existing	Care and maintenance	Planned	Planned	Prospective
Date of first production	1971	2009	1978	2010	NA	NA	NA
Deposit name(s)	Tamou-Artois-Tamgak-Taza-Tamou	Low-grade stockpiles	Akouta-Akola-Ebba Ebene	lik-Teguidda-Abokurum	mouraren	Miriam-Marianne-Marilyn-MSNE-Maryvonne	Dasa
Deposit type(s)	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone
Recoverable resources (tU)	44 626	NA	3 538	9 684	228 932	42 599	31 568
Grade (‰ U)	0.196	0.08	0.314	0.142	0.072	0.08	0.22
Mining operation:							
Type (OP/UG/HL)	OP	HL	UG	OP/UG	OP/HL	OP/UG	OP
Size (tonnes ore/day)		1 800 kt/yr					
Average mining recovery (%)							
Processing plant:							
Acid/alkaline	Acid	Acid	Acid	Alkaline	Acid	Acid	
Type (IX/SX)	SX	SX	SX			SX	
Size (tonnes ore/day)							
Average process recovery (%)	78	up to 85	93	85	82	82	80
Nominal production capacity (tU/year)	1 700		1 800	700	5 000	1 030	770
Plans for expansion						Yes up to 5 000	Yes, 1 130) (up to 1 900)
Other remarks			Production to end of March 2021 h 31, 2021				

Ownership structure of the uranium industry

The ownership structure of Niger's four uranium production companies are set out in the table below:

Somaïr	Cominak	Somina	Imouraren
36.6% Sopamin (Niger)	31% Sopamin (Niger)	33% Sopamin (Niger)	33.35% Sopamin (Niger)
63.4% Orano (France)	34% Orano (France)	37.2% CNUC (China)	57.65% Orano (France)
	25% OURD (Japan)	24.8% ZXJOY invest (China)	9% KEPCO
	10% ENUSA (Spain)	5% Trend Field Holdings SA	

Employment in the uranium industry

As of 1 January 2018, 898 workers were employed at the Somaïr mine and 776 at the Cominak mine. It is reported that 99% of the workers at these two mines are Nigerien. About 680 workers were employed at the Azelik mine, but due to the cessation of mining operations, only 25 workers have been retained. The Imouraren project employed about 300 during the development stage and is expected to create about 1 400 permanent and up to 3 000 indirect jobs when the facility will be in full production.

Future production centres

In May 2009, development of the Imouraren mine was launched with an initial investment of more than USD 1.9 billion. Once ramped-up to full capacity, production of 5 000 tU/yr for 35 years is expected. Production, originally scheduled to start mid-2015, remains delayed owing to poor market conditions.

GoviEx has completed a preliminary feasibility study and proposed an open-pit/ underground mine development for the Madaouela project, which could go into production after 2022 with a capacity to produce 1 040 tU/yr at the beginning and plans to reach 5 000 tU/yr when fully operational.

GAC plans to construct its first mine at Dasa, targeting a 770 tU annual capacity with potential to ramp up to 1 900 tU/yr. It has spent approximately CAD 50 million (about USD 35 million) on exploration and development to date on its Niger projects and is expected to apply for its mining licence for the Dasa project.

Environmental activities and socio-cultural issues

Both mining operations at Somaïr and Cominak have maintained their ISO 14001 certification for environmental management for many years (certification is renewed every three years). Areva maintains that environmental issues, including water preservation, is fundamentally important to their operations. The mandate of the AMAN project, established in 2004, is to study the existing aquifers in the Arlit and Akokan areas to ensure an adequate supply of potable and industrial water is available and not being compromised. Ways to conserve and reduce water consumption have been implemented and over the past 15 years the annual consumption of water at the mines has been reduced by 35%, despite uranium production doubling at Somaïr in the past 10 years.

In April 2010, Areva and local authorities signed a series of protocols and procedures to implement multipartite radiological control of materials and equipment in the streets of Arlit and Akokan, including more stringent monitoring of used materials being taken from the industrial sites.

Somaïr and Cominak manage two hospitals in Arlit and Akokan with technical support centres. First created to provide medical care for the miners and their families, the centres are now largely open to the public free of charge. Imouraren also recently opened a medical centre that treats local residents for free.

As the country's largest private employer, Orano has been contributing to the improvement of living conditions in local communities. In 2010, Orano (then Areva) initiated an ambitious social policy and committed EUR 6 million per year (about USD 6.5 million) for the next five years for implementation. Mining activity has resulted in the construction of housing and a modern network of water distribution as well as contributing to the funding of public services and the construction of educational facilities (schools, libraries, lunch rooms, etc.).

In 2018, Orano invested EUR 2 million (about USD 2.2 million) in the Irhazer project in order to develop irrigation systems and agricultural activities in desert areas in the Agadez region. The objective of the project is to contribute to sustainable food safety against powerty.

Uranium requirements

There are currently no uranium requirements in Niger. However, it has been reported that Niger has started consultations with the IAEA and is considering the installation of two civilian nuclear reactors to meet domestic energy requirements and assist in national economic development.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

One of the main objectives of Niger's national uranium policy is to achieve a higher degree of international competitiveness in the industry. In July 2011, President Issoufou stated that he would seek a better price for the country's uranium exports to maximise their value to support economic and social development. About one-third of Niger's export revenue comes from uranium.

In May 2014, the Nigerien government and Areva signed a new five-year agreement for the two mines based on the 2006 mining law, in which the royalty rate will increase potentially to 12% of market value, depending on profitability. The deal also stipulates that for the first time that the firms' boards will include Nigerien managing directors – appointed in 2014 for Somaïr, and in 2016 for Cominak. Also, Areva (now Orano) will provide EUR 90 million (USD 97 million) to support constructing a road from Tahoua to Arlit, near the uranium developments, as well as a further EUR 17 million (USD 18.4 million) for development in the surrounding Irhazer Valley. Orano will also build a new headquarters building (Maison de l'uranium) for its operating companies in the capital Niamey at a cost of EUR 10 million (USD 11 million). The government expects more than USD 39 million in additional tax revenues annually from the new Strategic Partnership Agreement. In October 2014, the Nigerien government formally approved the agreement.

Production of each year is sold to joint venture partners, usually in proportion to their equity, at a set transfer price known as *prix Niger*. The quantities not sold to joint venture partners, if any, are sold to trading companies at prevailing spot price.

Uranium prices

The price of uranium sold to joint venture partners (prix Niger) is proposed by mining companies to the Ministry of Mines, which ultimately decides on its level and duration of validity – usually equivalent to one year. This price is officially published in the *National Gazette* (Journal Officiel de la République du Niger) and posted on its website. In case the price determination is made during the course of the year, it is retroactively applied to already made deliveries.

Reasonably assured conventional resources by production method
(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	1 399	10 232	22 050	81
Open-pit mining (OP)	0	8 521	228 439	293 427	81
Total	0	9 920	238 671	315 477	81

Reasonably assured conventional resources by processing method
(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	1 399	10 232	22 050	81
Conventional from OP	0	8 521	54 243	66 856	81
Heap leaching from OP	0	0	174 196	226 571	82
Total	0	9 920	238 671	315 477	81

Reasonably assured conventional resources by deposit type
(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	9 920	238 671	315 477
Total	0	9 920	238 671	315 477

Inferred conventional resources by production method
(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	0	0	20 715	79
Open-pit mining (OP)	0	0	37 733	42 267	82
Unspecified	0	0	0	60 929	76
Total	0	0	37 733	123 911	78

Inferred conventional resources by processing method
(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	0	0	20 715	79
Conventional from OP	0	0	35 372	39 906	82
Heap leaching from OP	0	0	2 361	2 361	82
Unspecified	0	0	0	60 929	76
Total	0	0	37 733	123 911	78

Inferred conventional resources by deposit type

(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	37 733	123 911
Total	0	0	37 733	123 911

Prognosticated conventional resources

(tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
0	13 600	13 600

Speculative conventional resources

(tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
0	51 300	0

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019
Open-pit mining*	66 713	2 164	2 153	1 750	72 780	1 903
Underground mining*	69 586	1 314	1 331	1 128	73 359	1 150
Total	136 299	3 478	3 484	2 878	146 139	3 053

* Pre-2015 totals include uranium recovered by heap and in-place leaching.

Historical uranium production by processing method

(tonnes U in concentrates)

Processing method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019
Conventional	NA	NA	NA	NA	NA	NA
Heap leaching*	NA	NA	NA	NA	NA	NA
Total	136 299	3 478	3 484	2 878	146 139	3 053

* A subset of open-pit and underground mining, since it is used in conjunction with them.

Historical uranium production by deposit type

(tonnes U in concentrates)

Deposit type	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019
Sandstone	136 299	3 478	3 484	2 878	146 139	3 053
Total	136 299	3 478	3 484	2 878	146 139	3 053

Ownership of uranium production in 2018

Domestic				Foreign				Totals	
Government		Private		Government		Private			
(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)
955	33.2	0	0	1 485	51.6	438	15.2	2 878	100

Uranium industry employment at existing production centres

(person-years)

	2016	2017	2018
Total employment related to existing production centres	3 935	3 843	3 011
Employment directly related to uranium production	1 800	1 745	1 478

Short-term production capability

(tonnes U/year)

2018				2020			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
NA	NA	3 500	3 500	NA	NA	3 500	3 500

2025				2030				2035			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
NA	NA	3 500	3 500	NA	NA	5 000	5 000	NA	NA	5 000	6 800

Portugal*

Uranium exploration and mine development

Historical review

There has been no exploration and exploitation of uranium in Portugal since 2001, although unexploited uranium deposits exist in the southern part of the country.

In 2001, the Portuguese Government launched the decree-law nº 198A/2001, which granted the state owned mining company Empresa de Desenvolvimento Mineiro (EDM) the concession for environmental rehabilitation of all abandoned and legacy mines (uranium and polymetallic). Since then activities undertaken by EDM have prioritised safety and the environmental rehabilitation and remediation of legacy uranium mining sites.

Recent and ongoing uranium exploration and mine development activities

There has been no activity at home or abroad.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

As previously reported (2007 edition of the Red Book), Portugal hosts an estimated 4 500 tU of reasonably assured resources recoverable at costs of <USD 80/kgU and 6 000 tU RAR recoverable at costs of <USD 130/kgU. Additionally, 1 000 tU are reported as inferred resources recoverable at a cost of <USD 130/kgU. Processing plus mining losses of approximately 25% have been applied to all resource categories (i.e. 75% recovery).

Undiscovered conventional resources (prognosticated and speculative resources)

As previously reported (2007 edition of Red Book), undiscovered conventional resources are estimated to include 1 500 tU of prognosticated resources. Speculative resources are not reported because only one out-dated appraisal is available.

Uranium production

Historical review

Portugal uranium deposits, located in the north-central area of the country, have been exploited from the beginning of the 20th century to 2001. Most of the uranium concentrates produced were exported.

In 1950-1951, a uranium mill facility processing 50 000 t/yr was built at Urgeiriça, and underground extraction continued until 1973, followed by in-place leaching from 1970 to 1991. The mine reached a depth of about 500 m and 1 600 m in length.

* Report prepared by the NEA/IAEA, based on previous Red Books and response to Questionnaire 2019.

Between 1951 and 1962, CPR produced a total of 1 123 tU from 22 concessions, of which 1 058 tU were milled at the Urgeiriça plant and 65 tU at other mines by heap leaching. A low-grade concentrate was obtained by precipitation using magnesium oxide.

During the period 1962 to 1977, JEN took over the mining and milling activities from CPR, introducing organic solvent extraction in 1967 and expanding ore treatment capacity to 100 000 t/y to produce a rich ammonium uranate concentrate. In July 1985, a new capacity expansion to 200 000 t/yr was implemented. A total of 825 tU were produced under JEN management from the Urgeiriça plant and the pilot plant at Senhora das Fontes. Between 1977 and 2001, Empresa Nacional de Uranio, SA (ENU) produced 1 772 tU.

Of the total historical concentrate production, 25% came from the Urgeiriça mine. The Urgeiriça mill stopped conventional ore processing in 1999 and was decommissioned in March 2001. In this interim period, only charged ion exchange resins from heap and in-place leaching plants, located in Bica e Quinta do Bispo mines, were processed at the Urgeiriça plant for yellow cake production. Nationally, 57 ore bodies have been mined, 29 by underground methods, 24 by open pit and 4 by mixed underground/open-pit methods. In 18 of these mines, local ore treatment was used, but only at Urgeiriça were uranium concentrates produced at an industrial scale. Two pilot treatment plants (Forte Velho and Sra das Fontes) produced limited amounts of concentrates (sodium uranate).

Ownership of the Urgeiriça mill plant evolved over its operational history and after CPR concluded the agreement with the Portuguese government in 1962, JEN took over until 1977 when ENU, a publicly-owned enterprise, acquired exclusive rights to uranium concentrate production and sales. In 1978, JEN exploration teams joined the Direccao-Geral de Geologia e Minas (DGGM). In 1992, ENU was integrated into the Portuguese state mining holding, Empresa de Desenvolvimento Mineiro. In March 2001, Empresa de Desenvolvimento Mineiro decided to liquidate ENU by the end of 2004.

Status of production facilities, production capability, recent and ongoing activities and other issues

Rehabilitation and remediation (environment and safety) are the only activities currently being developed by EDM.

Future production centres

No future production centres are planned.

Environmental activities and socio-cultural issues

EDM, a state-owned mining company, was granted the concession by the Portuguese government to deal with mining legacy sites, including remediation work at several uranium legacy sites. This work on former uranium and radium mine sites has required expenditures of more than EUR 52.6 million (USD 57 million) between 2001 and 2015. An additional investment of EUR 35.3 million (USD 39 million) has been expended between 2016 and 2020.

Up until 2020, the uranium mining and milling sites that have either been or are being remediated include the Urgeiriça, Bica, Cunha Baixa, Rosmaneira, Mondego Sul, Vale da Abrutiga, Barroco, and Freixiosa mine sites.

Uranium requirements

Portugal has no uranium requirements.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

The government energy programme follows the same track as outlined in previous Red Books. The recently published Ministerial Council Resolution No. 107/2019 approves the Roadmap for Carbon Neutrality 2050 (RNC 2050), adopting the commitment to achieve carbon neutrality in Portugal by 2050. Nuclear energy is not considered in Portugal's energy mix. A new energy strategy, Energia 2020, reaffirms the importance of renewable sources (mainly wind and hydropower) and increased efficiency as a means of reducing external energy dependence, as well as its associated impact on trade balance and meeting commitments made with respect to the Kyoto Protocols.

Uranium stocks

There have been no changes of stocks since the 2007 edition of the Red Book.

Reasonably assured conventional resources by production method
(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	0	500	500	80
Open-pit mining (OP)	0	4 500	5 500	5 500	75
Total	0	4 500	6 000	6 000	

Reasonably assured conventional resources by processing method
(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	0	500	500	80
Conventional from OP	0	4 500	5 500	5 500	75
Total	0	4 500	6 000	6 000	

Reasonably assured conventional resources by deposit type
(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Granite-related	0	4 500	6 000	6 000
Total	0	4 500	6 000	6 000

Inferred conventional resources by production method
(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	0	0	1 000	1 000	75
Total	0	0	1 000	1 000	

Inferred conventional resources by processing method

(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from OP	0	0	1 000	1 000	75
Total	0	0	1 000	1 000	

Inferred conventional resources by deposit type

(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Granite-related	0	0	1 000	1 000
Total	0	0	1 000	1 000

Prognosticated conventional resources

(tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
1 000	1 500	1 500

Historical uranium production by production method

(tonnes U in concentrate)

Production method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Open-pit mining*	1 810	0	0	0	1 810	0
Underground mining*	1 326	0	0	0	1 326	0
Unspecified	584	0	0	0	584	0
Total	3 720	0	0	0	3 720	0

* Pre-2015 totals may include uranium recovered by heap and in-place leaching.

Historical uranium production by processing method

(tonnes U in concentrate)

Processing method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Conventional	3 136	0	0	0	3 136	0
In-place leaching*	250	0	0	0	250	0
Heap leaching**	321	0	0	0	321	0
Other methods***	13	0	0	0	13	0
Total	3 720	0	0	0	3 720	0

* Also known as stope leaching or block leaching.

** A subset of open-pit and underground mining, since it is used in conjunction with them.

*** Includes mine water treatment and environmental restoration.

Historical uranium production by deposit type

(tonnes U in concentrate)

Deposit type	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Granite-related	3 720	0	0	0	3 720	0
Total	3 720	0	0	0	3 720	0

Total uranium stocks

(tonnes natural U-equivalent)

Holder	Natural uranium stocks in concentrate	Enriched uranium stocks	Depleted uranium stocks	Reprocessed uranium stocks	Total
Government	168	0	0	0	168
Producer	0	0	0	0	0
Utility	0	0	0	0	0
Total	168	0	0	0	168

Russia

Uranium exploration and mine development

Historical review

Since the beginning of uranium exploration in 1944, more than 100 uranium deposits have been discovered within 14 districts in Russia. The most significant deposits are located within four uranium-bearing districts:

- the Streltsovsk district, which includes 19 volcanic, caldera-related deposits where underground mining of some deposits is ongoing;
- the Trans-Ural and Vitim districts, where basal-channel sandstone-type deposits are being developed for uranium production by ISL;
- the Elkon district that contains large metasomatite-type deposits prospective for future mining.

Recent and ongoing uranium exploration activities

There are two types of uranium exploration activities in Russia, one involves prospecting aimed at new deposit discovery and evaluation, and the second involves additional, more detailed exploration of earlier discovered deposits to improve resource estimates and delineate new resources.

Uranium exploration

Uranium prospecting is financed by the federal budget of the Russian Federation. In 2017-2018, the work was carried out mainly in the Siberian Federal District (Irkutsk and Novosibirsk Region) and the Far Eastern Federal District (Republic of Buryatia, Trans-Baikal Region, Amur Region and Jewish Autonomous Region). The work focused on two main goals: expanding the resource base near existing uranium production centres and identifying large deposits in new regions suitable for development by ISL.

In 2016, within the Vitim uranium ore district (Republic of Buryatia), prognosticated resources of all previously identified sandstone type uranium deposits located on the periphery of the Khiagda ore field were re-evaluated. As a result, eight ore fields with 58 500 tU of prognosticated resources (category P1 in the Russian classification system) and 90 620 tU of speculative resources (category P2) were allocated. These areas are recommended for further exploration for development by ISL.

As a result of the resource re-evaluation in the northern and southern portions of the East-Sayan prospective region, 53 800 tU of speculative (P2) resources related to unconformity type deposits were identified. Prospecting continues. Within the Sayan area 4 000 tU of speculative (P2) resources were identified and confirmed by drilling.

Exploration of existing deposits

Exploration of identified deposits is carried out by subsidiary uranium mining enterprises of JSC Atomredmetzoloto (ARMZ), which is part of the State Atomic Energy Corporation ROSATOM.

In 2018, the Dalur company completed exploration of the Khokhlovskoye deposit in the Kurgan Region, resulting in an 800 tU increase in RAR resources. In June 2017, Dalur obtained a license for exploration and mining of uranium at the Dobrovolnoye deposit with identified resources of 7 077 tU (in situ), and in 2018, began its exploration by drilling.

The main drilling work in 2018 was concentrated at the Priargunsky production centre and was aimed at identifying uranium resources on the flanks of the deposits by exploration boreholes from underground mine workings. A significant increase in investments, from 21 million rubles in 2018 to 213.2 million rubles in 2019, is associated with the start of drilling exploration work at the Dobrovolnoye deposit.

Uranium exploration abroad

In 2016-2019 the Russian Federation, through the Canadian-based company Uranium One Inc., owned by the State Atomic Energy Corporation ROSATOM, carried out exploration and pilot test work for uranium at joint ventures in Kazakhstan, pilot test work in Tanzania to prepare for the development of the Mkuju River uranium project, and early-stage exploration in Namibia.

In Kazakhstan, six uranium mines jointly owned by Uranium One are in commercial operation. Data on investments and exploration are accounted for in accordance with the Russian share in the joint ventures. The main investment in Kazakhstan (USD 4.6 million) was made in 2016 when drilling exploration and pilot test work was completed at the Yuzhny Inkai mine (included in the Southern Mining and Chemical Company, or SMCC) and the Kharasan mine to move the resources into more reliable categories. Exploration led to a significant increase in resources, which is confirmed by technical reports issued in 2018. Through 2017 to 2019, geological exploration continued at the Zarechnoye mine.

In Tanzania, Mantra Resources (purchased by ARMZ in 2011) completed two pilot well tests in 2016 that in principle confirmed the possibility of developing a portion of the Mkuju River deposit by ISL.

In Namibia, Uranium One conducted ground geophysical and geochemical surveys in 2016-2017, carried out metallurgical studies of drill core with uranium mineralisation in 2018, and began large-scale drilling exploration work in 2019. Based on these results, sandstone type uranium resources that are potentially suitable for development by ISL have been identified.

Recent mine development activities

JSC Dalur (Kurgan Oblast) completed pilot uranium mining at the Khokhlovskoye deposit in 2018 and switched to commercial uranium mining by ISL in 2019. JSC Khiagda (Republic of Buryatia) launched pilot test work at the Istochnoye deposit with resources of 2 100 tU, and in January 2019 the satellite Sorption Plant (SP) was put into operation. In 2018, construction of the surface complex and infrastructure elements of new mine No. 6 at the Priargunsky production centre began. This mine, with a design capacity of 2 300 tU/yr, will support the development of the Argunskoye and Zherlovoye deposits. Hydrogeological studies were completed in 2019 and mining is scheduled to begin in 2023. The development of deposits in the Elkon and Trans-Baikal uranium regions has been suspended due to unfavourable market conditions.

Uranium resources

Identified resources (reasonably assured and inferred resources)

In 2017-2018, exploration, technical and economic evaluation of uranium resources continued. As of 1 January 2019, total recoverable uranium resources in Russia (RAR + inferred) amounted to 661 929 tU, while in situ known resources comprised 847 513 tU. Compared with the data as of 1 January 2017, this is an increase of 5,070 tU in recoverable resources due to exploration of the sandstone type Khokhlovskoye deposit in the Kurgan Oblast and evaluation of resources of the Shargadykskoye deposit in the Republic of Kalmykia (depletion of the resources by mining in 2017 and 2018 was taken into account).

Total recoverable RAR amounted to 256 608 tU (in situ – 333 224 tU), of which 82% are recoverable at a cost of <USD 130/kgU and 9% at <USD 80/kgU. With respect to RAR, 68% are planned to be developed by traditional underground mining methods, the majority of which relate to metasomatic type uranium deposits in the Elkon region. All resources in the cost category of <USD 80/kgU relate to the sandstone type deposits that are planned to be developed by ISL.

Inferred recoverable uranium resources in Russia amounted to 405 321 tU (in situ – 514 179 tU), of which less than 4% can be recovered at less than USD 80/kg. More than 70% of inferred resources are planned to be developed by underground mining from metasomatic and volcanic type deposits.

Undiscovered conventional resources (prognosticated and speculative resources)

In the Russian classification system, prognosticated resources relate to the P1 category, and speculative resources relate to the P2 category. As of 1 January 2019, prognosticated (P1) resources in the Russian Federation amounted to 169 300 tU, of which 110 650 tU are in the cost category of <USD 130/kgU. Speculative (P2) resources amounted to 540 200 tU, of which 148 200 tU are categorised as <USD 130/kgU.

The main portion of the undiscovered uranium resources occur in the Trans-Baikal region (the Urulyunguevsky and East-Trans-Baikal uranium ore regions), in the Irkutsk Region (Sayan region), and in the Republic of Buryatia (Vitim region).

Undiscovered resources categorised at <USD 130/kgU are dominated by sandstone type deposits, and in the cost category of <USD 260/kgU, vein-stockwork deposits in volcanics and unconformity type deposits prevail. The main sandstone type resources are concentrated in the Republic of Buryatia (the Vitim and South Vitim uranium ore regions), where P1 resources amount to 71 300 tU and P2 resources amount to 90 600 tU, accounting for 42% and 17% of all speculative resources of the Russian Federation, respectively. Resources with unconformity type mineralisation in volcanic structures prevail in the Trans-Baikal Region and the Irkutsk region. Additional P1 resources (20 000 tU) associated with fishbone detritus (phosphate deposit type) are located in the Ergeninsky uranium region in the Republic of Kalmykia.

For the period 2017-2018, the total prognosticated (P1) resources category increased by 25 400 tU due to the re-evaluation of several deposits in the Vitim region. Reduction of speculative P2 resources by 50 900 tU occurred as a result of reclassification into the P1 category (Vitim region) and due to the lack of confirmation of resources based on recent geological survey data.

Uranium production

Historical review

As of 1 January 2019, cumulative uranium production in the Russian Federation amounted to 170 725 tU. Total production at the Priargunsky production centre amounted to 151 222 tU, making it the world's largest enterprise for aggregate production of uranium.

Status of productive capabilities

Uranium mining in Russia is carried out by three enterprises that are part of the uranium mining company Uranium Holding ARMZ (JSC Atomredmetzoloto). The annual uranium production in Russia in 2018 amounted to 2 904 tU, of which 1 456 tU was obtained by traditional underground mining and 1 448 tU by ISL.

The PJSC Priargunsky Industrial Mining and Chemical Union (PIMCU) remains the main uranium mining centre in Russia. The resource base for the enterprise includes the volcanic type uranium deposits of the Streltsovsk uranium ore region with recoverable resources of 77 400 tU (99 240 tU in situ), as of 1 January 2019.

Uranium mining was carried out at three underground mines (Mine No. 1, Mine Gluboky and Mine No. 8), and ore was processed either at the hydrometallurgical plant or at the heap leaching site. Of the 1 456 tU mined in 2018 by the underground method, 1 337 tU were produced at the hydrometallurgical plant and 119 tU were processed by heap leaching. In 2017, Mine No. 8 was put into operation (design capacity of 500 tU/yr) for the development of the Malo-Tulukuevskoye deposit. In 2018, construction of the Mine No. 6 surface complex and infrastructure elements began (design capacity of 2 300 tU/yr) for the development of the Argunskoye and Zherlovoye deposits. The start of mining is scheduled for 2023.

Uranium production centre technical details

(as of 1 January 2019)

	Centre #1	Centre #2	Centre #3	Centre #4	Centre #5
Name of production centre	Priargunsky Mining Combine (Priargunsky)	Dalur	Khiagda	Elkon Mining and Metallurgical Complex (Elkon)	Gornoe Uranium Mining Company (Gornoe)
Production centre classification	Existing	Existing	Existing	Prospective	Prospective
Date of first production	1968	2004	2010	NA	NA
Source of ore:					
Deposit name(s)	Antei, Streltsovskoe and others	Dalmatovskoe Khokhlovskoe and others	Khiagda, Vershinnoe and others	Yuzhnoe, Severnoe	Gornoe, Berezovoe
Deposit type(s)	Volcanic	Sandstone basal channel	Sandstone basal channel	Metasomatic	Vein
Recoverable resources (tU)	77 400	10 630	27 040	303 600	3 200
Grade (% U)	0.16	0.04	0.05	0.15	0.20
Mining operation:					
Type (OP/UG/ISL/HL)	UG, HL	ISL	ISL	UG	UG, HL, IPL
Size (tonnes ore/day)	6 700	NA	NA	5 500	1 900
Average mining recovery (%)	95	75	75	85	70
Processing plant:					
Acid/alkaline	Acid	Acid	Acid	Acid	Acid
Type (IX/SX)	IX	IX	IX	IX	IX
Size (tonnes ore/day)	4 700	No data	No data	No data	No data
Average process recovery (%)	95	98	98	95	95
Nominal production capacity (tU/year)	3 000	600	1 000	5 000	300
Plans for expansion	Mine #6	Dobrovolnoye dep.	Yes	No	No
Other remarks					

JSC Dalur in the Kurgan Oblast carries out the development of the Dalmatovskoye and Khokhlovskoye deposits by ISL. To maintain a production capacity of 600 tU/yr, the Dobrovolnoye uranium deposit will be developed. As of 1 January 2019, recoverable resources of the three deposits amounted to 10 630 tU (14 170 tU in situ). Uranium production in 2018 amounted to 590 tU.

JSC Khiagda carries out ISL uranium mining of deposits at the Khiagda ore field in the Republic of Buryatia with recoverable resources of 27 040 tU (36 050 tU in situ). In 2018, 858 tU were produced, which is 164 tU more than in 2017. In 2017, the development of the Vershinnoye deposit began, and in 2019 development of the Istochnoye deposit was initiated.

Employment in the uranium industry

In 2018, the number of employees working in the uranium industry amounted to 6 263, of which 5 258 are PIMCU employees, 457 are Dalur employees and 548 are Khiagda employees. Considering that a portion of PIMCU personnel is involved in general-purpose auxiliary and service facilities, the number of employees directly related to PIMCU uranium production amounted to 3 596.

Future production centres

In 2017-2019, the development of deposits in the Elkon and Trans-Baikal uranium ore regions was suspended due to unfavourable market conditions.

Uranium requirements

As of 1 January 2019, 10 nuclear power plants in Russia were comprised of 37 units with a total installed capacity of 29.1 GWe. In 2018, Russian nuclear power plants generated 204.3 TWhr of electricity, which amounted to 18.7% of the electricity produced in the country.

The current annual consumption of Russian NPPs amounts to a uranium equivalent of about 5 000 tU. Uranium fuel requirements are supplied by uranium produced in Russia and Kazakhstan, from uranium stockpiles and secondary sources.

The development of nuclear energy and the construction of new power plants in Russia assumes installed capacity growth up to 38 GWe by 2040 and proportional growth in uranium requirements to as much as 6 100 tU/yr.

Uranium exploration and development expenditures (non-domestic)

(USD millions)

	2016	2017	2018	2019 (expected)
Industry* exploration expenditures	4.2	1.6	1.4	3.9
Government exploration expenditures	0.0	0.0	0.0	0.0
Industry* development expenditures	1.9	0.2	0.1	<0.1
Government development expenditures	0.0	0.0	0.0	0.0
Total expenditures	6.1	1.8	1.5	3.9

* Russian State Corporation Rosatom.

Uranium exploration and development expenditures and drilling effort – domestic

(RUB millions)

	2016	2017	2018	2019
Industry exploration expenditures	52	47	21	213
Government exploration expenditures	491	216	365	442
Industry development expenditures	675	331	493	NA
Government development expenditures	0	0	0	0
Total expenditures	1 218	594	879	655
Industry exploration drilling (m)	10 500	7 700	7 600	48 200
Industry exploration holes drilled	62	36	46	111
Government exploration drilling (m)	28 432	3 000	7 610	8 379
Government exploration holes drilled	271	28	72	80
Industry development drilling (m)	76 700	0	0	0
Industry development holes drilled	130	0	0	0
Government development drilling (m)	0	0	0	0
Government development holes drilled	0	0	0	0
Subtotal exploration drilling (m)	38 932	10 700	15 210	56 579
Subtotal exploration holes	333	64	118	191
Subtotal development drilling (m)	76 700	0	0	0
Subtotal development holes	130	0	0	0
Total drilling (m)	115 632	10 700	15 210	56 579
Total number of holes drilled	463	64	118	191

Reasonably assured conventional resources* by production method

(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	0	173 454	173 454	85-90
In situ leaching acid	0	23 278	23 278	23 278	75
Co-product and by-product	0	0	0	45 424	65
Unspecified	0	0	14 452	14 452	75
Total	0	23 278	211 184	256 608	77

Recoverable resources, overall recovery factor was 77%.

Reasonably assured conventional resources by processing method

(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	0	155 348	155 348	85
In situ leaching acid	0	23 278	23 278	23 278	75
In-place leaching*	0	0	516	516	70
Heap leaching** from UG	0	0	17 590	17 590	70
Unspecified	0	0	14 452	59 876	75
Total	0	23 278	211 184	256 608	77

* Also known as stope leaching or block leaching.

** A subset of open-pit and underground mining, since it is used in conjunction with them.

Reasonably assured conventional resources by deposit type

(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	23 278	23 278	23 278
Granite-related	0	0	1 550	1 550
Intrusive	0	0	0	45 424
Volcanic-related	0	0	73 056	73 056
Metasomatite	0	0	103 982	103 982
Phosphate	0	0	9 318	9 318
Total	0	23 278	211 184	256 608

Inferred conventional resources by production method

(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	0	251 014	301 448	85-90
Open-pit mining (OP)	0	0	0	1 973	70
In situ leaching acid	0	14 681	14 681	23 032	75
Co-product and by-product	0	0	0	35 217	65
Unspecified	0	0	9 087	43 651	75
Total	0	14 681	274 782	405 321	80

Recoverable resources, overall recovery factor was 80%.

Inferred conventional resources by processing method

(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	0	242 521	290 281	85
In situ leaching acid	0	14 681	14 681	23 032	75
In-place leaching*	0	0	2 068	4 565	70
Heap leaching** from UG	0	0	6 425	6 602	70
Heap leaching** from OP	0	0	0	1 973	70
Unspecified	0	0	9 087	78 868	75
Total	0	14 681	274 782	405 321	80

* Also known as stope leaching or block leaching.

** A subset of open-pit and underground mining, since it is used in conjunction with them.

Inferred conventional resources by deposit type
(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	14 681	14 681	51 510
Granite-related	0	0	2 686	5 689
Intrusive	0	0	0	34 701
Volcanic-related	0	0	29 036	42 683
Metasomatite	0	0	221 252	258 031
Phosphate	0	0	7 127	12 707
Total	0	15 293	274 782	405 321

Prognosticated conventional resources
(tonnes U)

Cost Ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
0	110 650	169 300

Speculative conventional resources
(tonnes U)

Cost Ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
148 200	540 200	0

Historical uranium production by mining method
(tonnes U concentrate)

Production method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Open-pit mining	38 655	0	0	0	38 655	0
Underground mining	112 172	1 873	1 631	1 456	117 132	1 300
In situ leaching	11 072	1 132	1 286	1 448	14 938	1 600
Total	161 899	3 005	2 917	2 904	170 725	2 900

Historical uranium production by processing method

(tonnes U concentrate)

Processing method	Total through end of 2015	2016	2017	2018	Total through end of 2019	2019 (expected)
Conventional	146 824	1 621	1 440	1 337	151 222	1 180
In-place leaching*	241	0	0	0	241	0
Heap leaching**	3 762	252	191	119	4 324	120
In situ leaching	11 072	1 132	1 286	1 448	14 938	1 600
Other methods***	0	0	0	0	0	0
Total	161 899	3 005	2 917	2904	170 725	2 900

* Also known as stope leaching or block leaching.

** A subset of open-pit and underground mining, since it is used in conjunction with them.

*** Includes mine water treatment and environmental restoration.

Historical uranium production by deposit type

(tonnes U in concentrate)

Deposit type	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Sandstone	11 072	1 132	1 286	1 448	14 938	1 600
Volcanic and caldera-related	150 827	1 873	1 631	1 456	155 787	1 300
Total	161 899	3 005	2 917	2 904	170 725	2 900

Ownership of uranium production in 2018

Domestic				Foreign				Totals	
Government		Private		Government		Private			
(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)
2 904	100%	0	0	0	0	0	0	2 904	100%

Uranium industry employment at existing production centres

(person-years)

	2016	2017	2018	2019 (expected)
Total employment related to existing production centres	6 077	5 696	6 263	6 288
Employment directly related to uranium production	4 956	4 646	4 601	4 579

Short-term production capability

(tonnes U/year)

2019				2020			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
1 600	1 600	2 900	2 900	1 600	1 600	2 780	2 780

2025				2030				2035			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
1 660	1 660	3 960	3 960	1 660	1 660	3 960	3 960	1 800	1 800	1 800	1 800

Net nuclear electricity generation

(TWh net)

	2017	2018
Nuclear electricity generated (TWh net)	202.9	204.3

Installed nuclear generating capacity to 2040

(GWe net)

2017	2018	2020		2025	
		Low	High	Low	High
27.9	29.1	29.50	29.5	29.8	29.8

2030		2035		2040	
Low	High	Low	High	Low	High
30.7	30.7	31.5	35.3	35.0	37.5

Annual reactor-related uranium requirements to 2035 (excluding MOX)

(tonnes U)

2017	2018	2020		2025	
		Low	High	Low	High
4 900	5 000	5 000	5 200	4 900	5 300

2030		2035		2040	
Low	High	Low	High	Low	High
4 700	5 600	4 900	5 700	5 000	6 100

Senegal

Historical review

There are two important phases of uranium exploration in Senegal: 1) 1957 to 1965, when a general inventory of the uranium potential of Africa was undertaken, at which time the large deposits in Niger and Gabon were discovered, and 2) 1974 to present, which is characterised by specific surveys focused on the Birimian Superior Precambrian sediments and secondary and tertiary basins with phosphate deposits. The collapse of uranium prices in the 1980s raised questions about the value of these focused surveys and the viability of uranium mineralisation in areas far inland and with no infrastructure; areas which could have been eliminated because of the limited chances of finding uranium concentrations large and rich enough to be economic.

1957-1965

The first work undertaken in Senegal by the French Atomic Energy Commission (CEA) from 1957 to 1961 was part of a systematic aerial survey of West Africa covering Senegal, Mali, Upper Volta and Niger. It was during these survey flights in 1960 that an aerial radiometric anomaly, Saraya, was identified at Kédougou (Southeast Senegal). Fourteen trenches were dug, and geochemical samples taken, which resulted in the identification of two types of anomalies: one in a fracture striking North 130° with yellow mineralisation and the other in a light-coloured syenite with calcite. Around the same time, ground verification of other airborne anomalies was undertaken, mainly by geochemical sampling and small research wells. Some geochemical anomalies were detected (the Dalafinn site, for example), which were usually associated with laterites. In 1961, the CEA made the decision to suspend the study of anomalies at Kédougou and nothing was undertaken in this area until work resumed in 1974.

In 1966, as part of a joint study between Mauritania and Senegal, CEA undertook a systematic radiometric study of the continental sedimentary basin of the Ferlo (northern Senegal) and along the bank of the Senegal River. This work, however, yielded no interesting results.

1974-present

On 29 May 1974, the Minister of Development of Senegal sent a letter to the General Administrator of the CEA, that later became the Compagnie Générale des Matières Nucléaires (COGEMA), requesting a resumption of uranium research. After a positive response, a research permit within East Senegal of 38 600 km² was awarded on 27 November 1974. From 1975 to 1976, studies focused on a series of Cambrian and Precambrian Superior lithologies on the remaining area of the permit. From 1979 to 1984, magnetometry and electromagnetism surveys on the Saraya granite identified uranium mineralisation in conjunction with episyenites, representing a geological in situ resource estimated at about 1 500 tU at an average grade of 0.2%.

COGEMA extensively explored uranium in eastern Senegal in the period 1975-1985 (about 400 vertical and oblique drill holes). The drastic drop in the price of uranium, in the context of rather mixed results, led to discontinuation of the exploration programme. In 1975, the Total Mining Company of Senegal led exploration studies on uranium anomalies associated with phosphates in secondary and tertiary basins of Cape Verde. The results were not encouraging.

In 2007, due to uranium price increases, exploration was revived, and as a result the East Saraya licence was purchased by Areva (ex COGEMA) from the junior South African company UraMin. The Saraya western perimeter was awarded to Kansala Resources on 22 March 2007. The exploration licence was renewed again in 2013 for a period of three years. The results of the work showed that the structural setting of the Saraya granitic complex can be considered favourable for alaskite type uranium mineralisation

At present, exploration has not identified any uranium resources of economic interest, but have nevertheless contributed greatly to understanding the geology of Senegal, particularly in eastern Senegal, on the upper Precambrian basin, including equivalents that exist throughout West Africa (i.e. the uranium belt of Zaire) prospected in the past by CEA-COGEMA teams. The research carried out in Senegal, as well as in Guinea and Mali, helped establish a detailed map and improved understanding of the geological history of the country.

Recent and ongoing uranium exploration and mining development

There has been no recent exploration and mining development for uranium in Senegal.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

The national potential is estimated at 1 500 tU at an average grade of 0.2% U.

Historically, Senegal has not reported identified resources. However, considering the amount of drilling completed in the Saraya area, the previously reported undiscovered resources should be classified as inferred resources.

Undiscovered conventional resources (prognosticated and speculative resources)

Senegal previously reported undiscovered conventional resources of 1 500 tU, which are now classified as Inferred Resources after IAEA Uranium Group Secretariat review of the drilling effort undertaken to identify the resources.

Unconventional resources and other materials

Senegal does not report unconventional resources.

Inferred conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Granite-related	0	0	0	1 500
Total	0	0	0	1 500

Slovenia

Uranium exploration and mine development

Historical review

Exploration of the Žirovski Vrh area began in 1961. In 1968, the P-10 tunnel was developed to access the orebody. Mining began at Žirovski Vrh in 1982 and uranium concentrate production (as yellow cake) began in 1985. The mine ceased operation in 1991.

Recent and ongoing uranium exploration and mine development activities

Expenditures for exploration ended in 1990. There are no recent or ongoing uranium exploration activities in Slovenia.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

A resource assessment of the Žirovski Vrh deposit was carried out in 1994. Reasonably assured resources are estimated to amount to 2 200 tU (in situ) with an average grade of 0.14% U in the <USD 80/kgU cost category. In situ inferred resources total 5 000 tU in the <USD 80/kgU cost category, and 10 000 tU in the <USD 130/kgU cost category at an average grade of 0.13% U. This deposit occurs in the grey sandstone of the Permian Groeden Formation, where the orebodies occur as linear arrays of elongated lenses within folded sandstone.

Undiscovered conventional resources (prognosticated and speculative resources)

Undiscovered resource estimates remain the same as previously reported.

Uranium production

Historical review

The Žirovski Vrh uranium mine, located 20 km south-west of Škofja Loka, was the only uranium producer in Slovenia. Ore production began in 1982 and the associated ore processing plant (annual production capability of 102 tU) began operations in 1984, initially treating stockpiled ore. The ore, which occurs in numerous small bodies in the mineralised coarse-grained sandstone, was mined selectively using a conventional underground room and pillar, cut-and-fill operation with a haulage tunnel and ventilation shaft. In 1990, operations were terminated. Cumulative production from the Žirovski Vrh mine and mill complex totalled 382 tU (620 000 tonnes ore at an average grade of 0.072% U).

Status of production capability

In 1992, a decision for final closure and subsequent decommissioning of the Žirovski Vrh mine and mill complex was made and there has been no production at the facility since. All production was reserved for the former Yugoslavia. In 1994, the plan for decommissioning of the facility was adopted by the Slovenian government. The production facility was dismantled and no longer exists.

Environmental activities and socio-cultural issues

The government-owned Žirovski Vrh Mine Company manages all activities connected with the rehabilitation of the former uranium production site, consisting of underground mining facilities, surface milling facilities, the waste rock pile and tailings disposal site. It obtains all remediation permits required, performs the remediation works and monitors the environmental impact of the site during the remediation phase. After finishing the remediation work, the remaining disposal sites and the mine water effluents are put under long-term environmental surveillance that is carried out by the national Agency for Radioactive Waste Management. The mine effluents are monitored for uranium, radium and other chemical contaminants, and the disposal sites are monitored for radon exhalation and uranium and radium in water effluents.

The annual effective dose contribution from all mine sites has significantly decreased as a result of remediation activities. Since 2011, dropping below 0.1 mSv/a, compared to about 0.4 mSv/a during operation. Background annual effective levels are 5.5 mSv/a in the area surrounding the mine.

Associated with the uranium production site are a hydrometallurgical tailings disposal site and a waste rock disposal site. Environmental remediation of the disposal site for hydrometallurgical tailings is in its final stage, the critical factor being the stability of the site. All remediation work is finished on the site of the mine waste pile, and in 2015, the long-term environmental surveillance of the site started.

Monitoring

The mine's air and water effluents have been monitored on a regular basis since the start of the ore production in 1982. The programme, modified when production stopped in 1990, is ongoing. Emissions to surface waters and air are monitored, and doses to the local population have been calculated since 1980. Treatment of the mine's effluents is not planned considering the low concentrations of radioactive contaminants.

Tailings impoundment

There is one 4.2 ha specially designed long-term site for hydrometallurgical tailings, called Boršt. It is situated on the slope of a hill between 535 and 565 m above sea level. At this disposal site, 610 000 tonnes (t) of hydrometallurgical waste, 111 000 t of mine waste and 9 450 t of material, collected during decontamination of the mill tailings in the Boršt site vicinity, have been disposed, with a total activity of 48.8 TBq. The tailings have been stored in dry condition as a result of the filtration of the leached liquor. The surface was topped with a 2-m thick, engineered multilayer soil cover with a clay base to prevent leaching of contaminants, and covered with grass. Although remediation of the site was completed in 2010, it required drainage intervention measures to reduce the groundwater level and slow down landslide movement that was activated beneath the disposal site. The results of additional slope stabilisation work, performed in 2016 and 2017, will help determine if the disposal site meets the conditions for site closure and the beginning of long-term environmental surveillance.

Waste rock management

All waste-rock piles were relocated to the central mine waste pile Jazbec. All other sites have been restored to a green field condition. The 6.7 ha Jazbec facility contains 1 910 425 t of mine waste, low grade uranium ore, red mud, filter cake from the mine water treatment station, and contaminated material from decommissioning of mining and milling facilities, with a total activity of 21.7 TBq. It is covered with an engineered two-metre thick multilayer of soil and planted with grass. A concrete drainage tunnel was constructed at the bottom of the waste rock pile to drain seepage and groundwater into a local stream. Environmental remediation works at the Jazbec disposal site were completed and the administrative procedure for site closure finalised in 2015. The responsibility for long-term surveillance and maintenance of the site was transferred to the Agency for Radioactive Waste Management in 2015.

Uranium requirements

The sole nuclear power plant in Slovenia is based at Krško. It started commercial operation in January 1983 and was modernised in 2000 with replacement steam generators that increased net capacity to 676 MWe. Net capacity was increased in 2006 to 696 MWe with low-pressure turbine replacement and again in 2009 to 698 MWe after modernisation of the turbine control system. The power plant is 50% owned by Slovenia and Croatia.

There has been no significant change in the Slovenian nuclear energy programme in the last few years. One nuclear power plant (Nuklearna Elektrarna Krško) is in operation. Uranium requirements for Nuklearna Elektrarna Krško are relatively stable and account for about 149 tU per year. The current fuel cycles are 18 months in duration and planned to continue at this cycle basis. In 2012, the Slovenian Nuclear Safety Administration approved the ageing management programme; a prerequisite for the operation of the Nuklearna Elektrarna Krško beyond 2030 up until the year 2043.

Supply and procurement strategy

The total uranium requirement of Nuklearna Elektrarna Krško per operating cycle remains as reported in the 2018 edition of the Red Book. There are no operating or strategic uranium reserves in Slovenia and supply is imported based on requirement contracts.

The current uranium supply contract covers requirements until 2020. The current procurement strategy utilises enriched UF_6 supplied to the fuel manufacturer from the uranium supplier when it is required for fuel assembly construction. No physical deliveries of U_3O_8 or UF_6 are made to the Nuklearna Elektrarna Krško site. The manufactured fuel assemblies arrive just before they are used for power production. There are no plans in the foreseeable future to build a uranium stockpile by Nuklearna Elektrarna Krško. The strategy for commercial spent nuclear fuel management currently does not include the use of reprocessed uranium and Nuklearna Elektrarna Krško is not licensed for MOX use.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

Slovenia is not a uranium-producing country. Uranium stocks are imported for the commercial operation of the nuclear power plant (Nuklearna Elektrarna Krško) as final products (manufactured nuclear fuel assemblies).

Uranium stocks

There is no uranium stock policy in Slovenia. Nuklearna Elektrarna Krško has no uranium stocks or intention to create a uranium stock policy. All required uranium stocks are purchased on a "just-in-time" basis.

Uranium prices

This information is considered confidential.

Reasonably assured conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Underground mining	0	2 200	2 200	2 200
Total	0	2 200	2 200	2 200

Reasonably assured conventional resources by deposit type
(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	2 200	2 200	2 200
Total	0	2 200	2 200	2 200

Inferred conventional resources by production method
(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Underground mining	0	5 000	10 000	10 000
Total	0	5 000	10 000	10 000

Inferred conventional resources by deposit type
(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	5 000	10 000	10 000
Total	0	5 000	10 000	10 000

Prognosticated resources
(tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
0	1 060	1 060

Historical uranium production by production method
(tonnes U in concentrate)

Production method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (preliminary)
Underground mining*	382	0	0	0	382	0
Total	382	0	0	0	382	0

* Pre-2015 totals may include uranium recovered by heap and in-place leaching.

Net nuclear electricity generation

	2017	2018
Nuclear electricity generated (TWh net)	5.967	5.489

Installed nuclear generating capacity to 2040

(MWe net)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
698	698	666	698	666	698	666	698	666	698	666	698

Note: Low and high values were taken as dependable power and maximum designed net power, respectively.

Annual reactor-related uranium requirements to 2040 (excluding MOX)

(tonnes U)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
149	149	119	179	119	179	119	179	119	179	119	179

Note: The Krško nuclear power plant operates 18-month cycles with a fresh fuel load of 224 tonnes of natural uranium equivalent. In some years no uranium supply will be required (e.g. 2021, 2024 and 2027). The values in the table are the average yearly values (i.e. 224 tU x 12/18 = 149 tU). Low and high variability is ±20% from the expected value; this is calculated from maximum change that could occur from a change in fuel assembly design or variation in cycle length (i.e. 12-24 months). The variability shown in some previous reports (2005, 2007, 2009 and 2011) was lower than shown in more recent editions, as it was based on observed 18-month cycle-to-cycle differences and may not be a fair representation in such a long timescale prediction. Since 2013, the larger variability has been reported.

South Africa*

Uranium exploration and mine development

Historical review

South Africa has been an important player in the international market since it first started producing uranium in 1952. It has been steadily and consistently producing uranium since then, albeit at a lower level in recent years. Seven of the fifteen deposit types defined in the Red Book are found in South Africa, namely paleo-quartz-pebble conglomerate, sandstone, lignite and coal, intrusive, surficial, phosphate and granite-related deposits. The major part of the resource base is hosted by the quartz-pebble conglomerates and derived tailings, with significant amounts of resources in the sandstone and coal-hosted deposits. The other deposit types make a relatively small contribution to the national uranium resource inventory.

There are six distinct uranium provinces in South Africa. The oldest are the Palaeozoic-aged Mozaan basin in the north-east and the slightly younger Witwatersrand Basin in central South Africa. The Precambrian-aged Palabora and Pilanesberg carbonatite complexes lie in the north, with the Precambrian to Cambrian granite complexes in the north-west. The sandstone deposits of the Karoo in the south-central parts, as well as the coal-hosted deposits of the Springbok Flats are of Permo-Triassic age. The youngest are the Tertiary to recent surficial deposits in the Northwest Cape and the phosphorite deposits off the south-west coast.

The surge in uranium prices between 2005 and 2007 stimulated significant corporate interest in South Africa. Much of the ground over the Witwatersrand Basin was held by existing mining companies and extensive re-evaluations of uranium resource holdings were undertaken. Of great interest were the resources held in the vast tailings dams created by over 100 years of gold mining. Gold Fields, Rand Uranium, Harmony and AngloGold Ashanti launched detailed feasibility studies into the resources contained in tailings.

Available areas with known uranium occurrences, such as in the Karoo Basin and Springbok Flats, were quickly acquired by companies UraMin, Holgoun Energy, and others. UraMin was subsequently acquired by Areva, which included the Trekkopjie deposit in Namibia and the Ryst Kuil Channel in the Karoo Basin. Smaller companies obtained prospecting licences over lesser known deposits in the Karoo Basin, as well as deposits in the granitic and surficial terrains in the north-west of the country.

Peninsula Energy operated in South Africa through its subsidiary Tasman RSA Holdings (Pty) Ltd, and had a total of 41 prospecting rights covering 7 774 km^2 in the Karoo Uranium Province. Peninsula Energy identified new areas of uranium mineralisation in the stacked sandstone units which host extended uranium mineralisation beyond the historic drilling limits, thereby increasing the resource potential. In December 2012, Peninsula Energy acquired all of Areva's properties located in the Karoo Uranium Province, including the Ryst Kuil deposit. Since the commencement of exploration in 2006, Tasman has completed approximately 31 000 m of reverse circulation and diamond drilling, and geophysically logged an additional 15 000 m of open historic holes. In February 2013, Tasman commenced drilling along the Ryst Kuil channel in the Eastern Sector of its Karoo Projects, which has returned encouraging initial results.

* Report prepared by the NEA/IAEA, based on previous Red Books and public data.

In 2013, Peninsula released the results of the initial scoping study that were positive, enabling the commencement of the pre-feasibility study in the second half of 2013, which included extensive metallurgical test work. In June 2014, the company submitted mining rights applications over all their prospecting areas in the Karoo region. The application process was expected to take up to two years and hence the planned commencement of mine development was delayed from 2016 to 2018.

In 2012, HolGoun Uranium and Power Limited completed a pre-feasibility study of its project in the Springbok Flats Basin, where uranium is hosted by coal, then followed-up with a more detailed economic feasibility study. The economic feasibility study comprised resource and reserve estimations, bulk sampling and pilot plant test work, geotechnical and groundwater study, mine and underground infrastructure design, overall environmental issues, financial and economic evaluations and a mining rights application. The initial development of this project envisaged an annual production capacity of about 700 tU_3O_8 (595 tU) at a feed grade of 0.096% U of ore during the first seven years of production. Thereafter, the annual production was planned to be about 500 tU_3O_8 (425 tU) at a feed grade of 0.063% U of ore.

Gold One International Ltd acquired the Rand Uranium properties, as well as the Ezulwini mine in 2012. One of the key objectives associated with these acquisitions was to re-establish the Cooke underground and Randfontein surface operations as gold mines and subsequently to develop uranium co-product potential. The Cooke underground operations comprise Cooke 1, 2, 3 and Ezulwini. Ezulwini was integrated into the Cooke underground complex as Cooke 4. Ongoing exploration and resource development work highlighted numerous potential resource extensions. A feasibility study was completed in 2012 on a high uranium yielding area at Cooke 3, which consists of both unmined ground and a number of higher-grade pillars. The area is associated with existing underground development. The feasibility study considered uranium extraction through the Cooke 4 uranium plant (Ezulwini). The Randfontein surface operations host gold and uranium surface resources which present attractive opportunities for future extraction. These tailings include the Cooke tailings dam, the Millsite complex, Lindum, Dump 20 slime and the Old 4 dam.

In 2012, Harmony Gold Ltd developed two uranium projects to the feasibility stage: Harmony Uranium TPM (Tshepong, Phakisa and Masimong) and the Free State Tailings Uranium Project. The initial plans were that the TPM Project would be extracting uranium from the Tshepong, Phakisa and Masimong underground mines while the Free State Tailings Uranium Project would be extracting uranium from the old tailings storage facilities owned by Harmony. The feasibility study of the TPM Uranium Project was supported by a demonstration plant campaign and associated metallurgical test work. However, these projects have been deferred because of financial constraints.

Namakwa Uranium conducted uranium exploration on the Henkries Project. Most of the delineated resources, mainly in Henkries Central, occur within 20 metres from the surface. Given the shallow and soft nature of the deposit, as well as good infrastructure serving the project area, the project was regarded as potentially viable for future uranium extraction. Xtract Resources conducted a due diligence with view to acquire the Henkries Project in the Namaqualand, Northern Cape Province in 2014. However, Xtract has decided not to go ahead with the acquisition of the Namakwa Uranium deposit as it has found that the project does not meet its investment criteria.

Recent and ongoing uranium exploration and mine development activities

In 2017, Peninsula completed draft Environmental Impact Assessment and Environmental Management Programme reports (EIA/EMPr) for the Ryst Kuil and Quaggasfontein areas (Karoo projects). The proposed mining operation was to be known as the Tasman RSA Mines and would be operated as a single entity, but with multiple production centres (Kareeport, Ryst Kuil, and Quaggasfontein) feeding a central processing plant to be located near the main ore body within the Ryst Kuil project area. In April 2018, Peninsula announced its decision to withdraw from the Karoo projects in which it had a 74% interest. It suspended all development activities including preparation of exploration and mining right applications.

AngloGold Ashanti's operations in South Africa are all located in the Witwatersrand Basin, in two mining districts: the Vaal River and West Wits areas. The Vaal River Surface operations are located to the north of the Vaal river, close to the town of Orkney in the North West province. The Mine Waste Solution (MWS) operations are located approximately 15 km from the town of Klerksdorp near Stilfontein within 20 km of the Vaal River surface operations. The MWS feed sources are scattered over an area that extends approximately 13.5 km north-south and 14 km east-west. The West Wits surface operations are located near the town of Carletonville, straddling the border between the North West and Gauteng provinces. These operations extract gold and uranium from the low-grade stockpile material emanating as a by-product of the reef mining activities within the mines in the Vaal River area. In October 2017, AngloGold Ashanti announced that it was selling assets, including the Moab Khotsong mine and related infrastructure, its interest in Nuclear Fuels Corp of South Africa (Nufcor) and its interest in the Margaret Water Company to Harmony Gold Mining. Anglo Gold Ashanti kept the Mponeng mine and Mine Waste Solutions (MWS) surface operations. As of 1 January 2019, AngloGold Ashanti uranium resources of Vaal River and MWS operations amounted to 39 466 tU of reasonably assured resources (6 131 tU of measured resources and 33 335 tU of indicated resources).

In 2014, Sibanye Gold Ltd acquired the Cooke assets and Randfontein operations from Gold One Ltd, and also the Witwatersrand Consolidated Gold Resources Limited (Wits Gold) assets. A detailed feasibility study of the West Rand Tailings Retreatment Project (WRTRP) was completed by mid-2015. The definitive feasibility study focused on leveraging existing surface infrastructure as well as the available uranium treatment capacity at the Ezulwini gold and uranium processing plant in order to sustain surface gold and uranium production prior to the development of the central processing plant.

The Driefontein, Kloof and Cooke surface operations and associated processing facilities are located on the West Rand of the Witwatersrand Basin, while Beatrix is in the southern Free State goldfields. Sibanye-Stillwater also has an interest in surface tailings retreatment facilities located from the East Rand to the West Rand through a 38.05% stake in DRDGOLD Limited (DRDGOLD).

As of 1 January 2019, Sibanye-Stillwater resources amounted to 10 338 tU of reasonably assured resources (3 288 tU of measured resources and 7 050 tU of indicated resources), 35 tU of inferred resources at the Beatrix underground mine and 19 894 tU of reasonably assured resources (16 072 tU of measured resources and 3 822 tU of indicated resources) at WRTRP. In 2018, uranium resources declined due to the sale of a portion of WRTRP to DRDGOLD. The surface rock dumps at Driefontein were depleted in 2018.

On August 2018, Mintails Mining South Africa (Pty) Ltd and several related companies announced their liquidation. Mintails used to mine and process gold and uranium from waste piles and open pits in Krugersdorp near Johannesburg.

Uranium resources

The last official country report by South Africa was in 2016. New resource estimates have been made since 2016, but mainly for tailings and a few deposits. The Secretariat estimate in this report does not include these new resource estimates as the breakdown of the deposits in the overall total is not known. Therefore, resource estimates, as of 1 January 2019, have been obtained by discounting the uranium production between 2015 and 2018 (estimated cumulative production: 1 537 tU) from the reasonably assured resources tailings category.

Identified conventional resources (reasonably assured and inferred resources)

The Witwatersrand Basin contains about 79% of total identified uranium resources in South Africa, in both the underground, hosted by quartz-pebble conglomerates, and their resulting tailings storage facilities. Approximately 47% of the total national identified resources are in the Witwatersrand underground operations, 28% in their associated tailings facilities, 20% in the Springbok Flats Basin and about 5% in the sandstone-hosted deposits of the Karoo Basin. The uranium pay limit in most parts of the Witwatersrand Basin is calculated on a by-product basis, according to which the uranium is not classified as a resource unless it occurs in an area of gold mineralisation that satisfy the estimated gold cut-off grades. In addition, uranium production in these projects only includes the costs of transporting ore from the underground or tailings operations to the processing plants and the treatment of uranium, while gold carries all other costs.

Undiscovered conventional resources (prognosticated and speculative resources)

Undiscovered conventional resources account for 850 000 tU, which takes into account the <USD 260/kgU and unassigned cost categories.

The Witwatersrand Basin has a total of about 470 tailings storage facilities with uranium resources, most of which are not included as reasonably assured and inferred conventional resource totals. The Karoo Uranium Province is estimated to contain between 90 000 to about 150 000 tU. This estimate has not changed since the last reporting period.

Unconventional resources and other materials

As reported in the 2011 edition of the Red Book, a field of manganiferous phosphate nodules was identified off the west and south-west coast of South Africa on the continental shelf. The nodules contain low grades of uranium and are currently considered uneconomic with respect to both phosphate and uranium extraction. Renewed interest in phosphate-hosted uranium deposits, however, may generate future investigation. The unconventional resources have been previously estimated to amount to 180 000 tU and are unchanged for this reporting period.

Uranium production

Historical review

South Africa has been a consistent producer of uranium since 1952, but its international importance has declined in recent years. In the late 1970s and early 1980s, it ranked as the second or third largest producer in the world, but since the end of the 1990s output has declined significantly, and by 2018, South Africa ranked 12^{th} in global uranium production. Peak production was achieved at over 6 000 tU/yr in the early 1980s when it accounted for 14% of total world output.

Virtually all of South Africa's historical uranium production was derived from quartz-pebble conglomerate deposits with a small proportion being from the Palabora copper-bearing carbonatite. All current production is sourced from the quartz-pebble conglomerate deposits and associated tailings.

The majority of past production was as a by-product of gold or, to a minor extent, copper. Only two primary uranium producers have existed in South Africa. The first was the Beisa mine in the Free State in the early 1980s, and the second was the Dominion Reefs Uranium Mine near Klerksdorp, which operated in the early 2000s.

In 2017 and 2018, the uranium production amounted to 308 tU and 346 tU, respectively at the AngloGold Ashanti's Vaal River Operations (properties owned by Harmony Gold after February 2018).

Status of production facilities, production capability, recent and ongoing activities and other issues

AngloGold Ashanti acquired the MWS tailings retreatment operation in the Vaal River region in July 2012. MWS comprises tailings storage facilities that originated from the processing of ore from the Buffelsfontein, Hartebeestfontein and the Stilfontein gold mines. After selling its Vaal River assets to Harmony Gold Mining in early 2018, operations at the NWS uranium plant ceased in 2018.

Uranium production from the Sibanye owned Cooke operations began in May 2014. The Cooke shafts were used to mine multiple reefs. Uranium processing was done at the Cooke 4 (Ezulwini) Uranium plant. Uranium production at the Ezulwini-Cooke plant and mine operations ended in 2016, and the associated surface rock dumps at Driefontein were depleted in 2018.

Ownership structure of the uranium industry

In February 2018, AngloGold sold its assets in the Vaal River region, including the Moab Khotsong mine, to Harmony Gold Mining. AngloGold kept the Mponeng mine and WWS surface operations.

In April 2018, Peninsula announced its decision to withdraw from the Karoo projects in which it had a 74% interest. It suspended all development activities including preparation of exploration and mining right applications.

In 2014, Sibanye assumed control of the Cooke underground and surface operations, including the Randfontein operations, from Gold One International Limited (Gold One) and also concluded the acquisition of Witwatersrand Consolidated Gold Resources Limited (Wits Gold). In 2018, Sibanye sold a portion of WRTRP to DRDGOLD.

Future production centres

Future production centres could include the Dominion Reef mine and Beaufort West deposit (Karoo Basin).

Environmental activities and socio-cultural issues

Exploration and mining companies are committed to the responsible use and management of the natural resources under their prospecting and mining rights. Site visits and inspections are conducted regularly to verify that the commitments detailed in their environment management programmes are being adhered to. Exploration and drilling include a responsibility to rehabilitate each site once drilling has been completed. In terms of applications for mining rights, and as part of the Social and Labour Plan, companies are required to inform the interested and affected parties in the proposed mining area of its intended activities.

The Broad-Based Socio-Economic Empowerment Charter for the South African Mining and Minerals Industry (The Mining Charter), which gives effect to the Mineral and Petroleum Resources Development (Act No. 28 of 2002), is aimed at transforming the mining industry to redress historical imbalances by substantially and meaningfully expanding opportunities for historically disadvantaged South Africans (HDSA). The charter has given mining companies provision to offset the value of the level of beneficiation achieved against a portion of its HDSA ownership requirements of up to 11% as compared to the current required level of 26% (to be achieved by the end of 2014). Furthermore, mining companies are required to procure a minimum of 40% of their capital goods, 70% of services and 50% consumables from Black Economic Empowerment entities.

AngloGold Ashanti has designed a framework, following extensive stakeholder engagement, to integrate community development into core business activities, while providing support for national development policies and objectives, particularly those addressing youth unemployment. AngloGold Ashanti's contribution to education in both local and labour-sending communities is a priority. In addition, the Merafong Agricultural Project, which employs 20 people, is funded by AngloGold Ashanti. Other social responsibilities included economic initiatives in the labour-sending areas such as the remote villages of the Eastern Cape Province.

Regulatory regime

The Department of Mineral Resources, the Department of Water Affairs, the Department of Environmental Affairs and the Department of Energy, including the National Nuclear Regulator, perform regulatory functions relating to exploration and mining of uranium in South Africa.

According to the Mineral Resources and Development Act No. 28 of 2002, an applicant of prospecting or mining right must make the prescribed financial provision for the rehabilitation or management of negative environmental impacts before the approval of such rights. If the holder of the prospecting or mining right fails to rehabilitate, or is unable to undertake such rehabilitation, then part or all of the financial provision will be used for rehabilitation. The holder of a prospecting or mining right must annually assess their environmental liabilities and accordingly increase their financial provision to the satisfaction of the Minister of Mineral Resources. If the minister is not satisfied with the assessment and the financial provision, then the minister may appoint an independent assessor to conduct the assessment and determine the financial provision. The requirement to maintain and retain the financial provision remains in force until a closure certificate has been issued after the closure of mining or prospecting operation. The minister may still retain a portion of the financial provision as may be required to rehabilitate the closed mining or prospecting operation in respect of latent or residual environmental impacts. No closure certificate will be issued until the rehabilitation has been done and the chief inspector, as well as all the governmental regulatory departments related to uranium exploration and mining, have confirmed that the provisions pertaining to health, safety, environment and management of potential pollution to water have been addressed.

Uranium requirements

Koeberg is South Africa's only nuclear power plant. It has two light-water thermal reactors: Koeberg I, commissioned in 1984, and Koeberg II, commissioned in 1985, with a combined installed capacity of 1 840 MW. Together, they require about 294 tU/yr.

In August 2018, the government announced that it had abandoned plans to build up to 9.6 GWe of new nuclear capacity by 2030. The Integrated Resources Plan (IRP) 2018, an update of that issued in 2010, did not include any new nuclear capacity by 2030. IRP 2010 outlined a required 52 GWe of new capacity by 2030, with nuclear to provide at least 9.6 GWe of that. An update to the IRP issued in November 2016 called for 1.4 GWe of new nuclear capacity by 2037, and a total of 20 GWe long term. IRP 2016 was released in the context of the Integrated Energy Plan (IEP), which projected a more than threefold increase in electricity demand by 2050.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

The National Nuclear Regulator Act No. 47 of 1999, the Nuclear Energy Act No. 46 of 1999, National Radioactive Waste Disposal Institute Act No. 53 of 2008, and the Mineral and Petroleum Resources Development Act No. 28 of 2002, are the basis of national policies relating to prospecting for and mining of uranium in South Africa, as well as the export of uranium and disposal of spent nuclear fuel. More information on these policies can be found at the following links:

- www.gov.za/documents/national-nuclear-regulator-act;
- www.gov.za/documents/nuclear-energy-act;
- www.energy.gov.za/files/policies/act_nuclear_53_2008_NatRadioActWaste.pdf;
- www.gov.za/documents/mineral-and-petroleum-resources-development-act.

Uranium stocks

The information and figures on uranium stocks are classified as confidential, and hence could not be accessed from Eskom (a South African electricity public utility, established in 1923, as the Electricity Supply Commission by the South African Government in terms of the Electricity Act).

Uranium prices

No uranium prices were available.

Reasonably assured conventional resources by production method

(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)*	0	0	7 261	9 672	80.0
Co-product and by-product	0	166 337	228 784	248 355	72.5
Total	0	166 337	236 045	258 027	70.0

* The resources for sandstone-hosted deposits in the Karoo Basin are included in the open-pit method; however, in reality the potential production will be conducted by both open-pit and underground mining, the ratio of resources to each method is unknown at present.

Reasonably assured conventional resources by processing method

(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG*	0	166 337	228 784	248 355	72.5
Conventional from OP	0	0	7 261	9 672	80.0
Total	0	166 337	236 045	258 027	70.0

* Conventional from UG also includes tailings resources from the Witwatersrand Basin.

Reasonably assured conventional resources by deposit type

(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	7 261	8 526
Paleo-quartz-pebble conglomerate*	0	166 337	228 784	248 355
Surficial	0	0	0	1 146
Total	0	166 337	236 045	258 027

* Paleo-quartz-pebble conglomerate resources include tailings resources as well.

Inferred conventional resources by production method

(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)*	0	0	0	70 775	68.0
Open-pit mining (OP)**	0	0	10 467	14 080	80.0
Co-product and by-product	0	61 656	74 361	104 861	75.0
Total	0	61 656	84 828	189 716	72.5

* Underground mining resources only include resources from the Springbok Flats Basin. The resources from underground operations in the Witwatersrand Basin are included in the "co-product and by-product" category.

** Resources in the Karoo Basin are included in the open-pit mining method, even though both open-pit and underground mining method are expected to be used. The recovery factor used for the open-pit method (80%) is speculative only.

Inferred conventional resources by processing method

(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	61 656	74 361	175 636	72.0
Conventional from OP	0	0	10 467	14 080	80.0
Total	0	61 656	84 828	189 716	72.5

Inferred conventional resources by deposit type

(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	10 467	13 491
Paleo-quartz-pebble conglomerate*	0	61 656	74 361	104 861
Surficial	0	0	0	589
Lignite and Coal	0	0	0	70 775
Total	0	61 656	84 828	189 716

* Includes tailings resources in the Witwatersrand Basin.

Prognosticated conventional resources

(tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
0	74 000	159 000

Speculative conventional resources

(tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
243 000	411 000	280 000

Historical uranium production by deposit type

(tonnes U in concentrates)

Deposit type	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Paleo-quartz-pebble conglomerate	159 903	490	308	346	161 047	NA
Total	159 903	490	308	346	161 047	NA

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Co-product/by-product	159 903	490	308	346	161 047	NA
Total	159 903	490	308	346	161 047	NA

Historical uranium production by processing method

(tonnes U in concentrates)

Processing method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Conventional	159 903	490	308	346	161 047	NA
Total	159 903	490	308	346	161 047	NA

Ownership of uranium production in 2018

Domestic				Foreign				Totals	
Government		Private		Government		Private			
(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)
0	0	346	100	0	0	0	0	346	100

Short-term production capability

(tonnes U/year)

2018				2020				2025			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
0	0	500	0	0	0	800	0	0	0	1 160	3 000

2030				2035				2040			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
0	0	1 160	3 000	0	0	1 180	2 800	0	0	1 090	2 500

Net nuclear electricity generation

	2017	2018
Nuclear electricity generated (TWh net)	15.1	10.6

Installed nuclear generating capacity to 2035

(MWe net)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
1 840	1 840	1 840	1 840	1 840	1 840	1 840	1 840	1 840	NA	1 840	NA

Annual reactor-related uranium requirements to 2040 (excluding MOX)

(tonnes U)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
294	294	294	294	294	294	294	294	294	NA	294	NA

Spain

Uranium exploration and mine development

Historical review

Uranium exploration started in 1951 and was carried out by the Junta de Energía Nuclear (JEN). Initial targets were the Hercynian granites of western Spain. In 1957 and 1958, the first occurrences in Precambrian-Cambrian schists were discovered, including the Fe deposit, located in the province of Salamanca. In 1965, exploration of sedimentary rocks began and the Mazarete deposit in Guadalajara province was discovered. In 1972, the Empresa Nacional del Uranio S.A., today Enusa Industrias Avanzadas S.A., S.M.E. (hereinafter ENUSA), a state-owned company, was established to take charge of all the nuclear fuel cycle front-end activities. Its shareholders are the Sociedad Estatal de Participaciones Industriales (SEPI) holding 60% of the capital, and the Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT, previously JEN), holding the remaining 40%. Exploration activities by ENUSA ended in 1992. Joint venture exploration between ENUSA and other companies continued until the end of 1994. During this period, most of the Spanish territory was surveyed using a variety of methods, adapted to different stages of exploration, and ample airborne and ground radiometric coverage of the most interesting areas was achieved.

Recent and ongoing uranium exploration and mine development activities

Berkeley Minera España S.L.U. (hereinafter Berkeley) has been granted one mining licence in the province of Salamanca covering 2 520 ha and a total of 26 investigation licences covering a total of 94 555 ha and one exploration licence covering 19 570 ha spanning the provinces of Salamanca, Cáceres and Badajoz. This company has been actively exploring for uranium for several years, with a focus on a number of historically known uranium projects located within their tenements.

Berkeley's Salamanca Project comprises the Retortillo, Zona 7 and Alameda deposits (in Salamanca province) and also the Gambuta deposit in Cáceres province, which now, according to Berkeley, accounts for 12.3 Mlb U_3O_8 (4 730 tU) in the measured and 47.5 Mlb U_3O_8 (18 270 tU) indicated resource categories, with an additional 29.5 Mlb U_3O_8 (11 350 tU) in the inferred resource category. All deposits are the granite-related type (perigranitic subtype), hosted by a sequence of metasediments which are adjacent to a granite intrusion.

According to the company, Retortillo, Alameda and Zona 7 would achieve a production capacity of 4.4 Mlb U_3O_8/yr (1 690 tU/yr) over a mine life of 14 years.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

Total reported in situ identified resources are 89.3 Mlb U_3O_8 (34 350 tU), which include 59.8 Mlb U_3O_8 (23 000 tU) in reasonably assured category (12.3 Mlb U_3O_8 or 4 730 tU as measured resources and 47.5 Mlb U_3O_8 or 18 270 tU as indicated resources) and 29.5 Mlb U_3O_8 (11 350 tU) as inferred. All resources are reported as in situ and mineable by conventional open pit. According to the Feasibility Study 95% of resources may be recovered by open-pit mining and 87% factor is applied for processing recovery. The overall recovery factor is about 83%.

Uranium production

Historical review

Production started in 1959 at the Andújar plant (Jaén province) and continued until 1981. The Don Benito plant (Badajoz province) remained in operation from 1983 to 1990. Production at the Fe mine (Salamanca province) started in 1975 with heap leaching (Elefante plant). A new dynamic leaching plant (Quercus) started operation in 1993 and was shut down in December 2000. The licence for the definitive shutdown of production, submitted to regulatory authorities in December 2002, was approved in July 2003.

Status of production capability

Mining activities were terminated in December 2000 with the closure of Saelices el Chico uranium mines and production of uranium concentrates ended in November 2002 when the associated Quercus processing plant was shut down.

A decommissioning plan was presented to the regulatory authorities in 2005. However, it was put on standby a first time due to the need decommissioning the former Elefante processing plant and restoring mines at the same site before decommissioning Quercus, and then a second time due to a 2009 agreement between ENUSA and Berkeley to complete a feasibility study on the state reserves in Salamanca province. Despite delays, once the Elefante processing plant was decommissioned, and the mines restored and the agreement between ENUSA and Berkeley finalised, a new plan for decommissioning was presented to the regulatory authorities in September 2015. This plan has been subject to several additional information requirements during 2016 and 2017 and is still being evaluated by the national regulatory body.

In 2018 and 2019, Berkeley continued to negotiate with the relevant authorities on permits and approvals required to commence construction of the mine, and in late 2019, reported on the ongoing approval process.

Ownership structure of the uranium industry

Quercus, the only production facility in Spain still pending decommissioning, belongs to the company ENUSA.

Employment in the uranium industry

There is no uranium production in Spain. Employment relates to former or planned mines. Since there are no existing production centres in Spain, employment is associated with decommissioning and mine development activities only.

Employment at the former Fe mine totalled 29 at the end of 2018. All of these workers are dedicated to the mining restoration, surveillance and decommissioning programmes.

Berkeley has between 45-55 employees, depending on the activity being carried out. Berkeley's activity is focused on the project development of the Salamanca Project, pending several authorisations.

Future production centres

Berkeley has announced its intention to bring four potential open-pit uranium mines into production: Retortillo-Santidad, Alameda, Zona 7 and Gambuta (the former three in the Salamanca region and the latter in the Cáceres region). Berkeley applied to the competent authority (autonomous regional government) for an exploitation permit for the Retortillo-Santidad mining project in October 2011, and the mining licence was granted in April 2014 once the Environmental Licence was in place and after a favourable report from the Nuclear Safety Council. Likewise, according to the nuclear regulation, Berkeley requested the site authorisation for the radioactive facility to the Ministry in charge of energy issues (former MINETUR, currently MITECO), in March 2012, which was granted by September 2015 after a favourable report of the Nuclear Safety Council. This allowed Berkeley to request construction authorisation, which is currently under evaluation by the competent authorities. If granted, an exploitation licence would still be pending. As of the end of 2019, amid on-going controversy and disagreements among local environmental groups, and regional and national authorities, the licensing situation has not yet been resolved. The project, according to Berkeley, and including only the Retortillo, Zona 7 and Alameda deposits, should have an average production of 4.4 Mlbs U_3O_8/yr (1 690 tU/yr) over a 14-year period of operation.

Secondary sources of uranium

Spain reports mixed oxide fuel and re-enriched tails production and use as zero.

Environmental activities and socio-cultural issues

The present condition of former uranium production facilities in Spain are as follows:

- Fábrica de Uranio de Andújar (Jaén province): Mill and tailings piles have been closed and remediated, with an ongoing ten-year surveillance and control programme (groundwater quality, erosion control, infiltration and radon control). This programme has been extended.
- Mine and plant "LOBO-G" (Badajoz province): The open-pit and mill tailings dump have been closed and remediated, with a surveillance and control programme (groundwater quality, erosion control, infiltration and radon control) in place until 2004. A long-term stewardship and monitoring programme was begun after the declaration of closure.
- Old mines (Andalucía and Extremadura regions): Underground and open-pit mines were restored, with work completed in 2000.
- Two old mines in Salamanca (Valdemascaño and Casillas de Flores) were restored in 2007, following which a surveillance programme was initiated, ending in 2011. Results were evaluated by regulatory authorities and it was determined that an extension of the surveillance period was required.
- Elefante plant (Salamanca province): The decommissioning plan, including industrial facilities and heap leaching piles, was approved by regulatory authorities in January 2001. The plant was dismantled, and ore stockpiles were levelled and covered in 2004. A monitoring and control programme has been in place since 2005.
- In 2004, the mining restoration plan of the open-pit exploitation in Saelices el Chico (Salamanca province) was approved by regulatory authorities. Implementation of this plan was finished in 2008 and the proposed surveillance and control programme was sent to regulatory authorities for approval. A monitoring and control programme has been in place since then.
- Quercus plant (Salamanca province): Mining activities ended in December 2000 and uranium processing in November 2002. A decommissioning plan was submitted to regulatory authorities in 2005. However, because of the need for the decommissioning of the former Elefante processing plant and for the restoration of some of the mines at the same site before turning to the decommissioning of Quercus, as well as the 2009 agreement between ENUSA and Berkeley, this decommissioning plan was put on standby. In September 2015, a new plan for decommissioning was presented to the regulatory authorities, which after several additional information requirements, is still pending approval. During this time, a surveillance and maintenance programme has remained active for the plant and associated facilities.

Uranium mining regulatory regime

In Spain, the mining regime is regulated by the Mines Act (Act 22/1973), modified by Act 54/1980, and also by Royal Decree 2857/1978. The investigation and use of radioactive ores is governed by this act in those areas that are not specifically considered in the Nuclear Energy Act (Act 25/1964), Chapter IV of which deals with the prospecting, investigation and use of radioactive ores, as well as the commercialisation of such ores and their concentrates.

According to Article 2 of the Mines Act, all-natural deposits and other geological resources in Spain are assets belonging to the public domain, investigation and use of which may be undertaken directly by the state or assigned in accordance with the rules. Pursuant to Article 1 of Act 54/1980, which amends the Mines Act, radioactive ores are part of Section D, i.e. resources of national energy interest.

Pursuant to Article 19 of the Nuclear Energy Act, the prospecting, investigation and use of radioactive ores and the obtaining of concentrates are declared to be open throughout the entire national territory, except in those areas set aside by the state. Individuals or companies who wish to prospect for radioactive ores are required to request an investigation permit from the state and subsequently, if the existence of one or more resources open to rational exploitation is revealed, to request an exploitation licence. This licence confers the right to exploit the resources and is granted for a 30-year period, extendable by similar periods to a maximum of 90 years. The permits and licences are granted by the autonomous communities, in keeping with the transfer to them of state competences in mining and energy issues, except when the mining activity in question affects several autonomous communities or state reserves, in which case the competent authority is the Ministry for the Ecological Transition (MITECO), by virtue of the Mines Act.

The Nuclear Safety Council is the organisation responsible for nuclear safety and radiological protection. In accordance with Article 2 of the act creating the Nuclear Safety Council (Act 15/1980), one of the main competences of the Council is to issue reports to the MITECO on nuclear safety and radiological protection, prior to the resolutions adopted by the latter regarding the granting of authorisations for the operation, restoration or closure of uranium mines and production facilities. These reports are mandatory in all cases and binding when negative in their findings or denying authorisation, or as regards to the conditions established when they are positive.

Regarding restoration plans and financial guarantees for the mining activities, according to the Royal Decree 975/2009 of 12 June on the management of waste resulting from extractive industries and the protection and restoration of the environment affected by mining activities, a restoration plan must be submitted for approval to the mining authority (the autonomous regional government or MITECO, in the case of those mining activities affecting several autonomous communities or state reserves), the approval of which will be given together with the granting of the exploitation licence. The mining authority will neither grant the licence nor approve the plan unless environmental restoration of the site is guaranteed. To that end, two financial guaranties have to be set up by the company before starting any mining activity. One must be set up for the rehabilitation of the environment affected by the exploitation of the ores and the second for the management of the generated waste. Both must comply with the objectives and conditions established in the authorised restoration plan even in the case that the company does not exist at the time of the restoration.

Decommissioning of the associated milling facilities is pursuant to the Regulation on Nuclear and Radioactive Installations (RINR, approved by Royal Decree 1836/1999 and modified several times afterwards). As radioactive facilities of the nuclear fuel cycle, these facilities are subject to all previous site, construction and exploitation licences. An exploitation licence requires the applicant to submit decommissioning and closure forecasts, including, among other things, the final management of the radioactive wastes as well as the economic and financial calculations to guarantee closure of the site. The RINR requires the constitution of a financial guarantee before granting an exploitation licence.

Uranium requirements

As of 31 December 2018, the net capacity of the seven Spanish nuclear reactors under commercial operation (Almaraz units 1 and 2, Ascó units 1 and 2, Cofrentes, Vandellós 2 and Trillo nuclear power plants) was about 7.1 GWe. No new reactors are expected to be built in the near future.

Through 2010 and 2011, the Spanish Government approved ten-year licence renewals for Ascó units 1 and 2, Almaraz units 1 and 2, Vandellós unit 2 and the lone Cofrentes unit. In 2014, the Trillo nuclear power plant received its renewal for operation until 2024.

During the first quarter of 2019, Almaraz units 1 and 2 and Vandellós 2 have requested ten-year renewals of their licences.

Accordingly, uranium requirements for the Spanish nuclear fleet in the coming years will depend on the renewal of the nuclear power plant licences and their terms, to be authorised in coherence with the Comprehensive National Energy and Climate Plan 2021-2030. This plan establishes the forecasts on the evolution of the nuclear energy contribution to the energy mix, and with the subsequent Protocol signed in March 2019 by the electric companies and ENRESA agreeing to a scheduled closure of the nuclear power plants during the period 2025-2035.

For the coming years, uranium requirements will therefore range from 925 to 1 600 tU/yr.

Supply and procurement strategy

All uranium procurement activities are carried out by ENUSA on behalf of the Spanish utilities that own the seven nuclear reactors under commercial operation in Spain.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

Spain's uranium import policy provides for diversification of supply. The Spanish legislation leaves uranium exploration and production open to national and foreign companies.

Uranium stocks

Present Spanish regulation provides that a strategic uranium inventory contained in enriched uranium should be held jointly by the utilities that own nuclear power plants. The current stock contains the equivalent of at least 608 tU. Additional inventories could be maintained depending on uranium market conditions.

Uranium exploration and development expenditures and drilling effort – domestic

(EUR)

	2016	2017	2018	2019 (expected)
Industry* exploration expenditures	1 048 499	1 037 166	784 530	341 700
Total expenditures	1 048 499	1 037 166	784 530	341 700
Industry* exploration drilling (m)	8 993	595	0	3 350
Industry* exploration holes drilled	108	28	0	13
Subtotal exploration drilling (m)	8 993	595	0	3 350
Subtotal exploration holes drilled	108	28	0	13
Total drilling (m)	8 993	595	0	3 350
Total number of holes drilled	108	28	0	13

* Non-government.

Reasonably assured conventional resources by production method
(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	9 800	23 000	23 000	23 000	83
Total	9 800	23 000	23 000	23 000	83

Reasonably assured conventional resources by processing method
(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from OP	9 800	23 000	23 000	23 000	83
Total	9 800	23 000	23 000	23 000	83

Reasonably assured conventional resources by deposit type
(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Granite-related	9 800	23 000	23 000	23 000
Total	9 800	23 000	23 000	23 000

Inferred resources by production method
(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	0	11 350	11 350	11 350	83
Total	0	11 350	11 350	11 350	83

Inferred resources by processing method
(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from OP	0	11 350	11 350	11 350	83
Total	0	11 350	11 350	11 350	83

Inferred resources by deposit type
(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Granite-related	0	11 350	11 350	11 350
Total	0	11 350	11 350	11 350

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Open-pit mining*	5 028	0	0	0	5 028	0
Total	5 028	0	0	0	5 028	0

* Pre-2015 totals may include uranium recovered by heap and in-place leaching.

Historical uranium production by processing method

(tonnes U in concentrates)

Processing method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Conventional	4 961	0	0	0	4 961	0
Other methods*	67	0	0	0	67	0
Total	5 028	0	0	0	5 028	0

* Includes mine water treatment and environmental restoration.

Historical uranium production by deposit type

(tonnes U in concentrates)

Deposit type	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Granite-related	5 028	0	0	0	5 028	0
Total	5 028	0	0	0	5 028	0

Uranium industry employment at existing production centres*

(person-years)

	2016	2017	2018	2019 (expected)
Total employment related to existing production centres	76	78	79	79
Employment directly related to uranium production	0	0	0	0

* Since there are no existing production centres in Spain, employment is related to decommissioning and mine development activities only. In 2016 for example, 29 were involved in Fe decommissioning and the remainder in Salamanca mine development work. See text for details.

Net nuclear electricity generation

	2017	2018
Nuclear electricity generated (TWh net)	55.7	53.2

Installed nuclear generating capacity to 2040

(MWe net)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
7 069	7 069	7 069	7 069	7 069	7 069	3 020	5 059	NA	NA	NA	NA

Annual reactor-related uranium requirements to 2040 (excluding MOX)

(tonnes U)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
1 291	906	944	944	1 600	1 600	400	500	NA	NA	NA	NA

Total uranium stocks

(tonnes natural U-equivalent)

Holder	Natural uranium stocks in concentrates	Enriched uranium stocks	Enrichment tails	LWR reprocessed uranium stocks	Total
Government	0	0	0	0	0
Producer	0	0	0	0	0
Utility	NA	608	0	NA	NA
Total	NA	608	0	NA	NA

Sri Lanka*

Uranium exploration and mine development

Historical review

Interest in radioactive minerals in Sri Lanka began when thorianite was discovered in 1904 in the gem-gravels of the Ratnapurna District. This resulted in a search for other radioactive minerals. From 1904 to 1909, a total of 9 tonnes of urano-thorianite containing up to 38% U_3O_8 (32% U) were recovered from stream gravels.

The most common radioactive mineral in Sri Lanka is monazite, which occurs in seasonal beach deposits predominately located on the southwest coast. From 1918 to the mid-1970s, the beach sands were extracted until coastal conservation regulations forced an end to the activity. Concentrations of monazite in beach sands around Beruwala were exploited using a small experimental plant during the period of 1918 to 1922. About 450 tonnes of monazite were reported to be recovered from approximately 3 000 tonnes of raw sand during this period. In 1956, a pilot plant was established in the Katukurunda area near Kalutara by the Geological Survey and Mines Bureau (GSMB) to process mineral sands. An average of 1 000 tonnes of sand per year with monazite concentrations of 6-8% were processed at the plant for export. The plant was abandoned in the 1980.

The first systematic exploration project for radioactive minerals began in 1958 with an airborne magnetic and radiometric survey carried out under the Canada/Ceylon Colombo Plan Technical Assistance Programme, which covered nearly a third of Sri Lanka. The survey identified nearly 250 anomalous areas, most of which coincided with monazite-bearing beach sands. In 1961, ground follow-up work was carried out with IAEA co-operation.

From 1979 to 1983 a countrywide geochemical stream sediment programme covering all of Sri Lanka (65 000 km^2) was implemented with IAEA assistance. A total of 1 750 samples were collected from 874 locations at a density varying from one per 27 km^2 to one per 278 km^2. The follow-up project area covered nearly 10 000 km^2 and was investigated in 1982 at a sampling density ranging from one per 2 km^2 to one per 5 km^2. This work led to the selection of nine areas totalling 7 800 km^2, which were assessed on a priority basis in 1983 and 1984. The high priority targets were Kantalei, Polonnaruwa, Kala Oya, and Maha Oya, which were geochemically sampled at a sampling density of up to one per km^2. The outcome of this programme was the selection of the Kayla Oya and Maha Oya areas for further work.

Except for Kala Oya, the eight other areas are mainly composed of highly metamorphosed rocks of the Proterozoic Viyayan series, intruded by granites, partly of alkaline composition. In the Kala Oya area, sedimentary rocks of Jurassic age (shales and arkose sandstones) are present. The average uranium values observed from the stream sediments are in the region of 50 ppm U_3O_8 (42 ppm U; 0.0042% U). However, values over 300 ppm U_3O_8 (254 ppm U; 0.0254% U) have also been recorded. In 1985, the Geological Survey Department of Sri Lanka limited its investigations of the Kala Oza (25 km^2) and Maha Oya (40 km^2) areas to laboratory analyses of samples previously collected. Additional exploration in these areas was restricted due to the impact of the Sri Lanka Civil War (1983-2009).

* Report prepared by the NEA/IAEA, based on previous Red Books and government data.

Recent and ongoing uranium exploration and mine development activities

A project team composed of officials from the GSMB and the Atomic Energy Board (AEB) of Sri Lanka was established with a focus on reviewing historical exploration data and implementing future GSMB mineral exploration projects. Under an IAEA-GSMB-AEB joint technical co-operation project "Survey of Nuclear Raw Materials with Emphasis on Locating Thorium/Uranium Mineralisation in Sri Lanka", GSMB received a car-borne gamma-ray spectrometer and an XRF spectrometer in 2016. Since then, surveys have been carried out using these instruments in the north western and central parts of Sri Lanka utilising 1:50 000 scale topographic base maps. In addition, detailed field investigations are being carried out to investigate the thorium and uranium occurrences in areas such as Bamabarakouwa, Rathnapura, and Naula, which were identified during previous surveys.

The current focus of this work is to identify radioactive mineralisation in the country with a particular emphasis on the future extraction of uranium from unconventional sources. Through IAEA technical co-operation projects, a substantial amount of technical assistance was provided to Sri Lanka for the discovery of economic mineralisation (U, Th).

Car-borne gamma-ray spectrometer survey

A car-borne gamma-ray spectrometer survey (2016-2018) identified three anomalies in the central highlands. Surveys over the Matale, Dambulla, Elahera, Pallegama, Kandy, Gampola, Mahiyanganaya and Hanguranketha 1:50 000 topographic map sheet areas were completed by the end of 2017. An initial field visit was carried out to investigate the thorium and uranium occurrences in the Bamabarakotuwa and Rathnapura areas. A detailed geological investigation of the thorium anomaly at the Naula area commenced in 2018, and a detailed grid-based follow-up radioactivity survey was completed over an anomaly identified in the Senagama Naula area. Data analysis is in progress and initial geochemical analyses show values of up to 60 ppm U (0.006% U) in this area.

Heavy mineral sands

Varying concentrations of heavy mineral sands (ilmenite, rutile, garnet, zircon, monazite) occur in the beach sands of the country. However, only certain locations have concentrations that are deemed sufficient for potential economic exploitation.

From 2016 to 2019, four new areas of anomalous radioactivity were identified in the coastal stretch from Talaimannar to Galle. Fieldwork from Talaimannar to Kudiramalai was completed in 2017 and continued to Puttalam to the end of 2019. Follow-up work is anticipated.

Monazite-rich beach sand placer deposits are known to occur along the coastal stretch covering the Aluthgama-Beruwala-Induruwa southwest sector and the Kudiramalai northwest sector of the island. Notable amounts of thorianite-rich sands are reported in beach sands in the Beruwala-Induruwa areas. Monazite and thorianite sands are reported to occur in lesser concentrations within the Pulmuddai, Thirukkovil, and Galle mineral sand occurrences. Urano-thorianite deposits also occur in river placers (southwest). Monazite concentrations of 0.3-1% are known to occur in approximately 75 million tonnes of inland red earth deposits (northwest).

Monazite-bearing beach mineral samples collected from the east coast Pulmoddai Deposit were processed to separate monazite and analyse for trace elements by AEB laboratories. The analysis revealed values up to 23% Ce in monazite.

Geophysical surveys for near offshore minerals in southwest Sri Lanka identified an estimated volume of sediments of 170 million tonnes in 11 potential basins to a depth of 2 metres. Monazite concentrations of up to 1.1% were estimated based on gamma-ray spectrometry analysis.

Airborne surveys

Detailed high quality digital aeromagnetic and radiometric surveys (1:100 000 scale) have been initiated, or are planned, over a large portion of the country to locate uranium and thorium mineralisation for assessing the country's nuclear raw material potential in support of future energy planning. The identification of radiogenically hazardous areas is another objective of this programme.

Uranium resources and production

Sri Lanka has no identified uranium resources or production.

Legislation

The Sri Lanka Atomic Energy Act No. 40 of 2014 created two independent institutes: the Sri Lanka Atomic Energy Board (AEB), and the Sri Lanka Atomic Energy Regulatory Council (AERC). The AEB is, empowered to carry out activities to promote and encourage the use of nuclear science and technology for national development purposes. In addition, the Act fulfils obligations of the government of Sri Lanka under relevant international instruments in the field of nuclear energy entered into by Sri Lanka and, in particular, the Treaty on the Non-Proliferation of Nuclear Weapons and the Safeguards Agreements. The Act came into force on 1 January 2015.

The AEB permits the beneficial and peaceful applications of nuclear science and technology in health, industry, environment, and agriculture for national development within Sri Lanka. The AERC ensures adequate protection of individuals, society and the environment, now and in the future, against the potentially harmful effects of ionising radiation. Furthermore, the AERC ensures the safety and security of radiation sources, by the establishment and maintenance of a regulatory control system, including the adoption of standards, a licensing system, as well as inspection and enforcement to govern all practices involving ionising radiation.

Future power generation

In Sri Lanka's power generation scheme, the contribution of hydropower has probably reached a maximum of about 40%, while more than 60% of the power supply is derived from oil and other thermal sources that release greenhouse gas emissions and other pollutants into the atmosphere that contribute to global warming. The high cost of oil imports has burdened the national economy and escalating energy prices has adversely affected many energy-intensive industries and production processes with a sharp impact on the economy. Due to the increasing dependence on expensive thermal energy, the cost of energy is becoming a significant proportion of expenses needed for other development efforts. An analysis of Sri Lanka's compound growth of power demand for the last 30 years shows an average of 6.5% per annum. With the coming of peace after 30 years of civil war and escalated development activities, particularly in the northern and eastern parts of the country, there will be demand for more power in the future. Shortages of suitable power sources will be a major barrier to the development of the country.

Sri Lanka is currently building a coal power plant, while exploration for offshore petroleum and natural gas is underway. A combined aeromagnetic and gamma-ray survey has also been proposed to support the identification of nuclear raw material resources. Depending on the information that will become available, the next 2-3 years will be a crucial period for the future energy planning for the country. Proper assessment of the country's nuclear raw material potential will be very important in future energy planning. Prevailing circumstances and global developments might force Sri Lanka to adopt alternative methods of power generation, such as nuclear power in the future. In this respect, the survey of nuclear fuel minerals in and around Sri Lanka is essential.

Sweden*

Uranium exploration and mine development

Historical review

Uranium exploration in Sweden was first carried out between 1950 and 1985, initially through AB Atomenergi and from 1967 by the Geological Survey of Sweden and associated companies. At the end of 1985, exploration activities were stopped because of the availability of uranium at low prices on the world market. This early work did, however, result in the delineation of four main uranium provinces in Sweden.

The first is in the Upper Cambrian and Lower Ordovician sediments in southern Sweden and along the border of the Caledonian mountain range in central Sweden. The uranium occurrences are stratiform, in black (aluminium) shales/schists. Billingen (Vastergotland), where the Ranstad deposits are located, covers an area of more than 500 km^2.

The second uranium province, Arjeplog-Arvidsjaur-Sorsele, is immediately south of the Arctic Circle. It comprises one deposit (Pleutajokk) and a group of more than 20 occurrences. The individual occurrences are discordant, of vein or impregnation-type, and associated with sodium-metasomatism.

A third province is located north of Ostersund in central Sweden. Several discordant mineralised zones have been discovered in, or adjacent to, a window of Precambrian basement within the metamorphic Caledonides.

A fourth province is located near Asele, in northern Sweden.

Exploration of aluminium shales/schists in central Sweden (the first province) resumed in 2003 due to increased uranium prices and with alternative production methods under consideration to reduce production costs. Continental Precious Minerals had 72 mineral exploration licences throughout Sweden, but the company focused on its Viken licence in central Sweden, a black shale deposit with elevated concentrations of uranium, nickel, molybdenum and vanadium. The potentially mineable portion of the resource for the Viken Deposit was estimated at 447 308 tU (1 163 Mlbs U_3O_8) according to the updated preliminary economic assessment made in 2014.

Mawson Resources completed work on the Tåsjö Project in 2006 and 2007, investigating uranium contained in mineralised phosphatic shale with rare earth elements in northern Sweden. The resources were discovered in 1957 by the Swedish Atomic Energy Company and subsequently explored in the early 1970s by the Geological Survey of Sweden and the Stora Kopparberg and Boliden companies. The size of the exploration target outlined by the Swedish Atomic Energy Company in the 1960s was confirmed by Mawson at about 42 300 tU at 0.042% U, although the tonnages and grades are considered conceptual at this time.

Since 2007, a number of exploration companies have been active in Sweden, in many cases focusing work on areas where discoveries were made during earlier initial phases of exploration. Two Canadian companies, Mawson Resources and Continental Precious Minerals, have been most active, and between the two companies, 12 800 tU (33.28 Mlbs U_3O_8 in situ) have been reported from nine historical occurrences using the Geological Survey of Sweden data combined with confirmation by twinned drill holes. The Duobblon project is the largest with an inferred

* Report prepared by the NEA/IAEA, based on previous Red Books and company reports.

resource of 3 370 tU grading 0.024% U. In addition to these small epigenetic vein, fracture and intrusive-related uranium deposits, some companies are reassessing the potential of the low-grade polymetallic black shales of central Sweden.

In late 2009, Aura Energy applied for significant landholdings to investigate some of these low-grade aluminium shales. The company initially reported a JORC compliant in situ inferred resource at its Häggån Project of 111 933 tU at 0.013% U. This was subsequently upgraded to 307 692 tU. Further increases can be expected, since the existing resource estimate is based on 15% of the Häggån Project area. A scoping study was completed that examined a range of heap leach options, including bio-heap leaching, with positive results reported. Aura and Areva (now Orano) entered into a binding co-operation agreement in February 2013. However, after completing due diligence on the project, Areva announced in July 2013 that it would not proceed with a proposed partnership to develop the Häggån uranium and polymetallic project. In December 2013, Aura decided that, given the current market conditions, a reassessment should be made of the 2012 Häggån Scoping Study on smaller scales more likely to attract funding. The company considered three smaller size options: 3.5 Mtpa, 5.0 Mtpa and 7.5 Mtpa, which could be used to provide a development alternative with a substantially lower front-end capital cost requirement. Aura concluded that the remodelling demonstrated robust project financials at all scales of operation.

Recent and ongoing uranium exploration and mine development activities

There are currently no uranium exploration activities in Sweden. Following the ban on uranium exploration and mining in 2018, Australia's Aura Energy, which owns the polymetallic Häggån project, lodged a claim in 2019 against the Swedish government for compensation for the financial loss. In the same year, they completed a new scoping study focusing on vanadium only, with no plans to recover uranium.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

As of 1 January 2019, Sweden’s total identified conventional recoverable resources are 9 595 tU and have not changed since the estimates reported in the 2014 Red Book edition.

Undiscovered conventional resources (prognosticated and speculative resources)

Neither prognosticated nor speculative resources are reported in Sweden.

Unconventional resources and other materials

In past editions of the Red Book, the potential for very large, low-grade resources of uranium in the aluminium shale/schists was noted. Resources associated with black shales/schists amount to 1 054 300 tU (includes the Haggan deposit, 307 692 tU; MMS Viken, 447 308 tU; Tasjo, 42 300 tU; and Narke uranium oil, 257 000 tU). These are significant unconventional uranium resources that potentially could be available to the market in future years if, for example, the costs of production of the bio-heap leaching technology under evaluation could justify economic production. Some of the deposits also contain high values of V, Mo, Ni and Zn.

Uranium production

Historical review

In the 1960s, a total of 200 tU were produced from the aluminium shale deposit in Ranstad that represents all of Sweden’s historical production. This mine is now being remediated to protect the environment.

Status of production capability

There is currently no uranium production in Sweden.

Future production centres

Aura's Häggån Project consists of 110 km^2 in the Storsjön District in Sweden. Uranium occurs along with molybdenum, nickel, vanadium and zinc in black shales that form a 20 to 250 m thick nearly continuous sheet throughout the area drilled by Aura during 2008-2011 programmes. A Scoping Study was completed in February 2012 by independent consultants RMDSTEM Limited using initial pit shells containing >741 Mt ore with much of the prospective area remaining in the tenements untested by drilling. The two stages of bio-heap leaching test work show up to 85% uranium extraction, as well as 58% nickel and 18% molybdenum. An annual production rate of 3 000 tU was considered. However, in December 2013, the results of remodelling the 2012 scoping study indicated that smaller size options were more likely to attract funding than a project with a high initial capital cost.

Secondary sources of uranium

Production and/or use of mixed oxide fuels

Sweden does not currently use mixed oxide fuel or reprocessed uranium.

Environmental activities and socio-cultural issues

The Ranstad mine was remediated in the 1990s at a total cost of SEK 150 million (about USD 20 million). As of March 2019, most of the activities for remediation had been completed and an application for site release is under review by the Swedish Radiation Safety Authority.

Uranium requirements

In response to costly post Fukushima safety upgrades as well as upgrades due to long term operation and reduced profitability, two reactors were permanently shut down, Oskarshamn 2 in 2015 and Oskarshamn 1 in 2017. The operators of the nuclear power plants have indicated the shutdown of two additional reactors, one in 2019 (Ringhals 2) and the second in 2020 (Ringhals 1).

As of 1 January 2019, eight reactors were connected to the grid and provided about 42% of the electricity generated in 2018, which required about 1 200 tU annually.

Following the 2014 election, the new coalition government invited parties across the parliament to participate in a multiparty energy commission, whose members in June 2016 announced an overall agreement on Swedish energy policy with a final report published on 9 January 2017. The agreement included the aim of 100% renewable electricity production by 2040. However, this does not preclude the operation of nuclear reactors after 2040. The agreement also confirmed (1) existing legislation, which allows new nuclear power reactors to be built at existing reactor sites to replace existing and closed reactors, and (2) that there is no longer an "end date" for nuclear energy in Sweden.

Supply and procurement strategy

The utilities are free to negotiate their own purchases.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

On 1 August 2018, a new law entered into force that prohibits uranium mining activities in Sweden. It is no longer possible to grant licences for exploration, exploitation or extraction, processing, or physical or chemical enrichment of uranium for the purposes of using its fissile characteristics.

At the same time, due to a change in the Minerals Act, uranium was removed from the list of concession minerals. This means that uranium will not be included in applications for exploration permits or exploitation concessions that come in from that date. Older regulations will still apply to applications granted before 1 August 2018 as stated by the transitional provisions. Cases of exploration permits and cases of renewal of exploration permits initiated by the Chief Mining Inspector before that date will also be subject to older regulations in accordance to the transitional provisions. Thus, it is not possible to grant either an application for an exploration permit or an exploitation concession for uranium if the application has been submitted to the Mining Inspectorate after 31 July 2018.

Uranium stocks

The Swedish parliament decided in 1998 to replace the previous obligation that utilities had to keep a stockpile of enriched uranium corresponding to the production of 35 TWh with a reporting mechanism. Sweden reports no information on uranium stocks.

Uranium prices

As Sweden is now part of the deregulated Nordic electricity market, costs of nuclear fuel are no longer reported.

Reasonably assured conventional resources by production method

(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified			4 870	4 870	75
Total			4 870	4 870	

Reasonably assured conventional resources by processing method

(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified			4 870	4 870	75
Total			4 870	4 870	

Reasonably assured conventional resources by deposit type

(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Granite-related			3 186	3 186
Volcanic-related			412	412
Metasomatite			1 272	1 272
Total			4 870	4 870

Inferred conventional resources by production method
(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified			4 725	4 725	75
Total			4 725	4 725	

Inferred conventional resources by processing method
(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unspecified			4 725	4 725	75
Total			4 725	4 725	

Inferred conventional resources by deposit type
(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Granite-related			452	452
Volcanic-related			3 635	3 635
Metasomatite			638	638
Total			4 725	4 725

Historical uranium production by production method
(tonnes U in concentrates)

Production method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Open-pit mining[1]	200	0	0	0	200	0
Total	200	0	0	0	200	0

1. Pre-2015 totals may include uranium recovered by heap and in-place leaching.

Historical uranium production by processing method
(tonnes U in concentrates)

Processing method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Conventional	200	0	0	0	200	0
Total	200	0	0	0	200	0

Historical uranium production by deposit type
(tonnes U in concentrates)

Deposit type	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Black shale	200	0	0	0	200	0
Total	200	0	0	0	200	0

Net nuclear electricity generation

	2017*	2018**
Nuclear electricity generated (TWh net)	63.0	65.8

* NEA (2019), *Nuclear Energy Data*, OECD Publishing, Paris.

** Preliminary data, NEA (2019), *Nuclear Energy Data*, OECD Publishing, Paris.

Installed nuclear generating capacity to 2040*

(MWe net)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
8 600	8 600	7 700	NA	NA	6 800	NA	6 800	NA	6 800	NA	6 800

* NEA (2019), *Nuclear Energy Data*, OECD Publishing, Paris.

Annual reactor-related uranium requirements to 2040 (excluding MOX)*

(tonnes U)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
1 200	1 200	NA	1 100	900	1 050	900	1 050	900	1 050	500	1 050

* NEA (2019), *Nuclear Energy Data*, OECD Publishing, Paris.

Tanzania*

Uranium exploration and mine development

Historical review

Uranium was first discovered in Chiwiligo pegmatite in the Uluguru Mountains in 1953. The first general evaluation of uranium potential of Tanzania was a country-wide airborne geophysical survey for the government between 1976 and 1979. Results revealed a large number of radiometric anomalies in a variety of geological settings.

A uranium exploration programme was subsequently carried out by Uranerzbergbau GmbH between 1978 and 1983, but ended because of declining uranium prices. Targets of this survey were anomalies in the Karoo, in younger surficial sediments, in phosphatic sediments of Pleistocene age and carbonatite of the Gallapo. Numerous occurrences of surface uranium mineralisation have been identified and there is potential for several uranium deposit types in the country.

Interest in uranium exploration was revived after the rise of uranium prices in 2007 and the Tanzanian government issued over 70 licences. Major exploration activities were focused on identification of sandstone-type uranium deposits in the Karoo Basin in the southern part and surficial-type deposits in the central part of the country.

Since 2007, three companies discovered four uranium deposits and identified JORC and NI-43/101 compliant uranium resources (measured, indicated and inferred) presented in the following table below. Total in situ resources amounted to 72 756 tU, including 49 596 tU in measured and indicated categories.

In situ uranium resources of Tanzania (UDEPO, 2013*; company reports)

Deposit name	Resources (tU)		Grade (% U)	Estimated in	Type	Subtype	Current owner
	Measured + indicated	Inferred					
Likuyu North		2 346	0.020	2011	Sandstone	Tabular	Uranex NL
Manyoni (Bahi)	1 669	9 477	0.012	2010	Surficial	Lacustrine-playa	Uranex NL
Mtonya		775	0.022	2013	Sandstone	Tabular/ roll-front	Uranium Resources Inc.
Nyota (Mkuju River)	47 927	10 562	0.026	2013	Sandstone	Tabular	Mantra/ Uranium One

* World Distribution of Uranium Deposits (UDEPO) – https://infcis.iaea.org/UDEPO/About.

Note: The largest deposit so far is the Nyota deposit, part of the Mantra/Uranium One Mkuju River Project.

Over 80% of the resources total relates to the large Nyota sandstone-type deposit, also known as Mkuju River Project. The systematic exploration at Nyota started in 2007 and in 2009 a maiden inferred resource estimate of 13 800 tU (35.9 Mlbs U_3O_8) and a pre-feasibility study were released. In 2011, Mantra Resources was acquired by the Russian Atomredmetzoloto and Uranium One Inc.

* Report prepared by the NEA/IAEA based on previous Red Books and company reports.

was appointed as the project operator. An update of in situ resources of the Nyota deposit estimate in September 2011 boosted total in situ resources to 45 924 tU (119.4 Mlbs U_3O_8) and formed the basis of a feasibility study. During 2012 and 2013, Mantra Resources continued exploration focused on new resource estimates and engineering optimisation.

Drilling activities and analysis of historical data resulted in a further in situ resource increase in June 2013 to 58 489 tU (152.1 Mlbs U_3O_8), including 124.6 Mlbs U_3O_8 (47 927 tU) in the measured and indicated categories at an average grade of 303 ppm U_3O_8 (0.0257% U). The Mkuju River feasibility study was completed in 2013 and the Tanzanian government issued a special mining licence (SML) to Mantra for project development. During 2013-2014, the main exploration activities of Mantra Resources focused on verifying Nyota deposit resources and on-site push-pull testing to identify amenability of the principal mineralisation to ISL mining.

Exploration drilling by Uranex at the Likuyu North deposit during 2009-2012 identified a maiden resource at 6.1 Mlb U_3O_8 (2 346 tU) with an average grade of 237 ppm U_3O_8 (0.02% U) reported at a 100 ppm U_3O_8 (0.0085% U) cut-off grade.

In 2010, Uranex reported resources of 11 146 tU in a shallow Manyoni deposit, also known as the Bahi project. The region incorporates an extensive closed draining system developed over weathered uranium rich granites. This drainage captures dissolved uranium leached from underlying rocks and transports it to suitable precipitation trap sites (playa lakes). The Manyoni Project encompasses up to five playa lakes.

Uranium Resources Plc. in 2013 announced the maiden resource of 3.6 Mt ore containing 2.014 Mlb U_3O_8 (775 tU) at a grade of 255 ppm U_3O_8 (0.00216% U) at the Mtonya deposit. The uranium mineralisation occurs to depths of 350 m in continuous 30 to 50 metre-wide roll fronts. The resource is potentially amenable to the in situ leach recovery mining method.

Recent and ongoing uranium exploration and mine development activities

Major 2015-2017 activities at the Nyota deposit were focused on additional investigations to test the amenability of the ISL extraction of resources. In 2015, Mantra Resources obtained official approval and started a more advanced hydrogeology and two spot ISL tests. The laboratory tests resulted in high uranium recoveries with acceptable values of uranium content in sulphuric acid solutions, acid consumption and liquid-to-solid ratio. The results of the hydrogeological test confirmed good aquifer permeability. The ISL test was conducted over ten months in 2016 using a two-well pattern and the final report was issued in 2017. The results confirmed the amenability of ISL mining for the portion of the resources located below the water table. During 2017, rehabilitation of aquifers and the surface was completed after ISL tests.

No other companies have reported other uranium related exploration activities in Tanzania since 2017.

Identified conventional resources (reasonably assured and inferred resources)

There are no changes in Tanzanian uranium resources since the previous report. Total identified in situ uranium resources from four deposits in Tanzania amount to 72 756 tU. Over 80% of the total relates to the Nyota sandstone deposit at the Mkuju River Project. It contains 47 927 tU of in situ measured and indicated resources and 10 562 tU of inferred resources all in the <USD 80/kgU cost category. The Manyoni playa lake calcrete deposits make up 11 146 tU of identified resources, of which 9 477 tU is inferred. The remaining inferred resources include two sandstone-type deposits: Likuju North with 2 346 tU and the Mtonya deposit, which comprises 775 tU and is potentially amenable to ISL extraction. An 80% recovery factor was applied to convert all in situ resources into recoverable resources.

Undiscovered conventional resources (prognosticated and speculative resources)

Undiscovered resources are not reported. There is, however, a high potential for sandstone-type uranium deposits in Karoo sediments in several areas of Tanzania.

Uranium production

There has been no uranium produced in Tanzania.

Future production centres

The Mkuju River feasibility study was completed in 2013 and the Tanzanian government issued an SML to Mantra for project development. Front-end engineering and design (FEED) and Pre-FEED initiatives continued until June 2014.

According to the current definitive feasibility study the resources will be mined in multiple pits feeding a single mill with conventional acid leach and resin-in-pulp recovery. Sulphuric acid ISL mining may be employed, particularly for about 15% of resources lying outside designed pits and below the water table. One-third of the total resource is situated below the water table, so the ISL potential could be greater.

Activities at the project during 2015 and 2016 focused on an ISL pilot test programme. ISL could prove to be an alternative extraction method for the Mkuju River Project and similar ore bodies in the region.

In late December 2016, Mantra Resources applied to the Ministry of Energy and Minerals of Tanzania (MEM) for suspension of its SML due to the unfavourable uranium market. In September 2017, the Ministry approved an amendment to the SML, which permits construction work to start in 2020. During 2018 and 2019, Mantra Resources and MEM negotiated on conditions for a further suspension of the SML. Development of the project was postponed until uranium demand increases, which is expected not earlier than 2020. Current activity at the Mkuju River Project is focused on preparatory operations and research work to determine applicability of ISL recovery.

Uranium production centre technical details

(as of 1 January 2019)

	Centre #1
Name of production centre	Mkuju River
Production centre classification	Prospective
Date of first production (year)	NA
Source of ore:	
Deposit name(s)	Nyota
Deposit type(s)	Sandstone
Recoverable resources (tU)	31 700
Grade (% U)	0.0425
Mining operation:	
Type (OP/UG/ISL)	OP
Size (tonnes ore/day)	18 000
Average mining recovery (%)	90
Processing plant:	
Acid/alkaline	Acid
Type (IX/SX)	Resin-in-pulp
Size (tonnes ore/day) For ISL (mega or kilolitre/day or litre/hour, specify)	18 000
Average process recovery (%)	85
Nominal production capacity (tU/year)	3 000
Plans for expansion (yes/no)	no
Other remarks	ISL option not assumed

Environmental activities and socio-cultural issues

The Tanzanian government has worked to allay public concerns over the prospect of uranium mining. The environmental, health, economic and social impacts are to be carefully considered and the government indicated that it is aware of the high safety standards required for uranium mining in order to protect people and the environment.

Elephant poachers have taken advantage of the road constructed for access to Mkuju River uranium project, located in the area excised from the Selous Game Reserve. In May 2014, the operator entered into a memorandum of understanding with the Ministry of Natural Resources and Tourism to conduct combined anti-poaching initiatives. The UNESCO World Heritage Committee is monitoring the situation since all of its demands must be met in order to fulfil the Mkuju River Project requirements.

National policies relating to uranium

In 2010, the Tanzanian government substantially amended the Mining Act of 1998. The revised act increased royalty payments for mineral extraction on the gross value of minerals produced (from 3% to 5% for uranium) and mandated the government the ability to acquire shareholdings in future mining projects through a development agreement negotiated between the government and the mineral rights holder. The Parliamentary Committee for Energy and Minerals in Tanzania has directed that no mining of uranium can take place until a policy and legislation on extraction are in place.

The IAEA conducted a Uranium Production Site Appraisal Team review in 2013, providing recommendations to the country, a newcomer to uranium mining, in the application of international good practices and preparations for planned uranium mining activities. The scope of the appraisal process included exploration, resource assessment, planning, environmental and social impact assessment, mining, processing, waste management, site management, remediation and final closure.

Reasonably assured conventional resources by production method

(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)		38 342	39 677	39 677	80
Total		38 342	39 677	39 677	80

Reasonably assured conventional resources by processing method

(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from OP		38 342	39 677	39 677	80
Total		38 342	39 677	39 677	80

Reasonably assured conventional resources by deposit type

(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone		38 342	38 342	38 342
Surficial			1 335	1 335
Total		38 342	39 677	39 677

Inferred conventional resources by production method
(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)		8 450	17 908	17 908	80
In situ leaching acid			620	620	80
Total		8 450	18 528	18 528	80

Inferred conventional resources by processing method
(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from OP		8 450	17 908	17 908	80
In situ leaching acid			620	620	80
Total		8 450	18 528	18 528	80

Inferred conventional resources by deposit type
(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone		8 450	10 946	10 946
Surficial			7 582	7 582
Total		8 450	18 528	18 528

Short-term production capability
(tonnes U/year)

2020				2025			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
0	0	0	0	0	0	0	0

2030				2035				2040			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
0	0	0	0	0	2 000	0	2 000	0	NA	0	3 000

Thailand

Uranium exploration and mine development

Historical review

Uranium exploration was carried out in the early 1970s by the Royal Thai Department of Mineral Resources (DMR). Uranium occurrences were found in various geological environments including sandstone and granite host rocks. Sandstone-type mineralisation occurs in the Phu Wiang district of the Khon Kaen province, northeastern Thailand. This area was first independently investigated by the DMR, then in co-operation with foreign organisations. Granite-hosted uranium occurrences associated with fluorite, discovered in the Doi Tao district, Chiang Mai province and the Muang district of Tak province (northern Thailand), have received the most attention.

The most important uranium exploration activity carried out in Thailand is the nationwide airborne geophysical survey completed between 1985 and 1987, covering an area of approximately 570 000 km^2. The survey was conducted by Kenting Earth Sciences International Limited of Canada under a contract with DMR. In 1994, based on available data, a series of airborne radioactive maps were generated and a uranium potential map was produced.

Based on the preliminary results of reconnaissance/regional surveys, exploration activities for rare earth elements (REE) were started in 2011 by the DMR. Associated uranium and thorium concentrations occurring within granitic weathering crusts have been determined in some working areas.

Recent and ongoing uranium exploration and mine development activities

Despite the identification of REE and associated radioactive elements through exploration, there is no direct ongoing uranium exploration or mine development activities in any part of Thailand. From 2017 to 2018, DMR conducted reconnaissance/regional survey activities for REE in various parts of Thailand in order to define areas of high potential, focusing on granitic weathering crusts. According to the preliminary results, the associated uranium and thorium concentrations occurring along the weathering profiles have been identified in the vicinities of Mae Hong Son, Chiang Mai and Tak provinces.

In 2017, the study area included the granitic exposures in Galyanivadhana, Omkoi and Doi Tao districts of Chiang Mai, and the Pai district of Mae Hong Son. Four REE-Th-U deposits were delineated at Pambok and Pongkhao-Watchan in Mae Hongson, and Mae Lai Daungchan and Yangkok in Chiang Mai.

In 2018, the study area included the granitic exposures in the Khun Yuam, Mae Lanoi and Mae Sariang districts of Mae Hong Son and Ban Tak, and the Sam Ngao and Mueang districts of Tak. Four REE-Th-U deposits were identified in Mae Hongson: Hwa No (within an area of 25 km^2), Huai Mai Sang (6 km^2), La-ub (39 km^2) and Mae Umpkok (24 km^2).

In 2019, exploration for REE was put on hold due to budget constraints.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

Inferred resources amounting to a total of 14.5 tU (in situ) have been identified in the Phu Wieng sandstone-type deposit (4.5 tU at 0.05% U), and the Doi Tao (5 tU at 0.04% U) and Doi Chang (5 tU at 0.017% U) granite-related deposits.

Undiscovered conventional resources (prognosticated and speculative resources)

Undiscovered conventional resources have not been estimated.

Unconventional resources and other materials

A study in uranium extraction from Thailand's seawater has been ongoing since the end of 2011. To date, no U_3O_8 has been separated and purified. The objective of the study is to improve the extraction technique, rather than to recover uranium.

In 2017, total unconventional prognosticated resources of 66 450 tonnes (t) UO_2 (58 576 tU) and 216 940 t ThO_2 were roughly estimated from the weathering horizons above the underlying granitic basement in the exploration target areas. The estimated uranium resources (UO_2) of the deposits are: 1) 18 460 t (at 28.7 ppm) for Pambok; 2) 24 480 t (at 17.2 ppm) for Pongkhao-Watchan; 3) 760 t (at 12.2 ppm) for Mae Lai Daungchan; and 4) 22 750 t (at 10.0 ppm) for Yangkok. The estimated Th resources (ThO_2) of the deposits are: 1) 80 550 t (at 122.2 ppm) for Pambok; 2) 72 890 t (at 50.6 ppm) for Pongkhao-Watchan; 3) 3 200 t (at 52.1 ppm) for Mae Lai Daungchan; and 4) 60 300 t (at 33.4 ppm) for Yangkok.

In 2018, additional total unconventional prognosticated resources of 83 330 tUO_2 (73 429 tU) and 291 520 tThO_2 were roughly estimated from thick weathering horizons overlying the granitic basement. The estimated uranium resources (UO_2) of the deposits are: 1) 21 990 t (at 19.2 ppm) for Hwa No; 2) 4 760 t (at 19.8 ppm) for Huai Mai Sang; 3) 39 410 t (at 19.0 ppm) for La-ub; and 4) 17 170 t (at 17.1 ppm) for Mae Umpkok. The estimated Th resources (ThO_2) of the deposits are: 1) 69 480 t (at 60.2 ppm) for Hwa No; 2) 17 260 t (at 69.5 ppm) for Huai Mai Sang; 3) 139 390 t (at 66.3 ppm) for "La-ub"; and 4) 65 390 t (at 65.1 ppm) for Mae Umpkok.

Therefore, roughly estimated unconventional uranium (prognosticated) resources of Thailand total approximately 132 000 tU, and belong to 8 REE-Th-U deposits.

Uranium production

Historical review

There has been no historical uranium production in Thailand.

Status of production facilities, production capability, recent and ongoing activities and other issues

There are no past or current production facilities in Thailand.

Ownership structure of the uranium industry

NA.

Employment in the uranium industry

None.

Future production centres

In the future, if uranium extraction from seawater becomes economically competitive, the Electricity Generating Authority of Thailand (EGAT) may consider investment in a production centre. However, at the present time, there is no plan for the foreseeable future.

Secondary sources of uranium

Production and/or use of mixed oxide fuels

There is no production or use of mixed oxide fuels in Thailand.

Production and/or use of re-enriched tails

There is no production or use of re-enriched fuels in Thailand.

Production and/or use of reprocessed uranium

There is no production or use of reprocessed uranium in Thailand.

Regulatory regime

There is no regulatory regime for uranium mining in Thailand because there is no uranium industry. The Office of Atoms for Peace (OAP) is the regulator on the use of atomic energy in Thailand. If there is a uranium mining industry in Thailand in the future, OAP will most likely be the main agency responsible for regulation.

Uranium requirements

According to Thailand's Power Development Plan 2015 (PDP 2015), which covers the years 2015-2036, the first two nuclear power plants will be connected to the electricity grid in 2035 and 2036. Each unit would produce about 1 000 MWe. However, the government has not made any formal decision to begin construction.

Supply and procurement strategy

All fuel assemblies for future nuclear power plants will be purchased from overseas suppliers and there is no future procurement strategy. There is no plan in the foreseeable future to set up a fuel production plant in Thailand.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

Although there is no government policy on uranium, there are laws and regulations on the use of atomic energy and radioactive materials. Uranium import and export is included in these laws. The laws are the Atomic Energy for Peace Act B.E. 2504 (1961) and the Ministerial Act on Licensing and Management Procedures for Special Nuclear Materials B.E. 2550 (2007).

Uranium stocks

There is no uranium stock for use in nuclear power reactors in Thailand.

Inferred conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	0	4.5
Granite-related	0	0	0	10.0
Total	0	0	0	14.5

Installed nuclear generating capacity to 2035

(MWe net)

2011	2012	2013		2015		2020		2025		2030		2035	
		Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
0	0	0	0	0	0	0	0	0	0	0	0	0	1 000

Annual reactor-related uranium requirements to 2035 (excluding MOX)

(tonnes U)

2011	2012	2013		2015		2020		2025		2030		2035	
		Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
0	0	0	0	0	0	0	0	0	0	0	0	0	160

Note: No first core load for the new plant is included in the uranium requirements data. The uranium requirement figures provided do not include plans to build an inventory of uranium.

Turkey

Uranium exploration and mine development

Historical background

Uranium exploration in Turkey began in 1956-1957 and was directed towards the discovery of vein-type deposits in crystalline terrain, such as acidic igneous and metamorphic rocks. As a result of these activities, some uneconomic occurrences of pitchblende mineralisation were found. Since 1960, studies have been conducted in sedimentary rocks that surround the crystalline rocks, and some small orebodies containing autunite and torbernite mineralisation have been found in various parts of the country. In the mid-1970s, the first uranium deposit was found in the Koprubaşı area of Manisa, consisting of black coloured ore located below the water table. After 2010, the Avanos-Gülşehir and Malatya-Kuluncak uranium fields were discovered by the General Directorate of Mineral Research and Exploration (MTA). Resources increased after intensive exploration and drilling operations by MTA and the private sector. By the end of 2019, a total of 19 736 tonnes U_3O_8 (16 736 tU) of in situ resources were identified in the Manisa-Köprübaşı (3 550 tonnes U_3O_8; 3 011 tU), Uşak-Eşme (490 tU_3O_8; 415 tU), Aydın-Koçarlı (208 t U_3O_8; 176 tU), Aydın-Söke (1 729 t U_3O_8; 1 466 tU), Yozgat-Sorgun (6 025 t U_3O_8; 5 109 tU) and Avanos-Gülşehir (7 734 t U_3O_8; 6 559 tU) regions.

The state-owned organisation, General Directorate of Eti Mining Operations (Eti Maden), is responsible for the exploration and development activities of five uranium deposits with identified resources. Geological exploration has been performed at these sites in the past by the General Directorate of Mineral Research and Exploration (MTA). Between 1960-1980, uranium exploration included aerial prospecting, general and detailed prospecting, geologic mapping and drilling. The uranium deposits were transferred from MTA to Eti Maden as potential mines, which can be operated by the state under Law No. 2840, "Operation of Boron Salts, Trona and Asphaltite Mines and Nuclear Energy Raw Materials", issued on 10 June 1983.

Recent and ongoing uranium exploration and mine development activities

In 2017, granite, acidic igneous and sedimentary rocks around Edirne, Kırklareli and Tekirdağ (an area of approximately 3 000 km^2) were explored for radioactive raw materials. Exploration was also performed in sites licensed by MTA inside Nevşehir and Aydın.

In 2018, granite, acidic igneous and sedimentary rocks around Edirne, Kırklareli and Tekirdağ (an area of approximately 3 460 km^2) were explored for radioactive raw materials. Exploration was also performed in sites licensed by MTA in the Nevşehir and Çanakkale provinces.

In 2019, granite, acidic igneous and sedimentary rocks around the Thrace Basin (Edirne, Kırklareli and Tekirdağ provinces), Çanakkale, Nevşehir, Giresun and Aydın provinces were explored for radioactive raw materials. Drilling in sites licensed by MTA inside the Thrace Basin, Nevşehir and Çanakkale provinces was completed. The exploration work will continue in 2020.

MTA initiated a drilling programme to confirm previous work and develop ore resources at the Manisa-Köprübaşı exploration site. As of 11 July 2019, a total of 12 203 m of drilling had been carried out in 135 drill holes, including 2 562 m in 18 holes in 2018 and 9 641 m in 117 wells in 2019. Drilling is planned to continue at the Uşak-Eşme/Fakılı, Aydın-Söke and Aydın-Nazilli sites through 2019 and 2020.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

In 2015 and 2016, an additional 698 tU_3O_8 (592 tU) of in situ resources were added to the original estimate of the Manisa-Köprübaşı area by MTA. In 2019, an additional 7 734 t U_3O_8 (6 559 tU) of resources were added to the Avanos-Gülşehir deposit. These recently identified resources occur within the Tertiary sediments and limestones.

Identified in situ conventional uranium resources in Turkey, determined from exploration activities performed by MTA in the past, with the addition of JORC compliant resources identified through recent work by Adur (a wholly-owned subsidiary of Anatolia Energy, a private Turkish uranium exploration company), are described in more detail below:

- Manisa-Köprübaşı: 3 011 tU in ten orebodies and at grades of 0.04-0.05% U_3O_8 (0.034-0.042% U) in fluvial Neogene sediments;
- Uşak-Eşme: 415 tU at 0.044% U_3O_8 (0.037% U) in Neogene lacustrine sediments;
- Aydın-Koçarlı: 176 tU at 0.05% U_3O_8 (0.042% U) in Neogene sediments;
- Aydın-Söke: 1 466 tU at 0.08% U_3O_8 (0.068% U) in gneiss fracture zones;
- Avanos-Gülşehir: 6 559 tU 0.05% U_3O_8 (0.042% U) in Eocene sediments.

The Temrezli (Yozgat/Sorgun) uranium deposit is one of Turkey's largest and highest-grade uranium deposits, with a JORC compliant in situ mineral resource estimate of 13 282 Mlb U_3O_8 (5 109 tU) at an average grade of 0.116% U_3O_8 (0.01% U) and an average depth of 120 m. A detailed mineral resource estimate follows:

Resource category	Tonnes	Grade (ppm U_3O_8)	Contained resources (pounds U_3O_8)	Contained resources (tonnes U)
Measured*	2 008 000	1 378	6 100 000	2 346
Indicated*	2 178 000	1 080	5 185 000	1 994
Inferred*	1 020 000	888	1 997 000	768
Total resource*	5 206 000	1 157	13 282 000	5 109

* Numbers rounded for reporting purposes.

Undiscovered conventional resources (prognosticated and speculative resources)

- Temrezli Project: The exploration drilling will continue and is expected to potentially increase the resource by an additional 400 to 1 200 tU.
- Sefaatli Prospect: Exploration and development drilling conducted in 2015 is expected to increase the known uranium resource by approximately 2 000-2 300 tU. The recent drill results include an intersection of 1.1 m of uranium mineralisation at a grade of 2 150 ppm U_3O_8 (0.18% U) at a depth from 39 m below surface.

Uranium production

Historical review

Research on laboratory-scale production of uranium and nuclear fuel was performed in the past as a part of the Seventh National Development Plan of the Republic of Turkey between 1996 and 2000.

Status of production facilities, production capability, recent and ongoing activities and other issues

None reported.

Environmental activities and socio-cultural issues

Uranium exploration is assessed within the scope of Article 55 of the Annex-II list in the by-law on environmental impact assessment (EIA) by the Ministry of Environment and Urbanisation. Mine production activities for 25 ha and above, together with the mine enrichment activities, are evaluated within the scope of the Annex-I list of the EIA by-law.

Regulatory regime

The Nuclear Regulatory Authority (NDK), as the regulatory authority of Turkey, undertakes regulatory activities concerning facilities, including nuclear power plants, devices, substances, and activities related to nuclear energy and ionising radiation. NDK was established by decree having the force of Law No. 702 dated 2 July 2018 as an independent authority associated with the Ministry of Energy and Natural Resources.

In Turkey, nuclear installations are licensed by NDK regarding nuclear safety, security and radiological protection issues. Before NDK, the Turkish Atomic Energy Authority (TAEK) was the licensing authority according to Law No. 2690, which regulated duties and responsibilities of TAEK as a regulatory body.

NDK was founded in July 2018, with the Decree of Law No. 702, and became the regulatory authority of Turkey. Within the same month, Presidential Decree, No. 4 dated 15 July 2018, came into force. Duties and responsibilities of NDK were determined and TAEK was reorganised as a research and development and technical support service organisation. As a part of the transition process, NDK issues new regulations according to the new licensing system. For the time being, the authorisation process of nuclear installations will continue as follows:

- The existing authorisation applications will be concluded following the provisions of the legislation in force (decrees, regulations, etc.) until the new regulations are issued according to Decree Law No. 702. In this context, the implementation of the Decree on Licensing of Nuclear Installations, which is the main legislation used for licensing, will continue. The references to TAEK in the applicable legislation are deemed to have been made to NDK.
- The licensing procedure for nuclear fuel cycle facilities is laid out in the Decree on Licensing of Nuclear Installations. According to this decree, nuclear fuel cycle facilities are:
  - mining, milling and refining facilities;
  - conversion facilities;
  - enrichment facilities;
  - nuclear fuel element fabrication facilities;
  - reprocessing facilities for used fuel elements;
  - radioactive waste management facilities for processing radioactive waste (including final storage).

The licensing procedure for nuclear fuel cycle facilities is initiated by an application from the owner. The licensing process comprises three main stages in succession: site licence, construction licence and operating licence. There are several permits required during the licensing process, such as a limited work permit, a permit to start test operations, a pre-operational test permit, a full capacity work permit, permission to restart operations and permission to modify the installation. For each authorisation the documents required for review and assessment by NDK are defined in the decree.

Uranium requirements

There are no nuclear power plants in operation or decommissioning. However, two reactors are under construction in Turkey. Turkey has considered building a nuclear power plant since the 1970s. Rising energy demand, import dependence and industrial activity are the driving forces behind Turkey's move towards developing a civil nuclear power generation programme.

Turkey's recent efforts in this area can be characterised as a first-of-a-kind approach in the nuclear sector and have been referred to as an intergovernmental agreement (IGA) model, with long-term contracts of power purchase agreements. In this approach, a project company undertakes to design, build, operate and maintain a power plant, whereas the Turkish government is responsible for providing the site, various financial and non-financial guarantees, construction support and licensing. The project company is also responsible for managing wastes and decommissioning the facility.

The construction and operation of a nuclear power plant, through a co-operation agreement between the Government of Russia and the Government of Turkey, is being carried out at Akkuyu, Mersin Province, Turkey. The Akkuyu NPP project plans the construction of four VVER-1200 reactors with a total capacity of 4 800 MWe.

Under the construction schedule, the following dates are planned for the commissioning of the Akkuyu NPP power units into operation:

- Unit No l – 2023;
- Unit No 2 – 2024;
- Unit No 3 – 2025;
- Unit No 4 – 2026.

Turkey also signed a Memorandum of Understanding (MOU) with Japan on 3 May 2013 to build four ATMEA1 units at the Black Sea Sinop site. The technical and economic feasibility studies for the Sinop NPP were completed in July 2018 and submitted to MENR for evaluation. After a detailed evaluation of the Feasibility Report, Turkey has decided to not continue the Sinop NPP project.

The site selection for the third NPP project is ongoing.

Supply and procurement strategy

Under the Agreement between the Government of the Russia and the Government of Turkey on co-operation in the construction and operation of the Akkuyu nuclear power plant, Akkuyu Nuclear Joint-Stock Company and TVEL signed a contract for nuclear fuel supply in 2017.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

The law on the "Operation of Boron Salts, Trona and Asphaltite Mines and Nuclear Energy Raw Materials" No. 2840, dated 10 June 1983, states that the exploration and mine operation are to be carried out by the state.

The Amendment No 6592 (dated 4 February 2015) to Mining Law No. 3213 (dated 4 June 1985) supersedes Law No. 2840, and classifies uranium under the section of the 4th group of minerals together with all other radioactive minerals. Article 50 of the Mining Law states that exploration and operation of thorium and uranium minerals are subject to the Mining Law and the minerals extracted can only be sold to the state or entities determined by the President.

The Ministry cancelled a total of 13 exploration and operational licences related to four companies in July 2018 due to legal requirements not being fulfilled. One of the companies has disputed the decision of the cancellation of the licences and brought an arbitration case against Turkey before the International Centre for Settlement of Investment Disputes. The case is still pending.

Uranium stocks

Uranium stocks in Turkey consist of natural uranium used by the Technology Development Department of the Turkish Atomic Energy Authority for research purposes.

Uranium exploration and development expenditures and drilling effort – domestic

(TRY [Turkish lira] – excluding VAT)

	2016	2017	2018	2019
Government exploration expenditures	643 394	2 702 091	13 709 537	82 193 522
Total expenditures	643 394	2 702 091	13 709 537	82 193 522
Government exploration drilling (m)	3 489	13 368	110 012	198 613
Government exploration holes drilled	19	50	310	484
Subtotal exploration drilling (m)	3 489	13 368	110 012	198 613
Subtotal exploration holes drilled	19	50	310	484
Total drilling (m)	3 489	13 368	110 012	198 613
Total number of holes drilled	19	50	310	484

Reasonably assured resources by production and processing method

(tonnes U*)

Production method	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
ISL	0	4 341	4 341
Total	0	4 341	4 341

* In situ resources.

Reasonably assured resources by deposit type

(tonnes U*)

Deposit type	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	4 341	4 341
Total	0	4 341	4 341

* In situ resources.

Inferred resources by production method

(tonnes U*)

Production method	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Conventional OP	0	10 161	10 161
ISL	0	768	768
Unspecified	0	10 929	12 395
Total	0	10 929	12 395

* In situ resources.

Inferred resources by processing method

(tonnes U*)

Production method	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Conventional OP	0	10 161	10 161
ISL	0	768	768
Unspecified	0	0	1 466
Total	0	10 929	12 395

* In situ resources.

Inferred resources by deposit type

(tonnes U*)

Production method	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	4 370	4 370
Metamorphite	0	0	1 466
Carbonate	0	6 559	6 559
Total	0	10 929	12 395

* In situ resources.

Installed nuclear generating capacity to 2035

(MWe net)

2019		2020		2025		2030		2035	
Low	High	Low	High	Low	High	Low	High	Low	High
0	0	0	0	1 200	2 400	4 800	4 800	4 800	4 800

Annual reactor-related uranium requirements to 2035 (excluding MOX)

(tonnes U)

2019		2020		2025		2030		2035	
Low	High	Low	High	Low	High	Low	High	Low	High
0	0	0	0	190	380	720	720	720	720

Total uranium stocks

(tonnes natural U-equivalent)

Holder	Natural uranium stocks in concentrates	Enriched uranium stocks	Enrichment tails	LWR reprocessed uranium stocks	Total
Government	1.97	0	0	0	1.97
Total	1.97	0	0	0	1.97

Ukraine

Uranium exploration and mine development

Historical review

Prospecting for uranium in Ukraine began in 1944 with the analysis of geological exploration data and mining activity results in the Northern Kryvyy Rig ore basin. The Pervomayske and Zhovtorechenske uranium deposits were discovered in the 1950s. These deposits were mined out in 1967 and 1989, respectively.

During the same period of time, the first sandstone-type deposits were discovered.

In the mid-1960s, the main geological exploration was concentrated in the Kirovograd ore area for the discovery of metasomatite-type uranium deposits. Deposits such as Michurinske, Vatutinske, Severinske, Tsentralne and Novokostyantynivske were discovered in this area.

Metasomatite-type deposits make up the main part of uranium resources of Ukraine. The average ore grade in these deposits is 0.1-0.2% U. Sandstone-type deposits, with an average ore grade between 0.02 and 0.06% U, make up the second most important uranium source. They are suitable for mining by ISL.

Ongoing uranium exploration and mine development activities

During 2014, 2015 and 2016, SE Kirovgeology finalised the geological survey mapping at a scale of 1:10 000 and 1:25 000 on all exploration targets mentioned in the Red Book 2016 report. Starting with 2017, all exploration will be carried out around the existing uranium mines. The evaluation of potential thorium resources in the Ukrainian Shield rocks will continue.

Ukraine thorium deposit types and speculative resources

(tonnes Th)

Deposit type	Resources tTh (in situ)
Carbonatite	
Placer	
Granite-related	53 940
Alkaline rocks	37 037
Metasomatite	150 439
Metamorphite	10 253
Other	
Total	251 669

The Ukrainian state and private companies do not carry out any exploration for uranium in other countries. Foreign or private companies do not carry out any uranium exploration activities in Ukraine.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

As of 1 January 2019, identified uranium resources (reasonably assured and inferred resources) recoverable at costs <USD 260/kgU were 186 896 tU. Uranium resources recoverable at costs <USD 80/kgU were 72 916 tU. Mining and processing losses are taken into account in these figures. This represents an increase of 14 648 tU in known resources at costs <USD 80/kgU and decrease of 32 169 tU in total known resources compared to previously reported amounts as of 1 January 2017. These changes occurred due to reassessment of the Vatutinske, Michurynske, Tsentralne, Severinske, Safonivske and Novokostyantynivske deposits during the past two years.

The main uranium resources of economic interest are found in two types of deposits:

- Metasomatite-type, monometallic deposits located within the Kirovograd block of the Ukrainian Shield. The uranium ore grade is 0.1-0.2% U. All deposits are suitable for underground mining.
- Sandstone-type deposits located within the Dnieper-Bug metallogenic area (17.3 thousand km^2). The uranium ore grade is 0.01-0.06% U. In addition to uranium, molybdenum, selenium and rare earth elements of the lanthanide group occur in these ores. These deposits are suitable for mining by ISL.

Undiscovered resources (prognosticated and speculative resources)

After review, undiscovered resources were recalculated and amount to 277 500 tU, including:

- Prognosticated resources amount to 22 500 tU and are found at the flanks of identified deposits.
- Speculative resources amount to 255 000 tU. The calculation is based on the data from the uranium prognostic map (scale of 1:500 000), which was developed by SE Kirovgeology. Speculative resources are subdivided according to geological types as follows:
  - 133 500 tU metasomatite-type;
  - 20 000 tU in sandstone deposits in the Ukrainian Shield;
  - 16 500 tU in sandstone (in bitumen) on the slopes of the Ukrainian Shield;
  - 40 000 tU in unconformity-related type deposits;
  - 30 000 tU in granite-related type deposits;
  - 15 000 tU in intrusive potassium metasomatite deposits.

Uranium production

Historical review

The mining of uranium ore began in 1946 at the deposits of Pervomayske and Zhovtorechenske, using conventional underground methods.

In 1949, the first production began in Ukraine at a uranium processing plant, Pridniprovskyy Chemical Plant (PCP), in the town of Dniprodzerzhinsk.

In 1951, the government founded the Vostochnyi Mining-process Combinat (VostGOK) in Zhovti Vody in the Dnipropetrovsk region, for the mining and processing of ore from Pervomayske and Zhovtorechenske deposits. The Pervomayske deposit was mined out in 1967 and the Zhovtorechenske deposit was mined out in 1989.

In 1959, the second uranium processing plant was built in Zhovti Vody.

In 1961, ISL uranium mining began in Ukraine. From 1966 to 1983, uranium in the Devladovske and Bratske deposits was extracted by using sulphuric acid ISL at depths of about 100 m.

Today, VostGOK operates uranium production facilities in the Central Ukrainian ore province. The company is mining the Michurinske (3 km south of Kropyvnytskyy; formerly Kirovograd), Tcentralne (on the south-east end of Kropyvnytskyy), Vatutinske (near the town Smolino) and Novokostyantynivske (40 km west of Kropyvnytskyy) deposits.

The government plans to mine the Safonivske and Sadove deposits by ISL. At present, aquifers of both Devladovske and Bratske deposits are under monitoring.

Status of production facilities, production capability, recent and ongoing activities and other issues

Hydrometallurgical processing plant

The VostGOK hydrometallurgical processing plant is situated in the town of Zhovti Vody. The annual capacity of the plant is 1.5 Mt of ore. The plant's staff is made up of 30 to 35 persons per shift. The ore is transported to the plant by specially equipped trains from two mines: Ingulska (100 km west) and Novokostyantynivska (130 km west).

Innovative techniques in uranium production

Metasomatite-type deposits in Ukraine have a uranium ore grade of about 0.1% U, with disseminated mineralisation (uraninite, brannerite, coffinite, pitchblende) throughout the volume of ore in steeply dipping ore bodies. Since the mines are located some 100 km and 150 km from the hydrometallurgical plant, transportation costs add to mining and processing costs.

Mining is carried out by underground method. Processing of ore begins with crushing, followed by extraction with sulphuric acid leaching in autoclaves. Low-grade uranium ore, combined with an expensive mining and ore process technology, makes uranium production unprofitable at current market prices. In order to decrease production costs, innovative technologies are being introduced, such as underground radiometric sorting, in-place leaching, heap leaching and reprocessing of materials in dumps of operating mines.

A multistage radiometric separator, designed by VostGOK for different sized piles, allows sorting of both mined ore and material in mine dumps. After the radiometric sorting, uranium content in the ore may reach 0.03-0.3% U. The uranium content in rock tailings following this sorting is 0.006% U or less.

After crushing, uranium ore undergoes heap leaching (HL) at the Vatutinske deposit, with a recovery factor during HL of about 82-83%. The uranium production cost of HL is 15% lower than at the hydrometallurgical processing plant.

Although most metasomatite-type ore deposits are suitable for HL, finely disseminated uranium mineralisation is necessary for effective HL. Therefore, the degree of crushing is the most important parameter, as it determines the degree of uranium recovery and permeability. The maximum size of uranium mineral particles is usually from 1 to 5 mm. With an optimum size of ore material of 10 mm, 80-90% uranium recovery can be achieved after 2-3 months of leaching.

The heaps contain ore grades of 0.050-0.080% U, obtained as a result of radiometric sorting. The volume of the heap is 40 000 t of ore. At the Vatutinske deposit, the HL site has been built. On the site, there are four heaps with total volume 160 kt of ore. At the Michurinske deposit, HL is still in the planning stage.

Uranium production centre technical details

(as of 1 January 2019)

	Centre #1	Centre #2	Centre #3	Centre #4	Centre #5
Name of production centre	Ingulskiy mine	Smolinskiy mine	Novokonstantinovskiy mine	Safonovskiy mine	Severinskiy mine
Production centre classification	Existing	Existing	Existing	Planned	Planned
Date of first production (year)	1968	1973	2011	2019	2020
Source of ore:					
Deposit name(s)	Michyrinskiy, Centralniy	Vatutinskiy	Novokonstantinovskiy	Safonovskiy	Severinskiy Podgaytsevskiy
Deposit type(s)	Metasomatic	Metasomatic	Metasomatic	Sandstone	Metasomatic
Recoverable resources (tU)	52 070	1 749	80 147	2 248	45 060
Grade (% U)	0.1	0.11	0.14	0.02	0.1
Mining operation:					
Type (OP/UG/ISL)	UG	UG	UG	ISL	UG
Size (tonnes ore/day)	2 000	2 000	6 000	NA	4 200
Average mining recovery (%)	95	96	96	75	96
Processing plant:					
Acid/alkaline	Acid	Acid	Acid	Acid	Acid
Type (IX/SX)	IX	IX	IX	IX	IX
Size (tonnes ore/day) For ISL (mega or kilolitre/day or litre/hour)	NA	NA	NA	15 000 litre/day	NA
Average process recovery (%)	93	94	94	95	92
Nominal production capacity (tU/year)	450	500	1 500	150	1 200
Plans for expansion (yes/no)	Yes	No	No	No	No
Other remarks					
Plans for extension					

Ownership of uranium industry

Almost all enterprises in the uranium industry (geology, mining, fuel processing) are owned by the state. The State Enterprise "Eastern Ore Dressing Complex" (VostGOK) is part of the Ministry of Energy and Coal Industry of Ukraine. SE Kirovgeology is responsible for the balance of uranium mineral resources of Ukraine (geological survey, evaluation and exploration of deposit) and is part of the State Service of Geology and Resources of Ukraine, the Ministry of Ecology and Natural Resources.

In April 2008, the government of Ukraine founded a new entity called State Concern Nuclear Fuel through the merger of existing organisations in the sphere of the directorate of the Ministry of Fuel and Energy of Ukraine.

Secondary sources of uranium

- mixed oxide fuel (MOX) has never been produced in Ukraine or used in its NPPs;
- re-enrichment tails have never been produced or used in Ukraine;
- reprocessing spent nuclear fuel is not conducted in Ukraine nor has it been used.

Environmental activities and socio-cultural issues

The main environmental impacts of uranium production at mines result from ore stockpiles, tailings, radiometric ore-sorting sites, waste dumps, ventilation systems infrastructure and transport (railways, technological motor roads).

The main environmental impacts from the hydrometallurgical process plant and heap leaching sites are harmful chemical and ore dust emissions, airborne transportation of aerosols and groundwater contamination from tailings impoundments. In order to control the environmental impacts, permanent monitoring is being conducted.

In the hydrometallurgical plant (Zhovti Vody), process water is recycled for the technological process. There are two tailings impoundments, one situated 9 km from the hydrometallurgical plant consisting of two sections (614.9 ha containing 45.346 Mt of wastes) with total activity of 455.68 10^{12} Bq, and the second 0.5 km from the plant (55 ha containing 16 Mt of wastes) with total activity of 93.3 10^{12} Bq. The latter is no longer used and reclamation is ongoing.

There are also issues connected with the decommissioning of uranium mining and uranium processing enterprises.

At the closed Prydniprovskyy Chemical Plant, there are nine tailings impoundments (covering a total area of 268 ha containing 42 Mt of wastes) with total activity of 2 775 10^{12} Bq and some buildings and other facilities are contaminated by radioactive elements. The Cabinet of Ministers of Ukraine initiated a state programme for reclamation with state funds amounting to USD 4.5 million since 2005.

The total cost of improving radiological protection at all enterprises of the atomic industry and all contaminated areas resulting from mining and processing of uranium is expected to amount to USD 360 million, including decontamination of polluted soils, environmental monitoring, installation of monitoring systems where necessary and improved technology for the management of water flows, radioactive rocks in dumps, polluted equipment and land areas.

Uranium requirements

Uranium production in Ukraine meets 40% of domestic nuclear energy requirements. Nuclear fuel requirements have always been provided by importing fuel from Russia (provided by TVEL). Annual fuel loadings of the 4 operating NPPs (comprised of 13 VVER-1000 units and 2 VVER-440 units) amounts to 15 sets of fuel elements at a total cost of about USD 300 million. In 2009, the government set a target that 100% of uranium requirements for the Ukrainian nuclear fleet will be met by domestic production by 2020. These plans are however under review due to unfavourable uranium prices.

Installed nuclear generating capacity by 2035

At present, 15 reactors are operating at 4 NPPs: 6 VVER-1000 units at Zaporozhskyy, 3 VVER-1000 units at South-Ukrainian, 2 VVER-1000 and 2 VVER-400 units at Rovenskyy and 2 VVER-1000 units at Khmelnitskyy.

The national programme for nuclear energy production foresees the production of about 45% of electricity by nuclear power plants by 2030. To fulfil this requirement, annual nuclear energy production will have to increase to 75.2 billion KWe/h. This will require life extension of operating NPPs, the construction of 12 additional units (with 10 of these having a total capacity 1 500 MWe) and during this time frame, the decommissioning of 12 NPPs that will be at the end of their operational lifetime.

Uranium policy, uranium stock and uranium price

Ukrainian government policy is to increase the production of natural uranium and improve the foreign investment climate in order to develop uranium projects in Ukraine.

Resolution N1004, the “Complex Program of Nuclear Fuel creation in Ukraine” (23 September 2009) was approved by the Cabinet of Ministers of Ukraine. It specifies that uranium enrichment will be conducted abroad.

On 17 April 2009, the Cabinet of Ministers of Ukraine passed Resolution N 650-p “Some Questions of Liquidation and Organisation of State Mergers in the Nuclear Industry”. The resolution founded the State Concern Nuclear Fuel, by the merger of all state enterprises and research and design institutes in the field of the nuclear fuel cycle. The aim of the resolution is to improve investment conditions.

The “Private Joint Stock Company Nuclear Fuel Fabrication Plant” for nuclear reactors VVER-1000 type was established in Ukraine in October 2011. The plant is situated in the Kirovograd region, close to the Vatutinske uranium deposits. In the JSC, a 50.000006% share belongs to State Concern Nuclear Fuel and 49.999994% share to the Russian state company TVEL.

The technical economic assessment for the construction of the nuclear fuel plant was approved by the Cabinet of Ministers of Ukraine (statement N437; 27 June 2012), at a total estimated cost of UAH 3.7 billion (about USD 130 million). Stage I construction was commissioned in 2015 and stage II was planned for 2020. Planned capacity of the plant was 800 nuclear fuel sets per year. However, the construction of the plant has been postponed.

The decision to build a central storage facility for used fuel from domestic VVER reactors in the Chernobyl exclusion zone, was made pursuant to the Law of Ukraine N4384 (2 September 2012). Initially, the commissioning was planned for 2016. The storage facility is under construction by the company Holtec International USA.

In September 2012, the decision to build two NPPs (N3 and N4 on the Khmelnitsky site), in collaboration with Russia was made under the Law of Ukraine N4384 dated 2 September 2012. Commissioning of these units was initially set for 2018 (N3) and 2020 (N4). However, the new build activities have been postponed.

The government of Ukraine decided to build a new process plant for the Novokostyantynivske uranium deposit (Resolution of the Ministry of Energy and Coal Industry of Ukraine N 933-P dated 24 February 2012). The process plant production capacity is 1 500 000 t of ore per year or 2 000 tU. There is no activity at the present time.

Uranium exploration and development expenditures and drilling efforts - domestic

(UAH million as of 1 January 2019)

	2016	2017	2018	2019 (preliminary)
Industry* exploration expenditures	0	0	0	0
Government exploration expenditures	5.2	5.3	6.4	5.9
Industry* development expenditures	0	14.9	9.3	30.2
Government development expenditures	6.9	8.7	5.5	4.2
Total expenditures	12.1	28.9	21.2	40.3
Industry* exploration drilling (m)	0	4 205	6 657	3 000
Industry* exploration holes drilled	0	79	119	56
Government exploration drilling (m)	822	684	753	680
Government exploration holes drilled	2	2	2	2
Industry* development drilling (m)	0	161 692	205 517	156 340
Industry* development holes drilled	0	10 780	13 701	10 423
Government development drilling (m)	10 307	11 435	NA	NA
Government development holes drilled	348	342	NA	NA
Subtotal exploration drilling (m)	822	4 889	7 410	3 680
Subtotal exploration holes drilled	2	81	121	58
Subtotal development drilling (m)	10 307	173 127	205 517	156 340
Subtotal development holes drilled	348	11 122	13 701	10 423
Total drilling (m)	11 129	178 016	212 927	16 0020
Total number of holes drilled	350	11 203	13 822	10 481

* Non-government

Reasonably assured conventional resources by production method

(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining		42 512	71 132	118 374	88.4
In situ leaching acid		3 718	3 718	3 718	75.0
Total		46 230	74 850	122 092	

Reasonably assured conventional resources by processing method

(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	42 512	71 132	118 374	88.4
In situ leaching acid	0	3 718	3 718	3 718	75.0
Total	0	46 230	74 850	122 092	

Reasonably assured conventional resources by deposit type

(tonnes U)

Deposits type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Proterozoic unconformity	0	0	0	0
Sandstone	0	3 718	3 718	3 718
Metasomatite	0	42 512	71 132	118 374
Total	0	46 230	74 850	122 092

Inferred conventional resources by production method

(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining	0	26 284	33 416	60 652	88.4
In situ leaching acid	0	402	402	4 152	75.0
Total	0	26 686	33 818	64 804	

Inferred conventional resources by processing method

(tonnes U)

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Inferred conventional resources by deposit type

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Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Sandstone	0	402	402	4 152	75.0
Metasomatite	0	26 284	33 416	60 652	88.4
Total	0	26 686	33 818	64 804	

Prognosticated conventional resources

(tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
0	8 400	22 500

Speculative conventional resources

(tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
0	120 000	255 000

Historical uranium production by production method

(tonnes U in concentrate)

Production method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (preliminary)
Open-pit mining*	10 000	0	0	0	10 000	0
Underground mining*	106 703	808	707	790	109 008	750
In situ leaching	3 925	0	0	0	3 925	0
Co-product/by-product	10 000	0	0	0	10 000	0
Total	130 628	808	707	790	132 933	750

* Pre-2015 totals may include uranium recovered by heap and in-place leaching.

Historical uranium production by processing method

(tonnes U in concentrate)

Processing method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (preliminary)
Conventional	126 583	777	666	706	128 732	607
In situ leaching	3 925	0	0	0	3 925	0
In-place leaching*	20	1	4	1	26	0
Heap leaching**	100	30	37	83	250	143
Total	130 628	808	707	790	132 933	750

* Also known as stope leaching or block leaching.

** A subset of open-pit and underground mining, since it is used in conjunction with them.

Historical uranium production by deposit type

(tonnes U in concentrate)

Deposits type	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (preliminary)
Sandstone	3 925	0	0	0	3 925	-
Granite-related	35 000	0	0	0	35 000	0
Metasomatite	91 703	808	707	790	94 008	750
Total	130 628	808	707	790	132 933	750

Ownership of uranium production in 2018

Domestic				Abroad				Total	
Government		Private		Government		Private			
(t U)	(%)	(t U)	(%)	(t U)	(%)	(t U)	(%)	(t U)	(%)
790	100	0	0	0	0	0	0	790	100

Uranium industry employment at existing production centres

(persons/years)

	2014	2015	2016	2017	2018	2019 (preliminary)
Total employment at existing production centres	4 500	4 555	4 426	4 450	4 275	4 104
Direct employment at uranium production	1 610	1 600	1 585	1 550	1 490	1 430

Short-term production capability

(tonnes U/year)

2020				2025			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
NA	NA	2 480	2 480	NA	NA	2 000	NA

2030				2035				2040			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
NA	NA	1 700	NA	NA	NA	NA	NA	NA	NA	NA	NA

Net nuclear electricity generation

	2017	2018
Net nuclear electricity generation (TWh net)	85.6	84.4

Installed nuclear generating capacity up to 2040

(GWe net)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
13.8	13.8	13.8	13.8	16.5	20.2	18.8	26.2	26.0	30.5	26.0	30.5

Annual reactor-related uranium requirements up to 2040 (excluding MOX)

(tonnes U)

2016	2017	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
2 480	2 480	2 480	2 480	3 020	3 660	3 600	4 800	4 800	5 300	4 800	5 300

United States

Uranium exploration and mine development

Historical review

From 1947 through 1970, the United States (US) government fostered a domestic private sector uranium exploration and production industry to procure uranium for military uses and to promote research and development in peaceful atomic energy applications. By late 1957, both the number of new deposits being brought into production by private industry and production capability had increased sufficiently to meet projected requirements. Federal exploration programmes were ended at that time.

Private exploration by the US uranium industry increased throughout the 1970s in response to rising prices and the projected large demand for uranium to fuel an increasing number of nuclear reactors being built or planned for civilian electric power stations. Total annual surface drilling peaked in 1978.

Exploration has been primarily for sandstone-type uranium deposits in districts such as the Grants Mineral Belt and Uravan Mineral Belt of the Colorado Plateau, the Wyoming basins and Texas Gulf Coastal Plain region.

Recent and ongoing uranium exploration and mine development activities

In 2017 and 2018, the uranium industry in the United States continued to contract uranium requirements from non-domestic sources, leading to historically low levels of exploration and production. Decreases in drilling, production and related expenditures are due in large part to a global oversupply of uranium and consequently low uranium prices. These continued low prices have dramatically impacted the domestic mining industry. Private companies, who explore for and produce uranium in the United States, have been reducing expenditures to minimal levels in order to retain property holdings and infrastructure in hopes of a potential price recovery. Additionally, the extraction of mining co-products, such as vanadium and copper, are being actively pursued to improve the economics of mines. Accompanying the reduction in activities related to production, environmental activities and costs are increasing as the nation works to remediate legacy mining impacts. These remediation efforts are largely led by federal regulators and land use agencies with significant financial contributions by previous mining companies through legal judgments.

From a recent peak of USD 352.9 million in 2012, US uranium expenditures have decreased by 69% to USD 109 million in 2018. In 2017, expenditures for uranium surface drilling totalled USD 4.0 million, down USD 18.3 million (82%) from expenditures in 2016 (see table). Surface drilling expenditures for 2018 are withheld to avoid disclosure of individual company data.

Private industry total expenditures for uranium exploration and mine development activities in 2018 were USD 42.9 million, a 3% decrease from 2017 expenditures of USD 44.2 million.

In 2018, expenditures on US uranium production, including facility expenses, were USD 65.9 million, 16% less than the USD 78.3 million spent in 2017. Expenditures for land in 2017 were USD 8.9 million, a 10% decrease from the USD 9.9 million spent in 2016. Land expenditures for 2018 are withheld to avoid disclosure of individual company data.

The total expenditures for land, exploration, drilling, production and reclamation decreased to USD 108.8 million in 2018, down 11% from USD 122.6 million in 2017. Reclamation expenditures in 2017 were USD 27.7 million, a 26% decrease compared with 2016 expenditures of USD 37.2 million. Reclamation expenditures for 2018 are withheld to avoid disclosure of individual company data.

United States uranium expenditures, 2008-2018

(USD million)

Year	Drilling	Production	Land and other				Total expenditures
			Total land and other	Land	Exploration	Reclamation	
2008	81.9	221.2	164.4	65.2	50.2	49.1	467.6
2009	35.4	141.0	104.0	17.3	24.2	62.4	280.5
2010	44.6	133.3	99.5	20.2	34.5	44.7	277.3
2011	53.6	168.8	96.8	19.6	43.5	33.7	319.2
2012	66.6	186.9	99.4	16.8	33.3	49.3	352.9
2013	49.9	168.2	90.6	14.6	21.6	54.4	308.7
2014	28.2	137.6	74.0	11.6	10.7	51.7	239.7
2015	28.7	118.5	76.2	12.1	4.7	59.4	223.5
2016	22.3	98.0	49.6	9.9	2.5	37.2	169.9
2017	4.0	78.3	40.3	8.9	3.7	27.7	122.6
2018	W	65.9	W	W	W	W	108.8

Notes: Expenditures in nominal USD. Totals may not equal sum of components because of independent rounding.

W = Data withheld to avoid disclosure of individual company data.

Drilling: All expenditures directly associated with exploration and development drilling.

Production: All expenditures for mining, milling, processing of uranium and facility expense.

Total land and other: All expenditures for land; geological research; geochemical and geophysical surveys; costs incurred by field personnel in the course of exploration, reclamation and restoration work; and overhead and administrative charges directly associated with supervising and supporting field activities.

Source: U.S. Energy Information Administration, Domestic Uranium Production Report, 2018, Table 8.

The trend of decreasing drilling that began in 2013 continued into 2017 and 2018. The number of holes drilled for uranium decreased by 64% from 2016 to 2017, from 1 158 holes to 420 holes (see table below). The number of holes drilled in 2018 are withheld to avoid disclosure of individual company data. The total metres (m) drilled decreased 74% from 230 733 m in 2016 to 59 741 m in 2017, a 97% decrease from the 2012 peak of 2 181 149 m. The total metres drilled in 2018 are withheld to avoid disclosure of individual company data.

In 2017 and 2018, the US government made no exploration expenditures for uranium domestically or abroad. Data on industry exploration expenses abroad are not available.

United States uranium drilling activities, 2008-2018

Year	Exploration drilling		Development drilling		Exploration and development drilling	
	Number of holes	Metres (thousand)	Number of holes	Metres (thousand)	Number of holes	Metres (thousand)
2008	5 198	775	4 157	778	9 355	1 552
2009	1 790	320	3 889	820	5 679	1 141
2010	2 439	445	4 770	1 050	7 209	1 495
2011	5 441	1 013	5 156	915	10 597	1 928
2012	5 112	1 051	5 970	1 131	11 082	2 181
2013	1 231	280	4 013	892	5 244	1 172
2014	W	W	W	W	1 752	396
2015	W	W	W	W	1 518	268
2016	W	W	W	W	1 158	231
2017	W	W	W	W	420	60
2018	W	W	W	W	W	W

Note: Totals may not equal sum of components because of independent rounding.

W = Data withheld to avoid disclosure of individual company data.

Source: U.S. Energy Information Administration, Domestic Uranium Production Report, 2018, Table 1.

Conventional mine development

No uranium was extracted from underground or surface mines in the United States during 2017 and 2018. The last conventional mining in the United States was completed at Energy Fuels Pinenut mine, a collapse breccia-type deposit in Arizona, in 2015. Ore from Pinenut is currently stockpiled for future processing.

At the White Mesa Mill, the only operating mill in the United States, a significant amount of production in 2017 and 2018 was from alternate feed material. Alternate feed material is not primary mined uranium, and it is recycled from several sources, not all of which originate in the United States. This material includes uranium extracted during municipal water treatment, process residues from uranium conversion, uranium-bearing tails from other metal recovery operations, and others. In late 2018, Energy Fuels began production of vanadium from existing tailings solutions at White Mesa Mill. This vanadium production is the first at White Mesa Mill since 2013.

Several small (400-2 000 tU) underground or open-pit mines or properties throughout the western United States with some degree of development, are on standby status awaiting higher uranium prices. Properties with more significant resources, including conventional mines on standby status, deposits in development or significant exploration projects, are listed below. Conventional mines previously detailed in the 2018 report are included only if conditions have significantly changed. Developments ancillary to the production of uranium, such as property transfers and financial actions, are not included.

Arizona

- Canyon Mine (Energy Fuels): Fully permitted and in development. An NI 43-101 resource estimate was published in 2017. A production shaft has been completed, as well as some underground and surface development. Metallurgical tests are in process, partly to explore the recovery of copper from mined ore to improve the economics of the mine. NI 43-101 are the Canadian standards of disclosure for mineral projects designed to ensure that misleading, erroneous or fraudulent information about mineral properties is not published.

- Anderson (Uranium Energy Corporation): An NI 43-101 compliant resource estimate has been published and a preliminary economic assessment has been completed. In 2017 and 2018, the company worked to advance permitting.

Utah

- Henry Mountains Complex (Energy Fuels): An NI 43-101 compliant resource estimate has been published. The Tony M mine is on standby (fully permitted and developed), and the Bullfrog portion of the project is being permitted.

Virginia

- Coles Hill deposit (Virginia Uranium): This deposit is the largest undeveloped uranium deposit in the United States. A feasibility study has been completed, but development cannot proceed until a state moratorium on uranium mining is lifted. Challenges to the moratorium during 2017 and 2018 are described elsewhere in this report.

ISR mine development

At the end of 2018, five US uranium ISL plants were operating with a combined capacity of 10.9 million pounds U_3O_8 per year (4 190 tU; Crow Butte Operation in Nebraska, Lost Creek Project, Nichols Ranch ISR Project, Ross CPP and the Smith Ranch-Highland Operation in Wyoming). Four ISL plants were on standby as of the end of 2018 and six ISL plants were planned for four states: New Mexico, South Dakota, Texas and Wyoming.

Cameco curtailed production in 2016 to negligible levels in 2018 at Smith Ranch/Highland in Wyoming and Crow Butte in Nebraska operations. In March 2017, Cameco announced that it would consider divesting its US assets, which include Smith Ranch/Highland and Crow Butte. At the Nichols Ranch mine, Energy Fuels was not developing new wellfields and, consequently, production during 2017 and 2018 fell off dramatically.

In 2018, Ur-Energy began production from an additional wellfield (MU2) at its Lost Creek Project operation in Wyoming and continued its permitting activities for other ore horizons. However, it is unclear if additional development will proceed. Peninsula Energy (Ross Central Processing Plant – Lance Mine) is working with the state of Wyoming to permit acid leach mining to increase uranium recovery. Acid leach mining techniques have not been used in the United States, except for limited test operations in the 1970s. Uranium One ceased production at its Willow Creek mine in Wyoming in the third quarter of 2018.

There are several small (<400 to 2 000 tU) ISL-amenable properties with some degree of development in the western United States that are on standby status awaiting higher uranium prices. Most exploration and development is concentrated in Texas and Wyoming. In addition to the permitting of satellite properties adjacent to existing processing plants, other significant ISL properties include those listed below. These deposits have a significant identified uranium resource (most containing >2 000 tU). Activity is only reported if there have been developments that might result in significant progress towards uranium production. Developments ancillary to the production of uranium, such as property transfers and financial actions are not included.

Texas

- Burke Hollow (Uranium Energy Corporation): An NI 43-101 compliant resource estimate has been published, and a feasibility study, permitting and exploration drilling activities are all in progress.

South Dakota

- Dewey-Burdock (Azarga Uranium): A preliminary economic assessment has been completed and permitting with a focus on complying with the US National Environmental Policy Act is in progress.

Wyoming

- Shirley Basin (Ur-Energy): An NI 43-101 compliant resource estimate has been published, a preliminary economic assessment has been completed, and permitting is in progress.

- Reno Creek (Uranium Energy Corporation): An NI 43-101 compliant resource estimate has been published for most of the deposits (including Pine Tree, Bing and Moore). In 2018, expenditures were for property maintenance and exploration.

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

At the end of 2018, estimated uranium reserves (in situ reasonably assured resources [RAR]) were 18 564 tU at a maximum forward cost of <USD 80/kgU. At a cost of <USD 130/kgU, estimated reserves were 67 089 tU. At a cost of <USD 260/kgU, estimated reserves were 135 870 tU. Uranium reserve estimates for mines in production at the end of 2018, and for properties with exploration completed, exploration continuing and only assessment work, are withheld to avoid disclosure of individual company data. Estimated uranium resources are prepared by private companies. These estimates change each year due to production (resource depletion), changes in resource estimation, site boundary expansions and evolving production costs. Uranium resource estimates are prepared by industry and reported to the US Energy Information Administration (US EIA), who aliases the resources by tabulating them into states or regions without further analysis.

Reserve estimates were available for 76 mines and properties at the end of 2017 and for 67 mines and properties at the end of 2018. The decline in the number of properties from 2017 to 2018 was primarily due to separate parcel consolidations.

Current estimates of uranium reserves cannot be compared with the much larger historical data set of uranium reserves published in the July 2010 US Department of Energy (DOE) report, *U.S. Uranium Reserves Estimates*. Those estimates were made by the US EIA based on data collected by the US EIA and data developed by the National Uranium Resource Evaluation (NURE) programme, operated out of Grand Junction, Colorado, by the DOE and predecessor organisations. The US EIA data covered approximately 200 uranium properties, with reserve estimates collected from 1984 through 2002. The NURE data covered approximately 800 uranium properties with reserve estimates, developed from 1974 through 1983. Although the 2014 data collected on the Form EIA-851A survey, Domestic Uranium Report (Annual), cover a much smaller set of properties than the earlier US EIA and NURE data, the US EIA believes that, within its scope, the EIA-851A survey data provide more reliable estimates of the uranium recoverable at the specified forward cost than estimates derived from 1974 through 2002. In particular, this is because the NURE data have not been comprehensively updated in many years and are therefore no longer considered a current data source.

The United States has not historically reported inferred resources. In 2014, the United States began an evaluation of the relative importance of the inferred resource category available in published estimates of US uranium properties. Based on this limited analysis, it is estimated that uranium resources for the United States would be increased minimally by 10% if inferred resources were tabulated in addition to reasonable assured resources. In recognition of the limited information available and the importance of this class of resource, mechanisms for collecting inferred uranium resource data for the United States are being considered.

Undiscovered conventional resources (prognosticated and speculative resources)

Prognosticated and speculative uranium resources for the United States were last comprehensively assessed in 1980. The US Geological Survey (USGS) is now re-estimating undiscovered resources for the United States using the USGS “3-Part” method of quantitative undiscovered mineral resource assessment. Estimates for various regions and deposit types have been prioritised and will be completed in an ongoing fashion. Two assessments have been completed, estimating about 84 000 tU recoverable in the Texas Coastal Plain and 15 500 tU in-place in the Southern High Plains region. The difference in estimation of in-place or recoverable uranium is a result of the different grade and tonnage models used for the estimates (one where in situ uranium data were available; the other where only recovered uranium data were available).

US undiscovered uranium resource assessments, 2015-2018

Tract name	Age	Sub-tract	Permissive area (km²)	N_{known}	N_{und}	Probability of at least the indicated amount of undiscovered tU			Mean undiscovered resources (tU)
						0.9	0.5	0.1	
Southern High Plains (TX, NM, OK)	Pliocene to Pleistocene	North	43 920	0	1.1	0	1 600	10 200	3 500
		South	46 630	2	3.9	3 000	10 200	23 000	12 000
Totals - Southern High Plains (in situ U)			90 550	2	5.0				15 500
Texas Coastal Plain - Claiborne-Jackson	Eocene	Rio Grande Embayment	38 460	18	27	4 900	19 000	38 000	20 300
		Houston Embayment	62 670	1	3	140	1 700	5 500	2 400
Texas Coastal Plain - Catahoula-Oakville TX	Oligocene to Miocene	Rio Grande Embayment	14 220	35	41	11 000	30 500	52 000	31 000
		Houston Embayment	16 710	0	3	135	1 800	5 500	2 400
Texas Coastal Plain - Goliad-Willis-Lissie, TX	Pliocene to Pleistocene	Rio Grande Embayment	45 200	10	33	8 000	20 000	50 000	25 000
		Houston Embayment	52 250	0	4	100	5 291 094	15 873 283	2 700
Totals - Texas Coastal Plain (produced U)			229 510	64	111				83 800

[N_{known}, number of known deposits in the tract that have identified resources; N_{und}, number of undiscovered deposits calculated using a regression equation (Singer and Menzie, 2010). The permissive tract area in square kilometres (km²) is inclusive of the favourable and prospective areas. Identified and undiscovered uranium resources are estimated as in-place for the Southern High Plains and produced in the Texas Coastal Plain. See: Singer, D.A. and W.D. Menzie (2010), Quantitative mineral resource assessments - an integrated approach. New York, Oxford University Press, for an explanation of quantitative mineral assessment methods. Numbers are rounded to the nearest 100 tU.

The USGS methodology used to estimate undiscovered resources produces probabilistic estimates of potential resources, but these estimates are not in cost categories. Therefore, these estimates are not included in undiscovered resource compilations elsewhere in this report.

A deposit model is in development for the Coles Hill Deposit in Virginia as part of the next planned assessment of undiscovered resources in the southern Appalachian region. Only about 10% of the undiscovered uranium resources for the United States have been assessed.*

Uranium production

Historical review

Following the passage of the Atomic Energy Act of 1946 (AEA), designed to meet US government uranium procurement needs, the Atomic Energy Commission (AEC) from 1947 through 1970 fostered the development of a domestic uranium industry (chiefly in the western United States) through incentive programmes for exploration, development and production. To assure that the supply of uranium ore would be sufficient to meet future needs, the AEC in April 1948 announced a domestic ore procurement programme designed to stimulate prospecting and build a domestic uranium mining industry. The AEC also negotiated concentrate procurement contracts, pursuant to the AEA, as amended in 1954, with guaranteed prices for source materials delivered within specified times. Contracts were structured to allow milling companies that

* For details of the undiscovered resource assessments for the US see: Hall, S., et al. (2017), "Assessment of undiscovered resources in calcrete uranium deposits, Southern High Plains region of Texas, New Mexico and Oklahoma, 2017", US Geological Survey Fact Sheet 2017-3078: 2 p; and Mihalasky, M. J., et al. (2015), "Assessment of undiscovered sandstone-hosted uranium resources in the Texas Coastal Plain, 2015", US Geological Survey Fact Sheet 2015-3069: 4p.

built and operated mills the opportunity to amortise plant costs during their procurement-contract period. By 1961, a total of 27 mills were being operated. Overall, 32 conventional mills and several pilot plants, concentrators, upgraders, heap leach and solution-mining facilities were operated at various times. The AEC, as the sole government purchasing agent, provided the only US market for uranium. While many of the mills were closed soon after completing deliveries scheduled under AEC purchase contracts, several mills continued to produce concentrate for the commercial market after fulfilling their AEC commitments.

The AEA, as amended, legalised the private ownership of nuclear reactors for commercial electricity generation. By late 1957, domestic ore reserves and milling capacity were sufficient to meet government needs. In 1958, the AEC's procurement programmes were reduced in scope and, in order to foster utilisation of atomic energy for peaceful purposes, domestic producers of ore and concentrate were allowed to sell uranium to private domestic and foreign buyers. The first US commercial-market contract was finalised in 1966. The AEC announced in 1962 a "stretch out" of its procurement programme that committed the government to take only set annual quantities of uranium for 1967 through 1970. This programme change also assisted in sustaining a viable domestic uranium industry. The US government's natural uranium procurement programme ended in 1970 and the industry became a private sector, commercial enterprise with no government purchases. The government, however, continues to monitor private industry exploration and development activities to meet federal information and data needs.

Exploration by the US uranium industry increased through the 1970s in response to rising prices and the projected large demand for uranium to fuel an increasing number of commercial nuclear power plants that were under construction or planned. US production peaked in 1980 (16 809 tU), after which the industry experienced generally declining production from 1981 to 2003. Beginning in 2004, production began increasing again in response to higher uranium prices. Production began decreasing in 2013 in response to an oversupply of uranium on the world market and consequent lower uranium prices. The oversupply was the result of reactor shutdowns in Germany and Japan following the accident at Fukushima Daiichi. Since 1991, production from ISR mining has dominated US annual production.

Status of production facilities, production capability, recent and ongoing activities and other issues

US uranium mines produced 442 tU in 2017, 55% less than in 2016. In 2018, US uranium mines produced 277 tU, 37% less than in 2017. Total production of US uranium concentrate in 2018 was 634 tU, 37% less than in 2017, from seven facilities: one mill in Utah (White Mesa Mill) and six ISL plants. The six ISL plants are located in Nebraska and Wyoming. When mined, uranium ore from underground mines is stockpiled and shipped to the White Mesa Mill for milling into uranium oxide (U_3O_8) concentrate (yellowcake).

Total shipments of uranium concentrate from US mill and ISL plants were 573 tU in 2018, 35% less than in 2017. US producers sold 593 tU of uranium concentrate in 2018, 23% more than in 2017.

At the end of 2018, one uranium mill (White Mesa in Utah) was operating with a capacity of 1 814 tonnes of ore per day. Two mills (Shootaring Canyon in Utah and Sweetwater in Wyoming) were on standby status with a combined capacity of 3 402 tonnes of ore per day. Both the Sweetwater and Shootaring Canyon mills have been on standby status since the early 1980s and will require rehabilitation. After acquiring the Shootaring Canyon mill in 2015, Anfield Resources Inc. submitted a plan in 2016 to the Utah Division of Waste Management and Radiation Control to renew the mill's operating licence. The Piñon Ridge mill in Colorado is planned and fully licensed for Colorado, but construction has not begun. The NRC received letters of intent for mill licence applications from Uranium Resources Inc. (Juan Tafoya mine area, New Mexico) and General Atomics (Mt. Taylor Mine area, New Mexico); however, both of these licensing actions have been delayed by the applicant.

Six ISR mines were operating in 2018 with a combined capacity of 4 683 tU per year (Crow Butte Operation, Lost Creek Project, Nichols Ranch ISR Project, Ross CPP, Smith Ranch-Highland Operation and Willow Creek Project). However, production at the Willow Creek mine in Wyoming ended in the third quarter of 2018 and is currently on standby, reducing the total combined operating capacity at the end of 2018 by 500 tU, to 4 183 tU/year. Smith Ranch, Crow Butte and Willow Creek extracted, dried and packaged uranium at the mine site, Nichols Ranch shipped U-loaded resin beads to the White Mesa Mill for stripping of uranium from resins, drying and packaging.

Uranium production centre technical details

(as of 31 December 2018)

	Centre #1	Centre #2	Centre #3	Centre #4	Centre #5
Name of production centre	Crow Butte Operation	Lost Creek Project	Smith Ranch/Highland (including North Butte satellite mine)	Ross CPP	Nichols Ranch ISR Project
Production centre classification[1]	Existing	Existing	Existing	Existing	Existing
Date of first production	1991	NA	1988	2015	NA
Source of ore:					
Deposit name(s)	Crow Butte and North Trend	Lost Creek	Smith Ranch-Highland	Late Cretaceous Lance and Fox Hills Formations	Nichols Ranch and Hank
Deposit type(s)	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone
Recoverable resources (tU)	W	NA	W	W	NA
Grade (% U)	W	NA	W	W	NA
Mining operation:					
Type (OP/UG/ISR)	ISR	ISR	ISR	ISR	ISR
Size (tonnes ore/day)	NA	NA	NA	NA	NA
Average mining recovery (%)	NA	NA	NA	NA	NA
Processing plant:					
Acid/alkaline					
Type (IX/SX)	ISX	IX	IX	IX	IX
Size (tonnes ore/day)					
Average process recovery (%)	NA	NA	NA	NA	NA
Nominal production capacity (tU/year)[1]	385	769	2 116	144	769
Plans for expansion	Unknown	Unknown	Unknown	Planned stage expansion, depending on market conditions	Unknown
Other remarks[1]	Operating	Operating	Operating	Operating	Operating
State	Nebraska	Wyoming	Wyoming	Wyoming	Wyoming

1. U.S. Energy Information Administration, Domestic Uranium Production Report, 2018, Tables 4 and 5.

NA = Not available. W = Data withheld to avoid disclosure of individual company data.

Uranium production centre technical details *(cont'd)*

(as of 31 December 2018)

	Centre #6	Centre #7	Centre #8	Centre #9	Centre #10
Name of production centre	Willow Creek Project	White Mesa Mill	Alta Mesa	Goliad	Moore Ranch
Production centre classification[1]	Existing	Existing	Existing	Existing	Existing
Date of first production	NA	1980	2005	NA	NA
Source of ore:					
Deposit name(s)	Willow Creek	Various	Alta Mesa	Goliad Formation	Wasatch River Formation
Deposit type(s)	Sandstone	Sandstone, breccia pipe	Sandstone	Sandstone	Sandstone
Recoverable resources (tU)	NA	W	W	W	W
Grade (% U)	NA	W	W	W	W
Mining operation:					
Type (OP/UG/ISR)	ISR	UG	ISR	ISR	ISR
Size (tonnes ore/day)	NA	NA	NA	NA	NA
Average mining recovery (%)	NA	NA	NA	NA	NA
Processing plant:					
Acid/alkaline		Acid			
Type (IX/SX)	IX	SX	IX		
Size (tonnes ore/day)		1 538			
Average process recovery (%)	NA	NA	NA	NA	NA
Nominal production capacity (tU/year)[1]	500	NA	577	385	192
Plans for expansion	Unknown	Unknown	Unknown	Unknown	Unknown
Other remarks[1]	Standby	Operating	Standby	Permitted and Licensed	Permitted and Licensed
State	Wyoming	Utah	Texas	Texas	Wyoming

1. U.S. Energy Information Administration, Domestic Uranium Production Report, 2018, Tables 4 and 5.

NA = Not available. W = Data withheld to avoid disclosure of individual company data.

Ownership structure of the uranium industry

Ownership of uranium facilities that produced uranium in 2017 and 2018 are public and privately-held firms with both foreign and domestic participation.

Employment in the uranium industry

Employment in the raw materials sector (exploration, mining, milling and processing) of the US uranium industry generally declined from 1998 to 2003, and then steadily increased from 2004 to 2008. Employment levels in 2009 showed the first significant decrease over the preceding five years, but from 2009 through 2012, there were marginal gains in total employment. Since 2012, however, employment has declined with the decrease in production. In 2018, total employment in the US uranium production industry was 372 person-years (including reclamation employment), a decrease of 12% from the 2017 total of 424 person-years, the lowest since 2003. Exploration employment in 2018 was 27 person-years, a 46% decrease compared with 2017. Milling and processing employment data are withheld for 2017 and 2018. Uranium mining employment in 2018 was 110 person-years, 19% less than in 2017. Reclamation employment increased 38% from 100 person-years in 2017 to 138 person-years in 2018. In 2018, uranium production industry employment occurred in seven states: Arizona, Nebraska, New Mexico, Oregon, Texas, Utah and Wyoming, one less than in 2017.

Future production centres

There are a number of future production centres that are currently in either the permitting or licensing process or under development. Fully permitted centres are listed in the table above, and other developing centres are described in the previous sections on conventional and ISR mine development.

Secondary sources of uranium

Production and/or use of mixed oxide fuels

In 1999, the DOE issued a final environmental impact statement (EIS) and record of decision to make 34 tonnes of surplus weapons-usable plutonium available as mixed oxide (MOX) fuel for use in commercial nuclear reactors.

In November 2018, MOX Services requested termination of the NRC issued Construction Authorisation (CA) for the Mixed-Oxide Fuel Fabrication Facility (MFFF) due to the cessation of NRC regulated activities following receipt of the Notice of Termination from the DOE/NNSA. The DOE/NNSA terminated the contract to design, build and operate the MFFF. The NRC terminated the CA on 8 February 2019. Because construction of the MFFF had not been completed, the NRC has not issued an operating licence for the MFFF and no nuclear fuel or special nuclear material has been brought onto the MFFF construction site. The MFFF was to be used to support international nuclear non-proliferation agreements under which the United States and Russia will decommission 68 tonnes of surplus plutonium. The Tennessee Valley Authority (TVA) had intended to use the MOX at its Sequoyah plant in Tennessee and the Browns Ferry plant in Alabama. The use of MOX fuel would have required an amendment to the plant operating licences.

Production and/or use of re-enriched tails

The DOE and the Bonneville Power Administration initiated a pilot project to re-enrich a portion of the DOE's tails inventory. This project produced approximately 1 940 tonnes of low-enriched uranium between 2005 and 2006 for use by Energy Northwest's 1 190 MWe Columbia Generating Station between 2007 and 2015. In mid-2012, Energy Northwest and the United States Enrichment Corporation (USEC), in conjunction with the DOE, developed a new plan to re-enrich a portion of the DOE's high-assay tails. The 2013 project produced approximately 3 738 tonnes of natural uranium, which will be used through 2029 to fuel Energy Northwest and TVA reactors.

In 2016, the DOE agreed to sell depleted uranium to GE-Hitachi Global Laser Enrichment, LLC (GLE) over a 40-year period, which would be enriched at a proposed GLE facility. GLE will finance, construct, own and operate the Paducah Laser Enrichment Facility (PLEF) adjacent to the DOE site. Silex Systems Limited, an Australian-owned company developing the laser enrichment technology, has licensed GLE to supply the depleted uranium.

In February 2019, Silex Systems Limited and Cameco Corporation agreed to restructure ownership of GLE with a joint purchase of GE-Hitachi Nuclear Energy's (GEH) share of GLE with Silex holding the majority at 51% and Cameco increasing its share to 49%.

Production and/or use of reprocessed uranium

Reprocessed uranium use and production is zero.

In June 2008, the DOE submitted a licence application to the NRC to receive authorisation to begin construction of a repository at Yucca Mountain. In September 2008, the NRC formally docketed the application. Former President Obama announced in March 2009 that the proposed permanent repository at Yucca Mountain was no longer an option and that the Blue Ribbon

Commission (BRC) on America's Nuclear Future would evaluate alternatives to deal with spent nuclear fuel. On 26 January 2012, the BRC issued its final report that recommended moving forward with a publicly supported siting process for a permanent repository and federally chartering an organisation to manage this process. The BRC also recommended the development of an interim storage site for spent nuclear fuel until a permanent repository is available. With regard to reprocessing or recycling, the BRC noted that "…no currently available or reasonably foreseeable reactor and fuel cycle technology developments – including advances in reprocessing and recycling technologies – have the potential to fundamentally alter the waste management challenge this nation confronts over at least the next several decades, if not longer…".

As of November 2019, no further NRC licensing activity has been posted.

Environmental activities and socio-cultural issues

Remediation activities

Navajo Nation

The US Environmental Protection Agency (EPA) is engaged in remediating uranium mining and milling impacted sites on the Navajo Nation. This mining took place between 1944 and 1986. Between 2008 and 2012, remediation was completed for 34 homes, 9 mine sites and high-priority drinking water supplies. A second five-year plan was developed (2014 to 2018) to remediate homes, increase water infrastructure, focus on priority mines located near homes, clean up the NE Church Rock mine and Tuba City dump, treat groundwater at mill sites, conduct health studies and expand interagency outreach. In 2018, the US EPA reached a settlement agreement with Tronox (Kerr-McGee), Cyprus Amax, Western Nuclear and other private companies that yielded USD 1.7 billion to be used to assess and remediate 219 mines, approximately 40% of the mines on the Navajo Nation. The US EPA and the Navajo Nation EPA are working together on assessment and enforcement actions at these sites.

Piketon

Decommissioning and environmental remediation continues at the Portsmouth Gaseous Diffusion Plant in Piketon, Ohio, which closed in 2001. In 2015, the DOE created a comprehensive plan to demolish the process buildings and support structures at the Portsmouth Gaseous Diffusion Plant. Three large buildings are currently being demolished by DOE contractor Fluor-BWXT. The estimated completion of clean-up activities is 2024.

DOE report to Congress on defence-related uranium mines

In 2014, in response to the 2013 US National Defense Authorization Act, the US Department of Energy (DOE) and the US EPA prepared a report to the US Congress describing the location and condition of abandoned uranium mines that provided uranium ore for US defence purposes from 1947 to 1970. The report identified 4 225 mines; however, the location of mines, status of reclamation, and risk to public health and safety were insufficiently understood for most of the mines.

In 2016, the Defense-Related Uranium Mines (DRUM) programme was initiated to provide verification and validation of the condition of the approximately 2 500 mines located on federal land. This work is proposed to be completed by 2022. The DOE Office of Legacy Management is now assessing the mines in partnership with other federal land management agencies. By the end of 2017, 400 mine sites had been investigated and 113 mines on federal land had been evaluated, with focus primarily on physical safety, radiological and chemical risk to the public who use these lands for recreational purposes. Many of these mines are small (less than 900 metric tons of ore were produced) and are likely to have few physical or health hazards. In a 2018 public presentation, the DRUM programme reported that of those mines that were evaluated, 58% had high or medium physical safety risks, and 35% had no physical, chemical or radiological risk.

Of interest, no relationship was found between the production volume and radiological or chemical risk ranking in the recreational use scenario. About a third of the total DRUM mines are estimated to be located on private land that could be used for residential purposes and might require more stringent screening scenarios than the recreations risk scenario now being used to evaluate these mines on public land.

Legislation/policy

Federal

In 2012, over one million acres of federal land near the Grand Canyon in Arizona were withdrawn from mineral entry for 20 years due to concerns about the environmental impacts of mining in this scenic area of the Colorado Plateau. Interdisciplinary studies of exploration and mining impacts in the region were initiated by the USGS in 2014 and are planned to continue throughout the moratorium. These studies are focused on the impacts of mining and exploration on the Grand Canyon watershed, wildlife, water resource and people. Research is focused on exposure pathways such as wind-borne dust, surface and groundwater, soil, and food-chain pathways. Soil samples throughout the region and adjacent to the developing Canyon Mine were collected and compiled to provide background geochemical data. Pre-mining biologic samples were collected near the Canyon Mine and showed bioaccumulation of heavy metals (As, Pb, Se, Tl and U) in tadpoles living in the mine containment pond and little to no accumulation of mine related analytes in other biotas (vegetation, birds, rodents or terrestrial invertebrates). Analysis of springs near the Pigeon mine show elevated uranium and other elements related to natural uranium sources and not mining activity. A more precise delineation of permissive areas for collapse breccia-type deposits has been developed in support of land use planning.

In 2018, the US Interior Department officially listed uranium as a critical mineral based on Executive Order 13817 issued by President Trump.

On 16 January 2018, two domestic uranium mining and milling companies petitioned the US Department of Commerce to investigate whether uranium imports posed a threat to national security. On 12 July 2019, President Trump declined to impose quotas or other trade measures on uranium imports and established a Nuclear Fuel Working Group to examine the current state of domestic nuclear fuel production to reinvigorate the entire nuclear fuel supply chain. On 23 April 2020, the US Department of Energy released the Administration's Nuclear Fuel Working Group strategy, which contains recommendations to revitalise and strengthen the front end of the fuel cycle and the domestic nuclear industry.

State

In October 2018, the state of Wyoming became an agreement state with the NRC and assumed regulatory authority, taking control of oversight of the state's uranium production. Regulations will remain the same, but the state would take primacy with regulatory oversight by the NRC. This transfer of oversight is designed to lower costs and shorten regulatory timelines, in particular for uranium recovery licensing applications. Other agreement states include Texas, Utah and Colorado.

Litigation

In June 2019, the US Supreme Court upheld the Commonwealth of Virginia's moratorium on banning uranium mining. This decision upheld earlier rulings by lower US courts that the Commonwealth of Virginia had the right to regulate uranium mining. Being the highest court in the land, this decision effectively prevents the development of the uranium deposit near Coles Hill, Virginia for the foreseeable future.

Regulatory regime

Regulation

Uranium recovery is regulated by the NRC and the EPA, and individual states, while mining regulations for federal lands are administered through the federal agency that controls this land (such as the Bureau of Land Management). Before mining commences, Environmental Impact Statements must be completed, adequate bonding must be posted, and additional regulatory requirements specified by federal and state agencies must be satisfied.

As of October 2018, the NRC is reviewing uranium recovery licence applications for two ISR facilities (one renewal and one expansion) and the agreement states are reviewing three ISR applications (two expansions and one renewal).

US NRC uranium recovery licence applications

Facility	Facility type	Applicant
Crownpoint	ISR - Renewal (NRC)	Hydro Resources, Inc.
North Trend	ISR - Expansion (NRC)	Crow Butte Resources
LC East/KM Horizon	ISR - Expansion	Lost Creek ISR LLC
Kendrick	ISR - Expansion	Stata Energy, Inc.
Smith Ranch-Highland	ISR - Renewal	Power Resources, Inc.

In October 2018, the EPA withdrew the January 2017 proposed rule, Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings (40 CFR 192), because of issues raised in the public comment period and because the once anticipated influx of new ISR licence applications is not likely to materialise. The EPA was reviewing and revising its standards for post-closure monitoring of uranium ISR sites (40 CFR 192). The proposed rule would focus on groundwater protection and restoration at ISR mining facilities. Post-restoration groundwater standards would be set for 12 constituents and monitoring requirements would be added. Post-restoration remediation and monitoring is currently administered by individual states, after EPA exempts the aquifer to be mined using ISR techniques from regulation under the Federal Clean Water Act of 1972. After reviewing public comments in 2015, EPA reproposed the rule and solicited additional public comment rather than finalising the rule. Any new or revised standards must be adopted by the NRC and its agreement states. In July 2020, EPA and the NRC signed a Memorandum of Understanding (MOU) regarding the regulation of in situ uranium recovery. The MOU describes how each agency will work with the other to accomplish their responsabilities under Title II the Uranium Mill Radiation Control Act 1978.

Uranium requirements

Annual US uranium requirements for the period 2020 to 2040 are projected to decrease from 19 435 tU in 2018 to 17 285 tU in 2040 (EIA high-case estimate). This decrease is based on the possibility that some nuclear power plants may retire early due to financial uncertainties in competitive electricity markets. These estimates include the operations of the new Watts Bar unit 2 in Tennessee and the construction of Vogtle units 3 and 4, scheduled to come online in 2021 and 2022.

In late July 2019, Ohio became the fifth US state to enact policies that provide for compensation or other assistance for nuclear power plants. Connecticut, Illinois, New Jersey and New York have implemented similar support programmes since 2017. These price and market support legislations currently affect 14 of the 96 operating commercial power reactors. Many of the plants in these states had announced plans to permanently shut down due to unfavourable market conditions. Other US states with nuclear power reactors operating in merchant markets are also examining legislative options for their nuclear power industry.

Supply and procurement strategy

The United States allows supply and procurement of uranium to be driven by market forces with resultant sales and purchases conducted solely in the private sector by firms involved in the uranium mining and nuclear power industries. Companies can petition the US government to conduct an investigation under Section 232 of the Trade Expansion Act of 1962, as amended, to determine the effect of imports on the national security. This occurred in 2018 when two US domestic mining and milling companies petitioned the Commerce Department to investigate whether uranium imports from foreign state-owned enterprises pose a threat to national security. In July 2019, President Trump declined to impose quotas or other trade measures but did establish a Nuclear Fuel Working Group to examine the current state of domestic nuclear fuel production to reinvigorate the entire nuclear fuel supply chain. On 23 April 2020, the Department of Energy released the Administration's Nuclear Fuel Working Group strategy, which contains recommendations to revitalise and strengthen the front end of the nuclear fuel cycle and the domestic nuclear industry.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

In July 2013, the DOE released the revised the *DOE Excess Uranium Inventory Management Plan* (2013 Plan). The 2013 Plan identified uranium inventories that have entered the commercial uranium market since the issuance of the December 2008 Plan, as well as transactions that are ongoing or being considered by the DOE through 2018. In the 2013 Plan, the guideline that the annual inventory release rate should not exceed 10% of US uranium requirements was removed. Several determinations have been made by the Secretary of Energy since 2008 to assess whether these transactions would have an adverse impact on the domestic uranium mining, conversion or enrichment industries. The determinations are required every two years. The June 2014 Secretarial determination found that continued transfers would have no impact on the domestic industry.

On 26 April 2017, Former US Secretary of Energy Rick Perry issued a determination permitting the DOE to continue making uranium transfers to support ongoing clean-up work at the Portsmouth Gaseous Diffusion Plant in Ohio, while also reducing the total amount of those transfers per year from 1 600 tU to 1 200 tU.

Currently, the United States does not possess a fully domestic uranium enrichment capability. The US uranium enrichment market consists of foreign enrichment technologies that cannot be used to meet national security requirements for enriched uranium. Acknowledging that it will take time to develop enrichment technologies and allow for a thorough analysis to inform an acquisition decision for producing unobligated low-enriched uranium (LEU), the US National Nuclear Security Administration's (NNSA) Domestic Uranium Enrichment strategy includes NNSA Defense Programs down-blending approximately 20 metric tons of highly-enriched uranium (HEU) to LEU for use as fuel in tritium production reactors. The uranium will be transferred to the NNSA federal partner, the Tennessee Valley Authority (TVA) only for use as fuel in a reactor producing tritium and not for resale or retransfer. The use of this material is compliant with long-standing US policy and international commitments that require LEU used for defence purposes to be free of peaceful use restrictions ("unobligated"). TVA is responsible for preserving the unobligated LEU to be used as fuel in tritium production reactors.

The Department's transfers of uranium are conducted in accordance with its authority under the Atomic Energy Act of 1954 and consistent with other applicable law. On 21 August 2018, the Secretary of Energy issued a determination covering the transfer of low-enriched uranium in support of the tritium production mission. The Secretarial Determination establishes the national security purpose of these transfers, therefore these uranium transfers will be conducted under Section 3112(e)(2) of the USEC Privatisation Act of 1996, which provides for transfers of enriched uranium to any person for national security purposes, as determined by the Secretary.

Uranium stocks

As of 2018, total commercial inventories (producer and utility stocks) were 50 578 tU, a 7% decrease from the 54 492 tU of inventories held in 2017. Nearly 85% of the commercial inventories, or 42 933 tU, were held by owners and operators of commercial reactors. This holding was a 10% decrease from the 47 639 tU owned by this group at the end of 2017.

Enriched uranium inventories held by utilities (including fuel elements in storage) decreased 7% from 2017 to 2018 (20 242 tU in 2017 to 18 860 tU in 2018), whereas natural uranium inventories held by utilities (including UF_6 in storage) decreased 12% from 2017 to 2018 (27 397 tU in 2017 to 24 072 in 2018).

Uranium prices

Owners and operators of US civilian nuclear power reactors (civilian owner/operators, or "COOs") purchased a total of 15 501 tU of deliveries from US suppliers and foreign suppliers during 2018, at a weighted-average price of USD 100.90/kgU.

The 2018 total of 15 501 tU decreased 6% compared with the 2017 total of 16 540 tU. The 2018 weighted-average price of USD 100.90/kgU was virtually the same as the 2017 weighted-average price of USD 100.87/kgU.

Nearly 10% of the 15 501 tU delivered in 2018 was US-origin uranium at a weighted-average price of USD 117.67/kgU. Foreign-origin uranium accounted for the remaining 90% of deliveries at a weighted-average price of USD 99.08/kgU. Canadian-origin uranium and Australian-origin uranium together accounted for 42% of total uranium purchased by United States. COOs in 2018. Uranium originating in Kazakhstan, Russia and Uzbekistan accounted for 40%.

COOs purchased three material types of uranium for 2018 deliveries from 37 sellers, one more seller than in 2017. Uranium concentrate was 59% of the 15 501 tU delivered in 2018. Enriched UF_6 was 21%, and Natural UF_6 was 20%. During 2018, 16% of the uranium delivered was purchased under spot contracts at a weighted-average price of USD 71.52/kgU. The remaining 84% was purchased under long-term contracts at a weighted-average price of USD 106.56/kgU. Spot contracts are contracts with a one-time uranium delivery (usually) for the entire contract, and the delivery typically occurs within one year of contract execution (signed date). Long-term contracts are contracts with one or more uranium deliveries to occur at least a year following the contract execution (signed date) and as such may reflect some agreements of short and medium terms as well as longer-term.

In 2018, COOs signed 36 new purchase contracts with deliveries in 2018 of 1 269 tU at a weighted-average price of USD 65.28/kgU. Five of these contracts were long-term and received deliveries of 231 tU at a weighted-average price of USD 74.41/kgU in 2018. The other 31 contracts were spot contracts with 1 269 tU delivered at a weighted-average price of USD 63.64/kgU in 2018. COOs report minimum and maximum quantities of future deliveries under contract to allow for the option of either decreasing or increasing quantities. At the end of 2018, the maximum uranium deliveries for 2019 through 2028 under existing purchase contracts for COOs totalled 67 182 tU. Also at the end of 2018, unfilled uranium market requirements for 2019 through 2028 totalled 77 337 tU. These contracted deliveries and unfilled market requirements combined represent the maximum anticipated market requirements of 144 628 tU over the next ten years for COOs.

Uranium exploration and development expenditures and drilling effort – domestic

(in USD million)

	2016	2017	2018	2019 (expected)
Industry* exploration expenditures[1]	2.5	3.7	W	NA
Government exploration expenditures	0	0	0	NA
Industry* development expenditures[2]	69.4	40.6	W	NA
Government development expenditures	0	0	0	NA
Total expenditures	71.9	44.3	W	NA
Industry* exploration drilling (m)[3]	W	W	W	NA
Industry* exploration holes drilled[4]	W	W	W	NA
Industry exploration trenches (metres)	NA	NA	NA	NA
Industry exploration trenches (number)	NA	NA	NA	NA
Government exploration drilling (m)	0	0	0	NA
Government exploration holes drilled	0	0	0	NA
Government exploration trenches (m)	NA	NA	NA	NA
Government exploration trenches (no.)	NA	NA	NA	NA
Industry* development drilling (m)[5]	W	W	W	NA
Industry* development holes drilled[6]	W	W	W	NA
Government development drilling (m)	0	0	0	NA
Government development holes drilled	0	0	0	NA
Subtotal exploration drilling (m)	W	W	W	NA
Subtotal exploration holes	W	W	W	NA
Subtotal development drilling (m)	W	W	W	NA
Subtotal development holes	W	W	W	NA
Total drilling (m)[7]	230 734	59 741	W	NA
Total number of holes drilled[8]	1 158	420	W	NA

* Non-government.

NA = Not available.

W = data withheld to avoid disclosure of individual company data.

1. Source: U.S. Energy Information Administration, Domestic Uranium Production Report, 2018, Table 8, Exploration.
2. Source: U.S. Energy Information Administration, Domestic Uranium Production Report, 2018, Table 8, Drilling + Land + Reclamation.
3. Source: U.S. Energy Information Administration, Domestic Uranium Production Report, 2018, Table 1, Exploration, feet (converted to metres using EIA Uranium Industry Annual Appendix D Uranium Conversion Guide).
4. Source: U.S. Energy Information Administration, Domestic Uranium Production Report, 2018, Table 1, Exploration, Number of Holes.
5. Source: U.S. Energy Information Administration, Domestic Uranium Production Report, 2018, Table 1, Development Drilling.
6. Source: U.S. Energy Information Administration, Domestic Uranium Production Report, 2018, Table 1, Development Drilling.
7. Source: U.S. Energy Information Administration, Domestic Uranium Production Report, 2018, Table 1.
8. Source: U.S. Energy Information Administration, Domestic Uranium Production Report, 2018, Table 1.

Average US uranium prices, 2004-2018

(USD per kilogram U-equivalent)

Year	Spot contracts	Long-term contracts
2018	71.52	106.56
2017	58.13	108.10
2016	76.82	119.59
2015	95.45	119.41
2014	95.26	129.29
2013	113.95	140.39
2012	132.69	144.68
2011	142.18	145.33
2010	114.36	131.11
2009	120.76	118.91
2008	174.06	108.12
2007	229.44	63.57
2006	102.64	42.59
2005	52.10	35.62
2004	38.40	31.82

Source: U.S. Energy Information Administration, Uranium Marketing Annual Report, 2018, Table 7.

Reasonably assured conventional resources by production method

(in situ tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Underground mining (UG)	0	W	18 000	W	NA
Open-pit mining (OP)	0	W	See Note 1	W	NA
In situ leaching alkaline	0	W	49 089	W	NA
Unspecified	0	0	0	0	NA
Total	0	18 564	67 089	135 870	NA

W = Data withheld to avoid disclosure of individual company data. NA = Not available.

Note 1: US reserves data do not draw a distinction between UG and OP; the combined value is assigned to UG.

Source: U.S. Energy Information Administration, Domestic Uranium Production Report, 2018, Table 10.

Reasonably assured conventional resources by processing method

(in situ tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from UG	0	NA	NA	NA	NA
Conventional from OP	0	NA	NA	NA	NA
In situ leaching acid	0	NA	NA	NA	NA
In situ leaching alkaline	0	NA	NA	NA	NA
In-place leaching*	0	NA	NA	NA	NA
Heap leaching** from UG	0	NA	NA	NA	NA
Heap leaching** from OP	0	NA	NA	NA	NA
Unspecified	0	NA	NA	NA	NA
Total	0	18 564	67 089	135 870	NA

* Also known as stope leaching or block leaching. ** A subset of open-pit and underground mining, since it is used in conjunction with them. NA = Not available.

Source: U.S. Energy Information Administration, Domestic Uranium Production Report, 2018, Table 10.

Reasonably assured conventional resources by deposit type

(in situ tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Unconformity-related	0	0	0	0	NA
Sandstone	0	18 564	67 089	135 870	NA
Intrusive	0	0	W	W	NA
Volcanic and caldera-related	0	0	W	W	NA
Other*	0	0	W	W	NA
Total	0	18 564	67 089	135 870	NA

* Includes surficial, collapse breccia pipe, phosphorite and other types of deposits, as well as rocks with elevated uranium content. Pegmatite, granites and black shale are not included.

NA = Not available.

Source: U.S. Energy Information Administration, Domestic Uranium Production Report, 2018, Table 10.

Historical uranium production by production method

(tonnes U in concentrate)

Production method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Open-pit mining*	0	0	0	0	0	0
Underground mining*	NA	W	W	W	W	NA
In situ leaching	NA	W	W	W	W	NA
Co-product/by-product	NA	W	W	W	W	NA
Total**	375 225	979	442	277	376 923	NA

Note: Data not available prior to 1968.

W = Data withheld to avoid disclosure of individual company data. NA = Not available.

* Pre-2015 totals may include uranium recovered by heap and in-place leaching.

** Also includes, in various years, mine water, mill site clean-up and mill tailings, and well field restoration as sources of uranium.

Source: U.S. Energy Information Administration, Domestic Uranium Production Report, 2018, Table 2.

Historical uranium production by processing method[a]

(tonnes U in concentrate)

Processing method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Conventional	NA	W	W	W	W	NA
In-place leaching*	NA	W	W	W	W	NA
In situ leaching	NA	W	W	W	W	NA
Other methods**	NA	W	W	W	W	NA
Total	374 361	1 122	940	634	377 057	NA

a – Does not equal production by method as it is produced concentrates and may include ore mined and shipped to a mill during the same year, ore that was mined during a previous year and later shipped from mine-site stockpiles, and/or ore obtained from drawdowns of stockpiles maintained at a mill site, and may additionally include uranium from mill clean-up, mine water, tailings water and other materials in various years.

Note: Data are available from 1947 to present.

W = Data withheld to avoid disclosure of individual company data. NA = Not available.

* Also known as stope leaching or block leaching.

** Includes mine water treatment and environmental restoration.

Source: U.S. Energy Information Administration, Domestic Uranium Production Report, 2018, Table 3.

Historical uranium production by deposit type

(tonnes U in concentrate)

Deposit type	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Unconformity-related	NA	NA	NA	NA	NA	NA
Sandstone	NA	NA	NA	NA	NA	NA
Hematite breccia complex	NA	NA	NA	NA	NA	NA
Quartz-pebble conglomerate	NA	NA	NA	NA	NA	NA
Vein	NA	NA	NA	NA	NA	NA
Intrusive	NA	NA	NA	NA	NA	NA
Volcanic and caldera-related	NA	NA	NA	NA	NA	NA
Metasomatite	NA	NA	NA	NA	NA	NA
Other*	NA	NA	NA	NA	NA	NA
Total	NA	NA	NA	NA	NA	NA

* Includes surficial, collapse breccia pipe, phosphorite and other types of deposits, as well as rocks with elevated uranium content. Pegmatite, granites and black shale are not included.

NA = Not available.

Ownership of uranium production in 2018

Domestic				Foreign				Totals	
Government		Private		Government		Private			
(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)
0	0	W	W	0	0	W	W	277	100

W = Data withheld to avoid disclosure of individual company data.

Source: U.S. Energy Information Administration, Domestic Uranium Production Report, 2018, Table 2.

Uranium industry employment at existing production centres

(person-years)

	2016	2017	2018	2019 (expected)
Total employment related to existing production centres[1]	462	324	234	NA
Employment directly related to uranium production[2]	424	274	207	NA

1. Source: U.S. Energy Information Administration, Domestic Uranium Production Report, 2018, Table 6, all sectors except Reclamation.

2. Source: U.S. Energy Information Administration, Domestic Uranium Production Report, 2018, Table 6, all sectors except Exploration and Reclamation.

NA = Not available.

Short-term production capability

(tonnes U/year)

2020				2025				2030			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

2035				2040			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
NA	NA	NA	NA	NA	NA	NA	NA

NA = Not available.

Re-enriched tails production and use[1]

(tonnes of natural U-equivalent)

Re-enriched tails	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Production	5 677.8	0	0	0	5 677.8	0
Use	1 939.8	0	0	0	1 939.8	0

1. Data provided by Energy Northwest, owner-operator of the Columbia Generating Station.

Net nuclear electricity generation[1]

(TWh net)

	2017	2018
Nuclear electricity generated	805	807p

1. OECD Nuclear Energy Data 2018. p = provisional data.

Installed nuclear generating capacity to 2040[1]

(MWe net)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
99 635	99 355p	98 336	98 336	92 285	93 286	71 952	91 500	64 819	90 940	49 991	91 273

1. OECD Nuclear Energy Data 2017. p = provisional data.

Annual reactor-related uranium requirements to 2040 (excluding MOX)[1]

(tonnes U)

2017	2018	2020		2025		2030		2035		2040	
		Low	High	Low	High	Low	High	Low	High	Low	High
17 852	19 435p	17 954	17 954	11 964	16 671	16 282	18 746	10 014	16 358	7 179	17 285

1. OECD Nuclear Energy Data 2017. p = provisional data.

Total uranium stocks

(tonnes natural U-equivalent)

Holder	Natural uranium stocks	Enriched uranium stocks	Depleted uranium stocks	LWR reprocessed uranium stocks	Total
Government[1]	5 285	4 396	90 000	NA	99 681
Producer[2]	NA	NA	NA	NA	7 645
Utility[2]	24 072[3]	18 860[4]	NA	NA	42 933
Total	NA	NA	NA	NA	150 259

1. U.S. Government Analysis of potential impacts of uranium transfers on the domestic Uranium Mining, Conversion, and Enrichment Industries, 2017.

2. U.S. Energy Information Administration, Uranium Marketing Annual Report, 2018, Tables 22 and 23.

3. The value for natural uranium stocks in this table does not include natural uranium hexafluoride (UF6). Values for total utility natural uranium stocks in the text include natural UF6.

4. The value for enriched uranium stocks in this table does not include fabricated fuel elements held in storage prior to loading in the reactor. Values for total utility enriched uranium in the text include fabricated fuel elements in storage.

NA = Not available.

Uzbekistan*

Uranium exploration and mine development

Historical review

Uranium exploration in Uzbekistan predates the 1945 start-up of uranium mining at the small vein ore deposits (Shakaptar, Uiguz Sai and others) in the Fergana Valley of Eastern Uzbekistan. Exploration conducted during the early 1950s, including airborne geophysical surveys, ground radiometry and underground work over the remote Kyzylkum desert in central Uzbekistan, led to the discovery of the Uchkuduk and Ketmenchi uranium deposits in 1952, the Bukinai deposit in 1959, the Sabyrsai deposit in 1960, and the South Bukinai, Sugraly and Lyavlyakan deposits in 1961. All deposits were discovered by the Krasnokholmskaya exploration company, which was renamed Kyzyltepageologia in 1990. Drilling confirmed the initial discovery and development of the first mine at the Uchkuduk deposit in 1959, followed by development of the Sabyrsai deposit. Both deposits were initially mined using open-pit and underground mining methods until 1975.

In the early 1960s, development of the in situ leaching (ISL) mining technique for recovery of uranium from sandstone deposits led to the re-evaluation of previously ignored deposits including Lavlakan and Ketmenchi and to an increase in exploration efforts in the sedimentary environments of the Kyzylkum desert. Three uranium districts with 24 sandstone-type deposits amenable to ISL mining have been established since the Uchkuduk discovery in 1952.

A number of black shale type uranium deposits, including Dzhantuar, Rudnoye, Kostcheka, Voskhod and Dzitym, were identified during the 1960s in the Auminzatau Mountains district. Mineralisation is in black shale related to strata-structure-type and occurs in stratiform and stockwork lodes. Resources of individual deposits are relatively small and grades range from 0.02 to 0.13% U, averaging 0.05% U.

Since 1994, the Navoi Mining and Metallurgy Combinat (NMMC) has funded all uranium exploration activities in Uzbekistan. In 1995-1996, Kyzyltepageologia developed the known resources of the Severny (Northern) Kanimekh, Alendy, Kendykijube and Tokhumbet deposits. In addition, assessments of undiscovered resources were completed in the Kyzylkum, Bukhara-Khiva and Fergana Provinces.

Between 1997 and 2000, Kyzyltepageologia evaluated the known resources of the Kendiktyube, Severny, Kanimeh, Tokhumbet and Ulus deposits, some of which were handed over to NMMC for further investigation. Delineation drilling was carried out in 2002 on the Kendytyube and Tokhumbet deposits, then transferred to Mining Division No. 5 for commercial development.

From 2003-2004, Kyzyltepageologia completed exploration and evaluation works in the Kendyktyube and Tokhumbet deposits, the southwestern flanks of the Sugraly deposit, and the western and eastern flanks of the Ketmenchi deposit. Kyzyltepageologiya further explored the northern and southern areas of Central Kyzylkum with government funding.

* Report prepared by the NEA/IAEA, based on previous Red Books, a report submitted by the Navoi Mining and Metallurgy Combinat in August 2020, and public data.

In August 2009, GoscomGeology (State Geology and Mineral Resources Committee) and the China Guangdong Nuclear Uranium Corp. (CGN-URC) set up a 50%-50% uranium exploration joint venture, Uz-China Uran, to focus on the black shale deposits in the Boztau area of the Central Kyzylkum Desert in the Navoi region. Approximately 5 500 tU resources have been reported. From 2011-2013, CGN-URC was to develop technology for the production of uranium and vanadium from these black shale deposits. No activities have been reported since that time.

In July 2013, the Japan Oil, Gas and Metals National Corporation (JOGMEC) received a five-year licence for uranium exploration at two prospective areas in the country's Navoi region. JOGMEC indicated that they would implement geological exploration work in the Juzkuduk and Tamdiykuduk-Tulyantash prospective ore fields. Historical uranium resources discovered at the licensed sites total about 13 000 tU according to Uzbek government data. No activities have been reported since that time.

Recent and ongoing uranium exploration and mine development activities

In December 2019, France and Uzbekistan established the French-Uzbek uranium joint venture, the Nurlikum Mining LLC, which is 51% owned by Orano (formerly Areva) and 49% by Uzbekistan's State Committee on Geological and Mineral Resources (GoscomGeology). Nurlikum Mining will conduct uranium exploration and mining operations throughout Uzbekistan, focusing on sandstone-type uranium mineralisation in the Djengeldi region of Kyzylkum province. Nurlikum's first field work should commence in 2020.

Uranium resources

Uzbekistan's uranium resources occur primarily in sandstone-type and black shale type deposits.

All significant sandstone roll-front type uranium resources are found in the Central Kyzylkum area, comprising a 125 km-wide belt extending over a distance of about 400 km from Uchkuduk in the northwest, to Nurabad in the southeast. Only sandstone-type deposits have been exploited.

In 2014, GoscomGeology determined that in situ resources of uranium in Uzbekistan amounted to 185 800 tU, with 138 800 tU of sandstone type and 47 000 tU of black shale type.

As of 1 January 2019, Uzbekistan's total identified recoverable uranium resources at a cost <USD 130/kgU amounted to about 132 300 tU. Compared with the data as of 1 January 2017, this is a decrease of 6 850 tU in recoverable RAR resources due to mining depletion in 2017 and 2018. There are no changes to inferred resources. About 95% of RAR and 40% of inferred sandstone-type resources are controlled by the NMMC, which is owned by the government of Uzbekistan and the balance of which resides in a "fund of undistributed resources". The table below gives a breakdown of resources under the control of NMMC by status and categories.

Prognosticated resources are estimated at about 25 000 tU.

Resources controlled by the NMMC

(tonnes U as of 1 January 2020)

Status	Deposits, prospective sites	Depth, m	Category*					
			Balance (economic feasible)			Off-balance (not feasible)		
			C1	C2	C1+C2	C1	C2	C1+C2
Northern Mining Unit:								
Under development	Uchkuduk	300	192	0	192	753	2 160	2 913
	Kendyk-Tyube	170	427	0	427	0	515	515
	Meilisai	195-360	3 918	28	3 946	0	0	0
	Subtotal under development:		4 537	28	4 565	753	2 675	3 428
Prospective	Kushkuduk open pit		0	2 839	2 839	0	0	0
	Kushkuduk open-pit piles	150	0	79	79	0	0	0
	Maidanli (Rudnoe)	140	2 412	0	2 412	384	0	384
	Subtotal prospective:		2 412	2 918	5 330	384	0	384
Northern Mining Unit totals:			6 949	2 946	9 895	1 137	2 675	3 812
Mining Unit No. 5:								
Under development	Northern Bukinai	520	3 698	1 208	4 905	388	0	388
	Istiklol	140	2 810	109	2 919	0	0	0
	Kukhnur	480	2 411	0	2 411	0	0	0
	Aulbek	310	3 456	0	3 456	0	0	0
	Southern Bukinai	420	613	0	613	0	0	0
	Northern Kanimekh	540	6 381	1 233	7 614	36	0	36
	Beshkak	280	0	688	688	589	2 327	2 916
	Loiliken	160	18	2 594	2 612	292	2 187	2 479
	Aksai-1	320	112	15	127	409	30	439
	Terekuduk	350	843	1 455	2 298	0	0	0
	Dzhengeldy	310	1 486	0	1 486	0	0	0
	Sugrali (for ISL and underground mining)	675	3 104	1 230	4 334	16 713	2 400	19 113
	Southern Sugrali	380	2 072	0	2 072	0	0	0
	Ketmonchi	460	1 280	130	1 410	1 313	118	1 431
	Egdu	600	0	0	0	445	1 266	1 711
	Maibulok	370	455	0	455	0	0	0
Mining Unit No. 5 totals:			28 739	8 660	37 399	20 185	8 328	28 513
Southern Mining Unit:								
Under development	Sabirsai	450	0	0	0	694	1 134	1 828
	Agron (eastern flank)	760	4	0	4	0	0	0
	Shark	220	472	0	472	531	228	759
	Ulus	200	204	0	204	0	0	0
	Nurbulok	350	543	0	543	0	0	0
	Ingichki	490-640	401	61	462	213	0	213
Southern Mining Unit totals:			1 623	61	1 684	1 438	1 362	2 800
Under development, prospective, and NMMC grand totals:								
Under development:			34 899	8 749	43 649	22 375	12 365	34 740
Prospective:			2 412	2 918	5 330	384	0	384
NMMC grand total:			37 312	11 667	48 979	22 759	12 365	35 124

* Resource categories according to the national Uzbekistan classification system. Secretariat estimate that balance economic feasible resources belong to < USD 80/kgU category and off-balance resources to < USD 130/kgU category. C1 resources correlate with RAR and C2 with Inferred resources (see Appendix 3, Figure A3.1).

Uranium production

Historical review

Uranium production in Uzbekistan began in 1946 at several small volcanic vein deposits in the Fergana valley and Kazamazar uranium district. The two largest deposits, Alatanga and Chauli, contained 4 500 tU each. Underground mining was undertaken from the late 1940s to the early 1960s. Cumulative production is estimated in the order of several thousand tU. The ore was processed in the Leninabad uranium production centre in Tajikistan.

The mining operator for the sandstone-type Uchkuduk and Sabyrsai deposits was Mining Complex No. 2, which was established in September 1958. In 1967, it was renamed the Navoi Mining and Metallurgy Combinat (NMMC). NMMC is part of the Uzbekistan state holding company Kyzylkumredmetzoloto that undertakes all uranium mining in the country.

In the late 1950s, NMMC commenced operation focusing on uranium and gold production in the desert region of Central Kyzylkum province. Early uranium mining was by underground (to 1990) and open pit (to 1994).

The first ISL tests occurred at the Uchkuduk deposit in 1963, followed by ISL tests at the Sabyrsai, South Bukinai and Ketmenchi deposits in 1968. Commercial ISL mining in Uzbekistan began in 1975. In 1980, ISL accounted for 29% of total uranium production and by 1985 ISL comprised 56% of total production. Since 1995, NMMC has been producing uranium using only ISL technology. Annual production peaked in the 1980s, when 3 700 to 3 800 tU were recovered.

In 2008, NMMC started mining the major new Northern Kanimekh deposit, northwest of Navoi. Northern Kanimekh ore occurs 260-600 m below the surface, with 77% of the uranium resources present at 400-500 m depth. NMMC has also started building a pilot plant for ISL at the Alendy and Yarkuduk deposits, and began operating the Aulbek ISL mine in Central Kyzylkum, as well as developing the Meilysai deposit. The Aulbek mine at the deposit of the same name commenced production in 2013.

NMMC has developed and implemented two new technologies of acid ISL for ores with high carbonate content. The first is a bicarbonate–acid method that is used for ores with a carbonate content above 2%. It is based on bicarbonate ion generation during the soft acidification stage, which oxidises and dissolves uranium minerals. This method reduces the kinetics of the leaching process, but chemical plugging may occur at the final leaching stage. The repair and restoration procedures for wells is reduced by 2.5-3 times using this method.

The second method uses a mini-reagent technology that is applied for ores with a carbonate content >0.5% located in an artesian aquifer. At the first stage, a preliminary ore oxidation occurs by pumping compressed air into the aquifer. At the second stage, slightly acidic solutions, formed during aquifer saturation with atmospheric oxygen, dissolve the contained uranium.

The implementation of these two technologies has significantly reduced acid consumption and in turn operating costs by 20-30%. Another important advantage has been the low impact of ISL mining on the total mineralisation and chemical composition of productive aquifers during and after the leaching process.

Status of production capability and recent and ongoing activities

NMMC is among the top 10 global gold and uranium mining companies and is the biggest mining company in Uzbekistan.

NMMC produces uranium by ISL at three mining divisions that operate nine uranium deposits at depths between 120 to 500 metres:

- the Northern Mining Unit in Uchkuduk operates the Kendyktube deposit;
- the Southern Mining Unit in Nurabad operates the Sabyrsai deposit;
- Mining Unit No. 5 in Zafarabad operates the Northern Bukinai, Lyavlyakan, Beshkak, Ketmenchi, Sugraly, Tokhumbet and Kanimekh deposits.

All mining units produce "yellow cake" uranium concentrates on-site and send it by rail to the Hydrometallurgical Plant No. 1, located in Navoi, for further processing and purification. NMMC exports all produced uranium. Annual production amounted to approximately 3 300 tU to 3 500 tU from 2015 to 2019. Production estimates over these years have been revised since the last edition based on new information provided by NMMC.

The NMMC promotes monitoring of working conditions and environmental protection. Local and central divisions of the national health monitoring authority, the National Committee for Nature Protection and the National Mining Monitoring Authority, conduct radiation monitoring of all NMMC's activities. Monitoring data from peripheral observation wells shows that for productive aquifers at all ISL sites, the natural geochemical background of the formation water is unchanged at a distance of 200-300 m from the ore body boundary, regardless of the leaching technology used (sulphuric acid, bicarbonate-acid or mini-reagent). Radiation monitoring at work locations, supervised areas and the environment, shows that the average annual effective equivalent radiation dose does not exceed permitted levels. For example, for a critical group of the population, radiation does not exceed one millisievert per year, which corresponds to the basic limit adopted by the International Commission on Radiological Protection (ICRP).

Ownership structure of the uranium industry

All uranium produced by the NMMC is owned by the government of Uzbekistan.

Employment in the uranium industry

During the Soviet era, Uzbekistan provided much of the uranium required by the Soviet military-industrial complex. Five "company towns" were constructed to support uranium production activities: Uchkuduk, Zarafshan, Zafarabad, Nurabad and Navoi, with a combined population of about 500 000. These towns remain central to the five mining districts. Uranium industry employment during 2016-2019 was about 7 300, though approximately 59 000 were employed by NMMC overall in 2015, with gold mining and other activities included (Navoi Mining and Metallurgy Combinat, 2015).

Uranium policies, uranium stocks and uranium prices

Until 1992, all uranium produced in Uzbekistan was shipped to Russia. From 1992 through 2013, practically all of Uzbekistan's uranium production was exported to the United States and other countries through the Nukem company. In 2008, Korea's KEPCO signed agreements to purchase 2 600 tU over six years to 2015, for about USD 400 million. In 2013, 1 663 tU was supplied to China according to the country's custom import statistics. In May 2014, China's CGN agreed to buy USD 800 million of uranium through to 2021. Uzbekistan's state-owned NMMC has also signed a contract to supply 2 000 tU to India from 2014 through 2018.

In December 2019, Uzbekistan agreed to sell uranium to two Japanese trading companies. Uzbekistan's NMMC signed separate contracts with ITOCHU (valued at USD 636.4 million) and Marubeni (valued at USD 510.1 million) with both agreements covering uranium deliveries between 2023 and 2030.

Reasonably assured conventional resources by production method

(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
In situ leaching acid	30 520	30 520	50 760	50 760	80

Reasonably assured conventional resources by processing method

(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
In situ leaching acid	30 520	30 520	50 760	50 760	80

Reasonably assured conventional resources by deposit type

(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Sandstone	30 520	30 520	50 760	50 760	80

Inferred conventional resources by production method

(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
In situ leaching acid	24 320	24 320	48 640	48 640	80
Open pit	0	0	32 900	32 900	70
Total	24 320	24 320	81 540	81 540	

Inferred conventional resources by processing method

(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
In situ leaching acid	24 320	24 320	48 640	48 640	80
Unspecified	0	0	32 900	32 900	70
Total	24 320	24 320	81 540	81 540	

Inferred conventional resources by deposit type

(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Sandstone	24 320	24 320	48 640	48 640	80
Black shales	0	0	32 900	32 900	70
Total	24 320	24 320	81 540	81 540	

Prognosticated conventional resources

(tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
24 800	24 800	24 800

Speculative conventional resources

(tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
NA	NA	NA

Historical uranium production by production method

(tonnes U in concentrates)

Production method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (preliminary)
Open-pit mining*	36 249	0	0	0	36 249	0
Underground mining*	19 719	0	0	0	19 719	0
In situ leaching	74 323	3 325	3 400	3 450	84 498	3 500
Total	130 291	3 325	3 400	3 450	140 466	3 500

* Pre-2015 totals may include uranium recovered by heap and in-place leaching.

Ownership of uranium production in 2018

Domestic				Foreign				Totals	
Government		Private		Government		Private			
(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)	(tU)	(%)
3 450	100	0	0	0	0	0	0	3 450	100

Uranium industry employment at existing production centres

(Person-years)

	2016	2017	2018	2019
Employment directly related to uranium production	7 183	7 266	7 340	7 387

Short-term production capability*

(tonnes U/year)

2020				2025				2030			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
3 500	3 500	3 500	3 500	3 000	3 000	3 000	3 000	2 000	2 500	2 000	2 500

2035				2040			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
500	2 500	800	2 500	0	2 000	0	2 000

* Secretariat estimate based on the information of resources controlled by the NMMC.

Viet Nam

Uranium exploration and mine development

Historical review

The first exploration programmes were started prior to 1955 by French geologists of the Geological Department of Indochina. Beginning in 1978, a systematic regional exploration programme was conducted over the entire country using radiometric methods combined with geological observations. About 25% of the country was also covered by an airborne radiometric/magnetic survey at a scale of 1:25 000 and 1:50 000. This led to the discovery of a large number of promising areas in the provinces of Cao Bang, Lao Cai, Yen Bai and Quang Nam. Uranium mineralisation in Viet Nam is associated with rare earth element deposits (Lao Cai province), phosphate deposits (Cao Bang province), and sandstone and coal deposits (Quang Nam province).

Between 1997 and 2002, the Geological Division for Radioactive and Rare Elements (GDRRE) carried out detailed uranium exploration and evaluation (including drilling, trenching and bulk sampling) in the Palua and Parong areas of the Quang Nam province.

Recent and ongoing uranium exploration and mine development activities

Since 2010, the GDRRE, in the Ministry of Natural Resources and Environment has been carrying out uranium exploration in the Parong area in the Quang Nam province in central Viet Nam. The project consists of an investigation and evaluation of Triassic sandstone-type deposits.

Exploration activities on the Parong deposit, covering an area of 1.9 km^2, consist of geophysical and geological surveys, trenching, drilling and mining tests. Over the main part of the deposit, 712 holes (60 954 m) have been drilled on a 25 x 25 m^2 grid to depths of between 30 and 150 m. Extensions of the deposit have also been drilled on a more widely spaced grid (between 50 x 50 m^2 and 50 x 25 m^2).

A mining test was conducted via a 130 m adit from which 3 holes were drilled to 300 m for hydrogeological tests. Results showed a limited amount of water in the formations.

Mineralisation at Parong is associated with medium to coarse-grained sandstone with organic matter. Three main levels of mineralisation in reduced formations have been defined, separated by oxidised sandstones. Mineralisation over a lateral extension of 200-300 m has been intersected that varies in thickness from a few centimetres to a few metres.

In support of this exploration project, research on ore leaching treatment methods, laboratory and pilot-scale tests, as well as investigations on the management of mining wastes and tailings, have been carried out by the Institute for Technology of Radioactive and Rare Elements. The results show that the heap leach method is suitable for the low-grade Parong ore, with uranium recovery greater than 75% achieved.

Uranium resources

Identified conventional resources

In 2011-2012, the uranium potential of part "A" of the Parong area (drilled at a 25 x 25 m^2 grid) was assessed. Uranium resources, estimated using a 0.0085% U cut-off grade, amounted to 1 200 tU at an average grade of 0.034% U. These resources are classified as reasonably assured resources in the highest cost category (<USD 260/kgU or <USD 100/lb U_3O_8).

From 2013 to 2015, the uranium potential of part "G" of the Parong-Palua area was assessed. Inferred uranium resources are estimated at 1 081 tU.

From 2016 to 2019, estimation of the uranium potential of remaining parts "B", "C", "D" and "F" of the Palua-Parong continued.

Results of a previous evaluation (uranium resources as of 31 December 2008) in the main area of the Quang Nam province concluded that:

- the Palua deposit consists of five orebodies with total resources amounting to 4 596 tU, including 984 tU inferred resources and 3 612 tU prognosticated;
- the Parong deposit consists of seven orebodies with total resources amounting to 3 867 tU, including 1 200 tU inferred resources and 2 667 tU prognosticated;
- the Khehoa-Khecao deposit consists of four orebodies with total resources amounting to 5 803 tU, including 1 125 tU inferred resources and 4 678 tU prognosticated;
- the Dong Nam Ben Giang deposit consists of eight orebodies with total resources amounting to 1 556 tU, including 337 tU inferred resources and 1 219 tU prognosticated;
- resources of the An Diem deposit amount to 1 853 tU, including 354 tU inferred and 1 499 tU prognosticated.

For the above deposits of the Quang Nam province, this totals 3 646 tU inferred resources, 12 176 tU prognosticated resources, and 15 822 tU combined inferred and prognosticated resources.

Undiscovered conventional resources (prognosticated and speculative resources)

The results of geological exploration conducted by GDRRE show that there are more than ten uranium occurrences and deposits located in the northern provinces (Lai Chau, Lao Cai, Yen Bai, Son La, Ha Giang, Cao Bang, PhuTho and Thai Nguyen), as well as in the highlands and central provinces.

Uranium deposits located in the Lai Chau province are associated with rare earth element deposits. In the Cao Bang province, uranium mineralisation is associated with phosphate deposits, and in the Quang Nam province, uranium is associated with sandstones and in coal deposits.

The undiscovered conventional uranium resources as of 31 December 2008 amounted to a total of 81 200 tU prognosticated and 321 600 tU speculative resources. Some of the prognosticated resources include: 3 612 tU at Palua; 2 667 tU at Parong; 4 678 tU at Khehoa-Khecao; 1 219 tU at Dong Nam Ben Giang; and 1 499 tU at An Diem.

Unconventional resources and other materials

Uranium exploration activities associated with rare earth element ores (Dong Pao bastnaesites, Namxe bastnaesite, YenPhu xenotime and beach sand monazite, etc.) are being conducted.

Uranium production

No uranium has been produced in Viet Nam.

Future production centres

The objective of the current uranium exploration programme is to increase the resource base to a total of 5 500 tU_3O_8 (4 665 tU) inferred and 8 000 tU_3O_8 (6 780 tU) prognosticated, as well as determining the feasibility of mining these deposits. The Institute for Technology of Radioactive and Rare Elements has carried out research on ore processing and has started to survey the environmental conditions of future mining operations. No production centre is planned at this time.

Environmental activities and socio-cultural issues

Environmental activities, such as monitoring the environmental impacts resulting from exploration, are being carried out.

Uranium requirements

Viet Nam had a plan to develop a nuclear power plant that was expected to include 14 nuclear units with a total net nuclear electricity generating capacity of about 15 000 MWe to 16 000 MWe by the year 2030. Seven sites for the construction of an NPP had been selected with each site having the potential to accommodate four to six units.

In March 2010, the Prime Minister of Viet Nam approved the overall plan for the implementation of the NinhThuan Nuclear Power Project, which included the PhuocDinh and Vinh Hai NPPs.

Under this plan, the first NPP would have consisted of two VVER-type PWRs with a total net nuclear electricity generating capacity of about 2 000 MWe, built in co-operation with Rosatom. This plant would have been located in the PhuocDinh commune, Thuan Nam district, NinhThuan province. The second NPP, to have been built in co-operation with Japan Atomic Power Co., would have had the same generating capacity (2 x 1 000 MWe) and been located in the Vinh Hai commune, Ninh Hai district, NinhThuan province. The expected annual reactor-related uranium requirements would have been satisfied by imports and domestic production.

Because of a lack of funding at the end of 2016, the Viet Nam government decided to stop the above-mentioned plans to build the NinhThuan Nuclear Power Project. However, uranium exploration activities and research on uranium extraction from uranium ores continue.

Uranium exploration and development expenditures and drilling effort –domestic

(Vietnamese dong)

	2014	2015	2016	2017
Industry* exploration expenditures				
Government exploration expenditures	40 000 000 000	57 000 000 000	40 000 000 000	35 000 000 000
Total expenditures	40 000 000 000	57 000 000 000	40 000 000 000	35 000 000 000
Government exploration drilling (m)	NA	12 097	NA	NA
Government exploration holes drilled	NA	NA	NA	NA
Total drilling (m)	NA	NA	NA	NA
Total number of holes drilled	NA	NA	NA	NA

* Non-government.

Reasonably assured conventional resources by production method

(tonnes U*)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Underground mining (UG)	0	0	0	1 200
Total	0	0	0	1 200

* In situ resources.

Reasonably assured conventional resources by processing method

(tonnes U*)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Heap leaching** from UG	0	0	0	1 200
Total	0	0	0	1 200

* In situ resources.

** A subset of open-pit and underground mining, since it is used in conjunction with them.

Reasonably assured conventional resources by deposit type

(tonnes U*)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	0	1 200
Total	0	0	0	1 200

* In situ resources.

Inferred conventional resources by production method

(tonnes U*)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Unspecified	0	0	0	4 000
Total	0	0	0	4 000

* In situ resources.

Inferred conventional resources by processing method

(tonnes U*)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Unspecified	0	0	0	4 000
Total	0	0	0	4 000

* In situ resources.

Inferred conventional resources by deposit type

(tonnes U*)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	0	4 000
Total	0	0	0	4 000

* In situ resources.

Prognosticated conventional resources

(tonnes U)

Cost ranges		
<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
NA	NA	81 200

Speculative conventional resources

(tonnes U)

Cost ranges		
<USD 130/kgU	<USD 260/kgU	Unassigned
NA	NA	321 600

Zambia*

Uranium exploration and mine development

Historical review

Uranium was first identified in Zambia (then Northern Rhodesia) at the site of the Mindola copper mine in Kitwe, leading to the mining of this small deposit between 1957 and 1959. A total of 102 tU_3O_8 (86 tU) was produced. Although no uranium has been produced from that mine or any other in Zambia since then, exploration activity has been carried out periodically by the government and by private companies.

Sporadic uranium exploration activities took place during the 1980-1990s but attention was primarily focused on copper. It was only in the mid-2000s that interest in uranium was stimulated by the dramatic rise in the spot market price for uranium.

The exploration environment in Zambia underwent a fundamental change in 1969. Prior to this date, all mineral rights were held privately, but in 1969 these rights reverted to the state. In 1969, the state also effectively nationalised mining by becoming a majority shareholder in all mining companies active in the country (principally copper). Financial realities, including a decline in copper prices, along with recommendations from external bodies, such as the World Bank and International Monetary Fund, encouraged the state to enter into a process of privatisation. This became a reality in 1997 with the primary objective of encouraging foreign investment in the country.

During the 1980s, active exploration for uranium by government and private companies within the Katanga metasediments revealed small, isolated medium grade deposits in the Dome areas of North-Western Province. The Karoo sediments were also prospected by private companies and revealed some small low-grade deposits at shallow depths. Speculative resources were estimated at 35 000 tU.

Recent and ongoing uranium exploration and mine development activities

In mid-2011, Equinox Minerals was taken over by Barrick Gold Corp. for CAD 7.3 billion. At that time, a total of 4.2 Mt of uraniferous ore at a grade of 0.118% U_3O_8 (0.1% U) was stockpiled at the Lumwana copper mine, which could be processed at a later date if Barrick decided to build a uranium mill for an estimated cost of USD 200 to 230 million. In 2012, drilling programmes at Lumwana were focused on resource definition at Chimiwungo, reserve delineation at Chimiwungo and Malundwe, extension exploration drilling at Chimiwungo and condemnation drilling to test for economic mineralisation in areas of planned mining infrastructure. A total of 237 277 m of diamond drilling and 49 029 m of reverse circulation drilling was completed during 2012 in order to better define the limits of mineralisation and develop an updated, more comprehensive block model of the ore body for mine planning purposes. Total resources, including the uranium ore stockpiled at Malundwe, amounted to 7 492 tU at an average grade of 0.07% U. However, the ore body did not meet economic expectations. The drilling defined significant additional mineralisation, some at higher grades. However, much of this mineralisation was deep and would therefore require a significant amount of waste stripping, making it uneconomic based on the expected operating costs and current market copper prices. Activity continues on several key initiatives to lower costs, including improvements to operating systems and processes.

* Report prepared by the NEA/IAEA, based on previous Red Books and company reports.

Denison completed extensive drilling in 2011 and 2012 on their Mutanga Project. Airborne geophysical techniques were used to locate anomalies and potential uranium mineralisation. Near-surface mineralisation at the Dibwe East zones 1 and 2 is consistent over a strike length of 4 km, with high-grade ore in its core. Future exploration activities are expected to include extensive surficial geochemistry and surface radon surveys, geological mapping, and airborne geophysics, all of which will be used to assist in defining drill targets.

At the end of 2012, African Energy concluded baseline environmental studies for the Chirundu Uranium Project, which was the only work completed by African Energy on its uranium projects. The Chirundu Project near the Zimbabwe border is focused on exploring the Njame and Gwabe deposits and reports 4 270 tU as measured, indicated and inferred resources. A mining licence was granted for the project in October 2009, with a view to a 500 tU/yr acid heap leach operation. It includes the Siamboka prospect. A feasibility study was commenced but then deferred because of low uranium prices. The company was also exploring the Chisebuka deposit, 250 km along strike south-west.

In June 2016, GoviEx Uranium acquired Denison's Mutanga Project, and in October 2017 completed the acquisition of Africa Energy's Chirundu Uranium Project consolidating these adjacent projects. In 2017, GoviEx released a new preliminary economic assessment for the Mutanga uranium project, including the mineral resource estimate for Mutanga, Dibwe, Dibwe East, Gwabe, Njame and Njame South ore deposits. The project currently consists of five main uranium deposits under three fully-permitted contiguous mining licences, totalling 140 km in strike length. It also includes two more prospective licences covering 100 km^2.

In 2017 and 2018, exploration expenditures by GoviEx amounted to USD 710 000 and USD 607 000, respectively

Uranium resources

Identified conventional resources (reasonably assured and inferred resources)

In October 2017, GoviEx published an NI 43-101 technical report on a preliminary economic assessment of the Mutanga Project. GoviEx's Mutanga and Chirundu deposits are estimated to hold 21.6 Mt of measured ore resources grading 269 ppm U (0.0269% U) and containing 5 810 tU. Inferred resources are estimated to be 74.6 Mt of ore grading 231 ppm U (0.0231% U) and containing 17 270 tU. A mineral reserve has yet to be evaluated for the project.

The Lumwana copper mine, where resources are hosted by mica-quartz-kyanite schists of the Katangan Supergroup contains identified recoverable resources of 6 967 tU. Potential for the discovery of additional uranium resources exists in various parts of the country that have been poorly explored. Of particular interest is the Copperbelt where many copper orebodies are associated with uranium mineralisation.

Uranium production

Historical review

A total of 102 tU_3O_8 (86 tU) was produced at the Mindola mine in Kitwe during the late 1950s. Production ceased in 1960 and no uranium has been produced since.

Uraniferous ore was stockpiled at Lumwana while mining the higher-grade Malundwe copper deposit. As of March 2011, the stockpile amounted to 4.2 Mt of ore grading at 0.1% U.

Future projects

GoviEx Uranium of Canada is planning to develop a USD 123 million project at Mutanga and Chirundu with estimated cash operating costs of USD 31.1/lb U_3O_8 (USD 80.85/kgU), excluding royalties, when uranium prices have improved to >USD 55/lb U_3O_8 (USD 143/kgU). Following a successful licence renewal, a preliminary economic study of the Mutanga deposit was undertaken for an open-pit mine with acid heap leaching. Most of the mineralisation occurs within 125 m of surface and is considered to have a reasonable prospect for economic mining. The project holds a 25-year mining licence, environmental approval and a radioactive materials licence. The project is forecast to produce 920 tU/yr for 11 years.

Uranium production centre technical details

(as of 1 January 2019)

	Centre #1	Centre #2
Name of production centre	Lumwana	Mutanga
Production centre classification	Planned	Planned
Date of first production (year)	NA	NA
Source of ore:		
Deposit name(s)	Malundwe-Chimiwungo	Dibwe-Mutanga-Gwabe-Njame
Deposit type(s)	Metasomatic (metamorphosed schists)	Sandstone
Recoverable resources (tU)	6 967	20 311
Grade (% U)	0.07	0.033
Mining operation:		
Type (OP/UG/ISL)	OP	OP
Size (tonnes ore/day)	2 800	11 000
Average mining recovery (%)	NA	NA
Processing plant:		
Acid/alkaline	Acid	Acid
Type (IX/SX)	SX	HL
Size (tonnes ore/day)		
Average process recovery (%)	93.1	88.0
Nominal production capacity (tU/year)	650	920
Plans for expansion (yes/no)		
Other remarks	Mine currently operated by Barrick: Uranium bankable feasibility study completed by Equinox Minerals	Mine construction on hold until uranium price increases

Environmental activities and socio-cultural issues

Waste rock management

Equinox Minerals' original plan in 2003 was to excavate, stockpile and return the uraniferous ore to the Malundwe pit at the Lumwana copper mine, following completion of mining, as it was considered uneconomic at the time to recover the uranium. However, in 2006, with a uranium spot price in excess of USD 50 lb/U_3O_8 (USD 130/kgU), the project was re-evaluated. In January 2011, Equinox Minerals reported that the portion of the stockpile containing 0.09% U and 0.8% Cu could be treated at a later date, if and when a uranium plant is built. The stockpile is currently classified and expensed as "waste" in the copper project.

Environmental activities and socio-cultural issues

The Mines and Minerals Development Act (1995) makes provision for the preparation of a project brief when applying for a mining licence. This must include an environmental impact statement detailing all potential impacts of the project. Annual environmental audits must be carried out to ensure compliance and contributions must be made to an environmental management fund for rehabilitation.

Local inhabitants around the Mutanga Project were involved in public hearings organised by the Environmental Council of Zambia. Agreements were reached regarding the displacement of 107 families in two villages to allow for the construction of the mine infrastructure.

Denison/GoviEx has been providing funding to several communities and sustainability projects including the construction of schools and clinics, water boreholes and agricultural programmes.

African Energy assisted with the construction of a community health post and also completed a water borehole at Sikoongo Village near their Chirundu Project.

Barrick invested in a wide range of sustainable development initiatives in 2012, including funding for infrastructures (such as schools and health centres), literacy and agricultural programmes, community sports and recreation, and an initiative to provide microcredit and small business loans to women.

Uranium requirements

Zambia has no nuclear generating capacity. In May 2016, Rosatom signed an intergovernmental agreement on co-operation in the peaceful uses of nuclear energy, which provides a framework for opportunities to construct nuclear power facilities. Further co-operation agreements were signed with Rosatom in December 2016 and in June 2017. The first is for the training of Zambian specialists in Russia so that within 15 years, Russia will assist Zambia with training young nuclear energy engineers, plan for nuclear power plant personnel, develop a nuclear energy regulator and build a research reactor, which will provide medicine, agricultural services and energy. Zambia aims to become a regional centre for nuclear medicine. With respect to energy, nuclear power is needed to prevent load shedding due to unreliable supply.

Uranium policies, uranium stocks and uranium prices

National policies relating to uranium

Mining activities, in general, were regulated by the Mines and Minerals Act (1995), but until recently there was no legislation specifically relating to the exploration and mining of uranium. The act was repealed in 2008 following widespread criticism of what was perceived to be excessive scope for granting tax concessions. This act was replaced by the Mines and Minerals Development Act 2008, which ruled that no special agreements should be entered into by the government for the development of large-scale mining licences. It also effectively ended development agreements concluded under the previous act. The Mines and Minerals Development (Prospecting, Mining and Milling of Uranium Ores and Other Radioactive Mineral Ores) and Regulations of 2008 deal with the mining, storage and export of uranium. Mining and export licences will only be granted when the Radiation Protection Authority is satisfied that the operations pose no environmental and health hazards. Applicants for export licences will also have to prove the authenticity of the importers in terms of IAEA guidelines.

A study by the Council of Churches concluded that current legislation and enforcement was inadequate for uranium mining. They recommended that current regulations be revised to address the concerns of local communities and that education and awareness programmes be initiated prior to any uranium exploration and mining activities.

In 2011, Zambia and Finland signed co-operating projects aimed at helping the southern African nation review regulations on uranium mining as well as the management of the mineral. The two projects are aimed at evaluating current regulations on uranium and other radioactive minerals as well as developing a modern geographical information infrastructure. These projects are designed to help the country evaluate, update and review regulations regarding the safety of uranium mining.

Zambia has upgraded its mining legislation to include uranium, following detailed consultation with the IAEA. It started issuing uranium mining licences late in 2008, and in 2017 was undertaking a further revision of regulations regarding uranium exploration and mining.

Reasonably assured conventional resources by production method

(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	0	0	12 777	12 777	88-93
Total	0	0	12 777	12 777	88-93

Reasonably assured conventional resources by processing method

(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from OP	0	0	12 777	12 777	88-93
Total	0	0	12 777	12 777	88-93

Reasonably assured conventional resources by deposit type

(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	5 810	5 810
Metasomatite	0	0	6 967	6 967
Total	0	0	12 777	12 777

Inferred conventional resources by production method

(tonnes U)

Production method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Open-pit mining (OP)	0	0	18 221	18 221	88-93
Total	0	0	18 221	18 221	88-93

Inferred conventional resources by processing method

(tonnes U)

Processing method	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	Recovery factor (%)
Conventional from OP	0	0	18 221	18 221	88-93
Total	0	0	18 221	18 221	88-93

Inferred conventional resources by deposit type
(tonnes U)

Deposit type	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Sandstone	0	0	17 270	17 270
Metasomatite	0		951	951
Total	0	0	18 221	18 221

Historical uranium production by production method
(tonnes U in concentrates)

Production method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Underground mining[1]	86	0	0	0	86	0
Total	86	0	0	0	86	0

1. Pre-2015 totals may include uranium recovered by heap and in-place leaching.

Historical uranium production by processing method
(tonnes U in concentrates)

Processing method	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Conventional	86	0	0	0	86	0
Total	86	0	0	0	86	0

Historical uranium production by deposit type
(tonnes U in concentrates)

Deposit type	Total through end of 2015	2016	2017	2018	Total through end of 2018	2019 (expected)
Metasomatite	86	0	0	0	86	0
Total	86	0	0	0	86	0

Short-term production capabilities
(tonnes U/year)

2019				2020				2025			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
0	0	0	0	0	0	0	0	0	0	0	NA

2030				2035				2040			
A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II	A-I	B-I	A-II	B-II
0	0	0	NA	0	0	0	NA	0	0	0	NA

Appendix 1. **List of reporting organisations and contact persons**

NEA	OECD Nuclear Energy Agency – Division of Nuclear Technology Development and Economics, Paris Contact person: Ms Luminita Grancea (*Scientific Secretary)*
IAEA	International Atomic Energy Agency, Division of Nuclear Fuel Cycle and Waste Technology, Vienna Contact persons: Mr Mark Mihalasky and Mr Martin Fairclough *(Scientific Secretary)*
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Argentina	Comisión Nacional de Energía Atómica, Gerencia Exploración de Materias Primas/Gerencia Producción de Materias Primas, Avenida del Libertador 8250, 1429 Buenos Aires Contact persons: M Mr Luis Eduardo Lopez and Mr Roberto Grüner
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Appendix 2. **Members of the Joint NEA-IAEA Uranium Group participating in 2018-2020 meetings**

NEA	Ms Luminita Grancea (*Scientific Secretary*)	Division of Nuclear Technology Development and Economics, Paris
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Argentina	Mr Luis Lopez	National Atomic Energy Commission, Buenos Aires
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Belgium	Ms F. Renneboog	Synatom S.A., Brussels
Brazil	Mr L. Filipe Da Silva	Indústrias Núcleares do Brasil INB-S/A, Rio de Janeiro
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	Mr Eric Potter	Canadian Nuclear Safety Commission Geological Survey of Canada, Ottawa
Chile	Mr Pedro Orrego Alfaro	La Comisión Chilena de Energía Nuclear , Ministry of Energy, Santiago

Czech Republic	Mr P. Vostarek	DIAMO, State Enterprise, Stráž pod Ralskem
Ecuador	Mr F. Herrera	Instituto de Investigación Geológico y Energético, Quito
Egypt	Mr Amer Bishr	Nuclear Materials Authority, Cairo
Finland	Mr E. Pohjolainen	Geological Survey of Finland, Espoo
France	Ms S. Gabriel	French Alternative Energies and Energy Commission (CEA), Saclay
	Mme Farahnaz Laldjee	Electricité de France (EDF), Saint-Denis
	Mr C. Polak (Vice-chair)	ORANO Mining, Paris
Germany	Mr M. Schauer	Federal Institute for Geoscience and Natural Resources, Hannover
Hungary	Mr András Barabás	Mecsekérc Environmental Ltd, Pecs
India	Mr Mohan Babu Verma Mr Deepak Kumar Sinha	Department of Atomic Energy, Atomic Minerals Directorate for Exploration and Research, Hyderabad
Indonesia	Mr Yarianto Sugeng Budi Susilo Mr Heri Syaeful	National Nuclear Energy Agency, Jakarta
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Jordan	Mr Hussein Allaboun	Jordan Atomic Energy Commission, Amman
Kazakhstan	Ms Aliya Akzholova	National Atomic Company (KAZATOMPROM), Nur-Sultan
Kenya	Mr Kenneth Anakoli	Nuclear Power and Energy Agency, Nairobi
Madagascar	Ms Lalanirina Ranoroarisoa Ep Ramonjy	Office of National Mines and Industries Strategic 21, Antananarivo

Mongolia	Ms Tamiraa Altangerel	Mineral Resources and Petroleum Authority, Ulaanbaatar
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Niger	Ms Salleye Soumana	Ministère des Mines, Niamey
Pakistan	Mr Arshad Ali Farooqi	Pakistan Atomic Energy Commission, Lahore
Philippines	Mr Rolando Reyes	Philippine Nuclear Research Institute, Tarlac City
Poland	Ms G. Zakrzewska-Koltuniewicz	Institute of Nuclear Chemistry and Technology, Warsaw
Romania	Mr Emil Macovei Mr Gelu Maracineanu Mr Andrei Musetoiu	SN Nuclearelectrica S.A., Bucharest
Russia	Mr A. Boytsov (Vice-chair)	TENEX, Moscow
	Mr A. Tarkhanov	All-Russian Research Institute of Chemical Technology (Rosatom), Moscow
Saudi Arabia	Mr Saeed Alamoudi Mr Abdullah Aljehani Mr Nahdi Mobarak	Saudi Geological Survey, Jeddah
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Tanzania	Mr Justin Ngaile	Tanzania Atomic Energy Comm., Arusha

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	Mr Tawatchai Chualaowanich	Department of Mineral Resources, Bangkok
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Ukraine	Mr A. Bakarzhiyev Mr Y. Bakarzhiyev	The State Geological Enterprise “Kirovgeology”, Kiev
United States	Ms Susan Hall (*Chair*)	US Geological Survey
	Mr Michael Scott	U.S. Energy Information Administration, Washington, DC
Viet Nam	Mr Hung NGUYEN TRONG	Vietnam Atomic Energy Institute, Hanoi
European Union/Euratom	Mr D. Kozak	Euratom Supply Agency, Luxembourg

Appendix 3. **Glossary of definitions and terminology**

Units

Metric units are used in all tabulations and statements. Resources and production quantities are expressed in terms of tonnes (t) contained uranium (U) rather than uranium oxide (U_3O_8).

1 short ton U_3O_8	=	0.769 tU
1% U_3O_8	=	0.848% U
1 USD/lb U_3O_8	=	USD 2.6/kg U
1 tonne	=	1 metric ton

Resource terminology

Resource estimates are divided into separate categories reflecting different levels of confidence in the quantities reported. The resources are further separated into categories based on the cost of production.

Definitions of resource categories

Uranium resources are broadly classified as either conventional or unconventional. Conventional resources are those that have an established history of production where uranium is a primary product, co-product or an important by-product (e.g. from the mining of copper and gold). Very low-grade resources or those from which uranium is only recoverable as a minor by-product are considered unconventional resources.

Conventional resources are further divided, according to different confidence levels of occurrence, into four categories. The correlation between these resource categories and those used in selected national resource classification systems is shown in Figure A3.1.

Reasonably assured resources (RAR) refers to uranium that occurs in known mineral deposits of delineated size, grade and configuration such that the quantities, which could be recovered within the given production cost ranges with currently proven mining and processing technology, can be specified. Estimates of tonnage and grade are based on specific sample data and measurements of the deposits and on knowledge of deposit characteristics. Reasonably assured resources have a high assurance of existence. Unless otherwise noted, RAR are expressed in terms of quantities of uranium recoverable from mineable ore (see: recoverable resources).

Inferred resources (IR) refers to uranium, in addition to RAR, that is inferred to occur based on direct geological evidence, in extensions of well-explored deposits, or in deposits in which geological continuity has been established but where specific data, including measurements of the deposits, and knowledge of the deposit's characteristics, are considered to be inadequate to classify the resource as RAR. Estimates of tonnage, grade and cost of further delineation and recovery are based on such sampling as is available and on knowledge of the deposit characteristics as determined in the best known parts of the deposit or in similar deposits. Less reliance can be placed on the estimates in this category than on those for RAR. Unless otherwise noted, inferred resources are expressed in terms of quantities of uranium recoverable from mineable ore (see: recoverable resources).

Figure A3.1. **Approximate correlation of terms used in major resources classification systems**

<table>
<tr><td></td><td colspan="3">Identified resources</td><td colspan="3">Undiscovered resources</td></tr>
<tr><td>NEA/IAEA</td><td colspan="2">Reasonably assured</td><td>Inferred</td><td>Prognosticated</td><td colspan="2">Speculative</td></tr>
<tr><td rowspan="2">Australia</td><td colspan="2">Demonstrated</td><td rowspan="2">Inferred</td><td rowspan="2" colspan="3">Undiscovered</td></tr>
<tr><td>Measured</td><td>Indicated</td></tr>
<tr><td>Canada (NRCan)</td><td>Measured</td><td>Indicated</td><td>Inferred</td><td>Prognosticated</td><td colspan="2">Speculative</td></tr>
<tr><td>United States (DOE)</td><td colspan="2">Reasonably assured</td><td colspan="2">Estimated additional</td><td colspan="2">Speculative</td></tr>
<tr><td>Russia, Kazakhstan, Ukraine, Uzbekistan</td><td>A + B + C1</td><td>C2</td><td>C2+P1</td><td>P1</td><td>P2</td><td>P3</td></tr>
</table>

The terms illustrated are not strictly comparable as the criteria used in the various systems are not identical. “Grey zones” in correlation are therefore unavoidable, particularly as the resources become less assured. Nonetheless, the chart presents a reasonable approximation of the comparability of terms.

Work to align the NEA/IAEA and national resource classification systems outlined above with the United Nations Framework Classification system remains under consideration. (For a summary of recent efforts, see: www.unece.org/fileadmin/DAM/energy/se/pdfs/egrc/egrc5_apr2014/ECE.ENERGY.GE.3.2014.L1_e.pdf.)

Prognosticated resources (PR) refers to uranium, in addition to inferred resources, that is expected to occur in deposits for which the evidence is mainly indirect and which are believed to exist in well-defined geological trends or areas of mineralisation with known deposits. Estimates of tonnage, grade and cost of discovery, delineation and recovery are based primarily on knowledge of deposit characteristics in known deposits within the respective trends or areas and on such sampling, geological, geophysical or geochemical evidence as may be available. Less reliance can be placed on the estimates in this category than on those for inferred resources. Prognosticated resources are normally expressed in terms of uranium contained in mineable ore, i.e. in situ quantities.

Speculative resources (SR) refers to uranium, in addition to prognosticated resources, that is thought to exist, mostly on the basis of indirect evidence and geological extrapolations, in deposits discoverable with existing exploration techniques. The location of deposits envisaged in this category could generally be specified only as being somewhere within a given region or geological trend. As the term implies, the existence and size of such resources are speculative. SR are normally expressed in terms of uranium contained in mineable ore, i.e. in situ quantities.

Cost categories

The cost categories, in United States dollars (USD), used in this report are defined as: <USD 40/kgU, <USD 80/kgU, <USD 130/kgU and <USD 260/kgU. All resource categories are defined in terms of costs of uranium recovered at the ore processing plant.

Note: It is not intended that the cost categories should follow fluctuations in market conditions.

Conversion of costs from other currencies into USD is done using an average exchange rate for the month of June in that year except for the projected costs for the year of the report.

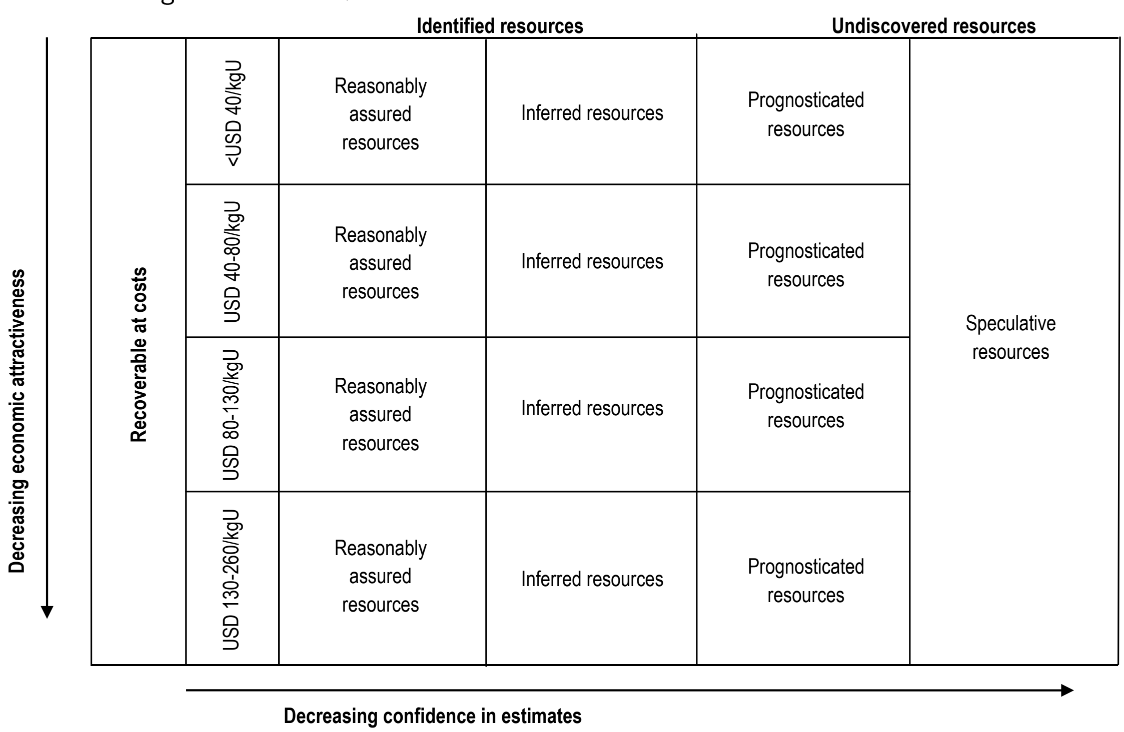
When estimating the cost of production for assigning resources within these cost categories, account has been taken of the following costs:

- the direct costs of mining, transporting and processing the uranium ore;
- the costs of associated environmental and waste management during and after mining;
- the costs of maintaining non-operating production units where applicable;
- in the case of ongoing projects, those capital costs that remain non-amortised;
- the capital cost of providing new production units where applicable, including the cost of financing;
- indirect costs such as office overheads, taxes and royalties where applicable;
- future exploration and development costs wherever required for further ore delineation to the stage where it is ready to be mined;
- sunk costs are not normally taken into consideration.

Relationship between resource categories

Figure A3.2 illustrates the inter-relationship between the different resource categories. The horizontal axis expresses the level of assurance about the actual existence of a given tonnage based on varying degrees of geologic knowledge while the vertical axis expresses the economic feasibility of exploitation by the division into cost categories.

Figure A3.2. **NEA/IAEA classification scheme for uranium resources**



Recoverable resources

RAR and IR estimates are expressed in terms of recoverable tonnes of uranium, i.e. quantities of uranium recoverable from mineable ore, as opposed to quantities contained in mineable ore, or quantities in situ, i.e. not taking into account mining and milling losses. Therefore both expected mining and ore processing losses have been deducted in most cases. If a country reports its resources as in situ and the country does not provide a recovery factor, the NEA/IAEA assigns a recovery factor to those resources based on geology and projected mining and processing methods to determine recoverable resources. The recovery factors that have been applied are:

Mining and milling method	Overall recovery factor (%)
Open-pit mining with conventional milling	80
Underground mining with conventional milling	75
In situ leaching (acid)	85
In situ leaching (alkaline)	70
Heap leaching	70
Block and stope leaching	75
Co-product or by-product	65
Unspecified method	75

Secondary sources of uranium terminology

Mixed oxide fuel (MOX): MOX is the abbreviation for a fuel for nuclear power plants that consists of a mixture of uranium oxide and plutonium oxide. Current practice is to use a mixture of depleted uranium oxide and plutonium oxide.

Depleted uranium: Uranium where the ^{235}U assay is below the naturally occurring 0.7110%. Natural uranium is a mixture of three isotopes, uranium-238 – accounting for 99.2836%, uranium-235 – 0.7110%, and uranium-234 – 0.0054%. Depleted uranium is a by-product of the enrichment process, where enriched uranium is produced from initial natural uranium feed material.

Production terminology[1]

Production centres

A production centre, as referred to in this report, is a production unit consisting of one or more ore processing plants, one or more associated mines and uranium resources that are tributary to these facilities. For the purpose of describing production centres, they have been divided into four classes, as follows:

- Existing production centres are those that currently exist in operational condition. Production projections continue until the identified resources (costs < USD 130/kgU) are exhausted.
- Committed production centres are those that are either under construction or are firmly committed for construction.
- Planned production centres are those for which feasibility studies are completed and regulatory approvals are at advanced stage.

1. IAEA (1984), *Manual on the Projection of Uranium Production Capability*, General Guidelines, Technical Report Series No. 238, IAEA, Vienna.

- Prospective production centres are those for which some level of feasibility study has been completed and the centres are supported by tributary RAR and Inferred resources. Indicative start-up dates should have been announced.

Production, production capacity, and production capability

Production: Denotes the amount of uranium output, in tonnes U contained in concentrate, from an ore processing plant or production centre (with milling losses deducted).

Production capacity: Denotes the nominal level of output, based on the design of the plant and facilities over an extended period, under normal commercial operating practices.

Production capability: Refers to an estimate of the level of production that could be practically and realistically achieved under favourable circumstances from the plant and facilities at any of the types of production centres described above, given the nature of the resources tributary to them. Projections of production capability are supported only by RAR and/or IR. The projection is presented based on those resources recoverable at costs <USD 130/kgU.

Mining and milling

In situ leaching (ISL): The extraction of uranium from sandstone using chemical solutions and the recovery of uranium at the surface. ISL extraction is conducted by injecting a suitable uranium-dissolving leach solution (acid or alkaline) into the ore zone below the water table thereby oxidising, complexing and mobilising the uranium; then recovering the pregnant solutions through production wells, and finally pumping the uranium bearing solution to the surface for further processing. This process is sometimes referred to as in situ recovery (ISR).

Heap leaching (HL): Heaps of ore are formed over a collecting system underlain by an impervious membrane. Dilute sulphuric acid solutions are distributed over the top surface of the ore. As the solutions seep down through the heap, they dissolve a significant (50-75%) amount of the uranium in the ore. The uranium is recovered from the heap leach product liquor by ion exchange or solvent extraction.

In-place leaching (IPL): involves leaching of broken ore without removing it from an underground mine. This is also sometimes referred to as stope leaching or block leaching.

Co-product: Uranium is a co-product when it is one of two commodities that must be produced to make a mine economic. Both commodities influence output, for example, uranium and copper are co-produced at Olympic Dam in Australia. Co-product uranium is produced using either the open-pit or underground mining methods.

By-product: Uranium is considered a by-product when it is a secondary or additional product. By-product uranium can be produced in association with a main product or with co-products, e.g. uranium recovered from the Palabora copper mining operations in South Africa. By-product uranium is produced using either the open-pit or underground mining methods.

Uranium from phosphate rocks: Uranium has been recovered as a by-product of phosphoric acid production. Uranium is separated from phosphoric acid by a solvent extraction process. The most frequently used reagent is a synergetic mixture of tri-n-octyl phosphine oxide (TOPO) and di 2-ethylhexyl phosphoric acid (DEPA).

Ion exchange (IX): Reversible exchange of ions contained in a host material for different ions in solution without destruction of the host material or disturbance of electrical neutrality. The process is accomplished by diffusion and occurs typically in crystals possessing – one or two – dimensional channels where ions are weakly bonded. It also occurs in resins consisting of three-dimensional hydrocarbon networks to which are attached many ionisable groups. Ion exchange is used for recovering uranium from leaching solutions.

Solvent extraction (SX): A method of separation in which a generally aqueous solution is mixed with an immiscible solvent to transfer one or more components into the solvent. This method is used to recover uranium from leaching solutions.

Demand terminology

Reactor-related requirements: Refers to natural uranium acquisitions *not* necessarily consumption during a calendar year.

Environmental terminology[2]

Close-out: In the context of uranium mill tailings impoundment, the operational, regulatory and administrative actions required to place a tailings impoundment into long-term conditions such that little or no future surveillance and maintenance are required.

Decommissioning: Actions taken at the end of the operating life of a uranium mill or other uranium facility in retiring it from service with adequate regard for the health and safety of workers and members of the public and protection of the environment. The time period to achieve decommissioning may range from a few to several hundred years.

Decontamination: The removal or reduction of radioactive or toxic chemical contamination using physical, chemical, or biological processes.

Dismantling: The disassembly and removal of any structure, system or component during decommissioning. Dismantling may be performed immediately after permanent retirement of a mine or mill facility or may be deferred.

Environmental restoration: Clean-up and restoration, according to predefined criteria, of sites contaminated with radioactive and/or hazardous substances during past uranium production activities.

Environmental impact statement: A set of documents recording the results of an evaluation of the physical, ecological, cultural and socio-economic effects of a planned installation, facility, or technology.

Groundwater restoration: The process of returning affected groundwater to acceptable quality and quantity levels for future use.

Reclamation: The process of restoring a site to predefined conditions, which allows new uses.

Restricted release (or use): A designation, by the regulatory body of a country, that restricts the release or use of equipment, buildings, materials or the site because of its potential radiological or other hazards.

Tailings: The remaining portion of a metal-bearing ore consisting of finely ground rock and process liquids after some or all of the metal, such as uranium, has been extracted.

Tailings impoundment: A structure in which the tailings are deposited to prevent their release into the environment.

Unrestricted release (or use): A designation, by the regulatory body of a country, that enables the release or use of equipment, buildings, materials or the site without any restriction.

Geological terminology

Uranium occurrence: A naturally occurring, anomalous concentration of uranium.

Uranium deposit: A mass of naturally occurring mineral from which uranium could be exploited at present or in the future.

2. Definitions based on those published in OECD (2002), *Environmental Remediation of Uranium Production Facilities*, Paris.

Geologic types of uranium deposits[3]: uranium resources can be assigned on the basis of the following 15 major categories of uranium ore deposit types (arranged according to their approximate economic significance):

1. Sandstone deposits
2. Proterozoic unconformity deposits
3. Polymetallic Fe-oxide breccia complex deposits
4. Paleo-quartz-pebble conglomerate deposits
5. Granite-related
6. Metamorphite
7. Intrusive deposits
8. Volcanic-related deposits
9. Metasomatic deposits
10. Surficial deposits
11. Carbonate deposits
12. Collapse breccia-type deposits
13. Phosphate deposits
14. Lignite and coal
15. Black shale

Detailed descriptions with examples follow. Note that for Red Book reporting purposes only the major categories are used. However, descriptions of the sub-types for sandstone and Proterozoic unconformity deposits have also been included because of their importance.

1. Sandstone deposits: Sandstone-hosted uranium deposits occur in medium- to coarse-grained sandstones deposited in a continental fluvial or marginal marine sedimentary environment. Uranium is precipitated under reducing conditions caused by a variety of reducing agents within the sandstone, such as carbonaceous material, sulphides (pyrite), hydrocarbons and ferro-magnesian minerals (chlorite), bacterial activity, migrated fluids from underlying hydrocarbon reservoirs, and others. Sandstone uranium deposits can be divided into five main sub-types (with frequent transitional types between them):

   - Basal channel deposits: Paleodrainage systems consist of wide channels filled with thick, permeable alluvial-fluvial sediments. The uranium is predominantly associated with detrital plant debris in orebodies that display, in a plan view, an elongated lens or ribbon-like configuration and, in a section-view, a lenticular or, more rarely, a roll shape. Individual deposits can range from several hundred to 20 000 t of uranium, at grades ranging from 0.01% to 3%. Examples are the deposits of Dalmatovskoye (Transural Region), Malinovskoye (West Siberia), Khiagdinskoye (Vitim District) in the Russia, deposits of the Tono District (Japan), Blizzard (Canada) and Beverley (Australia).

   - Tabular deposits consist of uranium matrix impregnations that form irregularly shaped lenticular masses within reduced sediments. The mineralised zones are largely oriented parallel to the depositional trend. Individual deposits can contain several hundred tons up to 150 000 tons of uranium, at average grades ranging from 0.05% to 0.5%, occasionally up to 1%. Examples of deposits include Hamr-Stráz (Czech Republic), Akouta, Arlit, and Imouraren (Niger) and those of the Colorado Plateau (United States).

   - Roll-front deposits: The mineralised zones are convex in shape, oriented down the hydrologic gradient. They display diffuse boundaries with reduced sandstone on the down-gradient side and sharp contacts with oxidised sandstone on the up-gradient side. The mineralised zones are elongate and sinuous approximately parallel to the strike, and perpendicular to the direction of deposition and groundwater flow. Resources can range from a few hundred tons to several thousands of tons of uranium, at grades averaging 0.05% to 0.25%. Examples are Budenovskoye, Tortkuduk, Moynkum, Inkai and Mynkuduk (Kazakhstan); Crow Butte and Smith Ranch (United States) and Bukinay, Sugraly and Uchkuduk (Uzbekistan).

3. This classification of the geological types of uranium deposits was updated in 2011-2012 through a number of IAEA consultancies that included an update of the World Distribution of Uranium Deposits (UDEPO).

- Tectonic/lithologic deposits are discordant to strata. They occur in permeable fault zones and adjacent sandstone beds in reducing environments created by hydrocarbons and/or detrital organic matter. Uranium is precipitated in fracture or fault zones related to tectonic extension. Individual deposits contain a few hundred tons up to 5 000 tons of uranium at average grades ranging from 0.1-0.5%. Examples include the deposits of the Lodève District (France) and the Franceville basin (Gabon).

- Mafic dykes/sills in Proterozoic sandstones: mineralisation is associated with mafic dykes and sills that are interlayered with or crosscut Proterozoic sandstone formations. Deposits can be subvertical along the dyke's borders, sometime within the dykes, or stratabound within the sandstones along lithological contacts (Westmoreland District, Australia; Matoush, Canada). Deposits are small to medium (300-10 000 t) with grades low to medium (0.05-0.40%).

2. Proterozoic unconformity deposits: Unconformity-related deposits are associated with and occur immediately below and above an unconformable contact that separates Archean to Paleoproterozoic crystalline basement from overlying, redbed clastic sediments of Proterozoic age. In most cases, the basement rocks immediately below the unconformity are strongly hematised and clay altered, possibly as a result of paleoweathering and/or diagenetic/hydrothermal alteration. Deposits consist of pods, veins and semimassive replacements consisting of mainly pitchblende. They are preferentially located in two major districts, the Athabasca Basin (Canada) and the Pine Creek Orogen (Australia). The unconformity-related deposits include three sub-types:

   - Unconformity-contact deposits: Except for the low-grade Karku deposit (Russia), these all occur in the Athabasca Basin (Canada). Deposits develop at the base of the sedimentary cover directly above the unconformity. They form elongate pods to flattened linear orebodies typically characterised by a high-grade core surrounded by a lower grade halo. Most of the orebodies have root-like extensions into the basement. While some mineralisation is open space infill, much of it is replacement style. Often, mineralisation also extends up into the sandstone cover within breccias and fault zones forming "perched mineralisation". Deposits can be monometallic (McArthur River) or polymetallic (Cigar Lake). Deposits are medium to large to very large (1 000-200 000 t) and are characterised by their high grades (1-20%).

   - Basement-hosted deposits are strata-structure bound in metasediments below the unconformity on which the basinal clastic sediments rest. The basement ore typically occupies moderately to steeply dipping brittle shear, fracture and breccia zones hundreds of metres in strike length that can extend down-dip for several tens to more than 500 m into basement rocks below the unconformity. Disseminated and vein uraninite/pitchblende occupies fractures and breccia matrix but may also replace the host rock. High-grade ore is associated with brecciated graphitic schists. These deposits have small to very large resources (300-200 000 t), at medium grade (0.10-0.50%). Examples are Kintyre, Jabiluka and Ranger in Australia, Millennium and Eagle Point in the Athabasca Basin and Kiggavik and Andrew Lake in the Thelon Basin (Canada).

   - Stratiform structure-controlled deposits: low-grade (0.05-0.10%), stratabound, thin (1-5 m) zones of mineralisation are located along the unconformity between Archean, U-Th-rich granites and Proterozoic metasediments with minor enrichments along fractures. This type of deposit (Chitrial and Lambapur) has only been observed in the Cuddapah basin (India). Resources of individual deposits range between 1 000-8 000 t.

3. Polymetallic iron-oxide breccia complex deposits: This type of deposit has been attributed to a broad category of worldwide iron oxide-copper-gold deposits. Olympic Dam (Australia) is the only known representative of this type with significant by-product uranium resources. The deposit contains the world's largest uranium resources with more than 2 Mt of uranium. Deposits of this group occur in hematite-rich granite breccias and contain disseminated uranium in association with copper, gold, silver and rare earth elements. At Olympic Dam, this breccia is hosted within a Mesoproterozoic highly potassic granite intrusion that exhibits regional Fe-K-metasomatism. Significant deposits and prospects of this type occur in the

same region, including Prominent Hill, Wirrda Well, Carrapeteena, Acropolis and Oak Dam as well as some younger breccia-hosted deposits in the Mount Painter area.

4. Paleo-quartz pebble conglomerate deposits: Deposits of this type contain detrital uranium oxide ores, which are found in quartz pebble conglomerates deposited as basal units in fluvial to lacustrine braided stream systems older than 2 400-2 300 Ma. The conglomerate matrix is pyritic and contains gold, as well as other accessory and oxide and sulphide detrital minerals that are often present in minor amounts. Examples include deposits in the Witwatersrand basin, South Africa, where uranium is mined as a by-product of gold as well as deposits in the Blind River/Elliot Lake area of Canada.

5. Granite-related deposits include: i) true veins composed of ore and gangue minerals in granite or adjacent (meta-) sediments and ii) disseminated mineralisation in granite as episyenite bodies. Uranium mineralisation occurs within, at the contact or peripheral to the intrusion. In the Hercynian belt of Europe, these deposits are associated with large, peraluminous two-mica granite complexes (leucogranites). Resources range from small to large and grades are variable, from low to high.

6. Metamorphite deposits correspond to disseminations, impregnations, veins and shear zones within or affecting metamorphic rocks of various ages. These deposits are highly variable in sizes, resources and grades.

7. Intrusive deposits are contained in intrusive or anatectic igneous rocks of many different petrochemical compositions (granite, pegmatite, monzonite, peralkaline syenite and carbonatite). Examples include the Rossing and Rossing South (Husab) deposits (Namibia), the deposits in the Bancroft area (Canada), the uranium occurrences in the porphyry copper deposits of Bingham Canyon and Twin Butte (United States), the Kvanefjeld and Sorensen deposits (Greenland) and the Palabora carbonatite complex (South Africa).

8. Volcanic-related deposits are located within and near volcanic calderas filled by mafic to felsic, effusive and intrusive volcanic rocks and intercalated clastic sediments. Uranium mineralisation is largely controlled by structures as veins and stockworks with minor stratiform lodes. This mineralisation occurs at several stratigraphic levels of the volcanic and sedimentary units and may extend into the basement where it is found in fractured granite and metamorphic rocks. Uranium minerals (pitchblende, coffinite, U_6+ minerals, less commonly brannerite) are associated with Mo-bearing sulphides and pyrite. Other anomalous elements include As, Bi, Ag, Li, Pb, Sb, Sn and W. Associated gangue minerals comprise violet fluorite, carbonates, barite and quartz. The most significant deposits are located within the Streltsovska caldera in the Russia. Other examples are known in China (Xiangshan District), Mongolia (Dornot and Gurvanbulag Districts), the United States (McDermitt caldera) and Mexico (Pena Blanca District).

9. Metasomatite deposits are confined to Precambrian shields in areas of tectono-magmatic activity affected by intense Na-metasomatism or K-metasomatism, which produced albitised or illitised facies along deeply rooted fault systems. In Ukraine, these deposits are developed within a variety of basement rocks, including granites, migmatites, gneisses and ferruginous quartzites, which produced albitites, aegirinites, alkali-amphibolic, as well as carbonate and ferruginous rocks. Principal uranium phases are uraninite, brannerite and other Ti-U-bearing minerals, coffinite and hexavalent uranium minerals. The reserves are usually medium to large. Examples include Michurinskoye, Vatutinskoye, Severinskoye, Zheltorechenskoye, Novokonstantinovskoye and Pervomayskoye deposits (Ukraine), deposits of the Elkon District (Russia), Espinharas and Lagoa Real (Brazil), Valhalla (Australia), Kurupung (Guyana), Coles Hill (US), Lianshanguan (China), Michelin (Canada) and small deposits of the Arjeplog region in the north of Sweden.

10. Surficial deposits are broadly defined as young (Tertiary to Recent), near-surface uranium concentrations in sediments and soils. The largest of the surficial uranium deposits are in calcrete (calcium and magnesium carbonates) found mainly in Australia (Yeelirrie deposit) and Namibia (Langer Heinrich deposit). These calcrete-hosted deposits mainly occur in valley-fill sediments along Tertiary drainage channels and in playa lake sediments in areas of deeply weathered, uranium-rich granites. Carnotite is the main uraniferous mineral. Surficial deposits also occur less commonly in peat bogs, karst caverns and soils.

11. Carbonate deposits are hosted in carbonate rocks (limestone, dolostone). Mineralisation can be syngenetic stratabound or more commonly structure-related within karsts, fractures, faults and folds. The only example of a stratabound carbonate deposits is the Tummalapalledeposit in India, which is hosted in phosphatic dolostone. At Mailuu-Suu, Kyrgyzstan and Todilto, United States. Another example includes deposits developed in solution collapse breccias occurring in limestone with intercalations of carbonaceous shale such as the Sanbaqi deposit, China.

12. Collapse breccia-type deposits occur in cylindrical, vertical pipes filled with down-dropped fragments developed from karstic dissolution cavities in underlying thick carbonate layers. The uranium is concentrated as primary uranium ore, mainly uraninite, in the permeable breccia matrix, and in the arcuate, ring-fracture zone surrounding the pipe. The pitchblende is intergrown with numerous sulphide and oxide minerals variably containing Cu, Fe, V, Zn, Pb, Ag, Mo, Ni, Co, As and Se. Type examples are the deposits in the Arizona Strip north of the Grand Canyon and those immediately south of the Grand Canyon in the United States. Resources are small to medium (300-2 500 t) with grades around 0.20-0.80%.

13. Phosphate deposits are principally represented by marine phosphorite of continental-shelf origin containing synsedimentary, stratiform, disseminated uranium in fine-grained apatite. Phosphorite deposits constitute large uranium resources (millions of tons), but at a very low grade (0.005-0.015%). Uranium can be recovered as a by-product of phosphate production. Examples include the Land Pebble District, Florida (land-pebble phosphate) (US), Gantour (Morocco) and Al-Abiad (Jordan). Another type of phosphorite deposits consists of organic phosphate, including argillaceous marine sediments enriched in fish remains that are uraniferous (Melovoye, Kazakhstan). Deposits in continental phosphates are not common.

14. Lignite-coal deposits consist of elevated uranium contents in lignite/coal mixed with mineral detritus (silt, clay), and in immediately adjacent carbonaceous mud and silt/sandstone beds. Pyrite and ash contents are high. Lignite-coal seams are often interbedded or overlain by felsic pyroclastic rocks. Examples are deposits of the south-western Williston basin, North and South Dakota (US), Koldjat and Nizhne Iliyskoe (Kazakhstan), Freital (Germany), Ambassador (Australia) and the Serres basin (Greece).

15. Black shale deposits include marine, organic-rich shale or coal-rich pyritic shale, containing synsedimentary, disseminated uranium adsorbed onto organic material, and fracture-controlled mineralisation within or adjacent to black shale horizons. Examples include the uraniferous alum shale in Sweden and Estonia, the Chattanooga shale (United States), the Chanziping deposit (China) and the Gera-Ronneburg deposit (Germany).

Appendix 4. **List of abbreviations and acronyms**

ARMZ	Atomredmetzoloto
BHP	BHP Billiton
CAREM	Central Argentina de Elementos Modulares
CCHEN	Chilean Nuclear Energy Commission
CGNPC	China General Nuclear Power Corporation
CEA	Commissariat à l'Energie Atomique et aux Energies Alternatives
CNEA	National Atomic Energy Commission (Argentina)
CNEN	National Nuclear Energy Commission (Brazil)
CNNC	China National Nuclear Corporation
CNPC	China National Petroleum Corporation
CNSC	Canadian Nuclear Safety Commission
COGEMA	Compagnie Générale des Matières Nucléaires
CRA	Conzinc Riotinto of Australia
DFS	Definitive feasibility study
DOE	Department of Energy (United States)
DU	Depleted uranium
EC	European Commission
EDF	Électricité de France
EIA	Environmental impact assessments
EPA	Environmental Protection Authority (United States)
EPL	Exclusive prospecting licence
EPR	European pressurised reactor
ENAMI	National Mining Company of Chile
ENUSA	Industrias Avanzadas, S.A. S.M.E. (Spain)
ERA	Energy Resources of Australia
ESA	Euratom Supply Agency
EU	European Union
Ga	Giga-years
GAC	Global Atomic Corporation
GDR	German Democratic Republic
GDRRE	Geological Division for Radioactive and Rare Elements
GWe	Gigawatt electric

ha	Hectare
HEU	Highly enriched uranium
HL	Heap leaching
IAEA	International Atomic Energy Agency
IBAMA	Brazilian Institute for the Environment and Renewable Natural Resources
INB	Industrias Núcleares do Brasil S.A
IPEN	Peruvian Institute Nuclear Energy
IPL	In-place leaching
IR	Inferred resources
ISL	In situ leaching
ISR	In situ recovery
IX	Ion exchange
JAEA	Japan Atomic Energy Agency
JAEC	Jordan Atomic Energy Commission
JOGMEC	Japan Oil, Gas and Metals National Corporation
JORC	Joint Ore Reserves Committee
KEPCO	Korea Electric Power Corporation
kg	Kilogram
km	Kilometre
lb	Pound
LEU	Low-enriched uranium
MOX	mixed oxide fuel
MRE	Mineral resource estimate
MTA	General Directorate of Mineral Research and Exploration (Turkey)
MWe	Megawatt electric
NatU	Natural uranium
NEA	Nuclear Energy Agency
NMMC	Navoi Mining and Metallurgical Complex
NNSA	National Nuclear Security Administration (United States)
NPP	Nuclear power plant
NRC	Nuclear Regulatory Commission (United States)
NUA	Namibian Uranium Association
NWMO	Nuclear Waste Management Organization (Canada)
OECD	Organisation for Economic Co-operation and Development
OP	Open pit
ppm	Parts per million
PMCPA	Priargunsky Mining-Chemical Production Association
PR	Prognosticated resources

Pu	Plutonium
RAR	Reasonably assured resources
REE	Rare earth elements
RepU	Reprocessed uranium
RMRE	Reptile Mineral Resources & Exploration (Namibia)
SDAG	Sowjetisch-Deutsche Aktiengesellschaft
SMR	Small modular reactors
SR	Speculative resources
STUK	Radiation and Nuclear Safety Authority (Finland)
SWU	Separative work unit
SX	Solvent extraction
t	Tonnes (metric tons)
TAEK	Turkish Atomic Energy Authority
TENEX	Techsnabexport
Th	Thorium
tHM	Tonnes heavy metal
TOE	Tonnes oil equivalent
tU	Tonnes uranium
tU_3O_8	Tonnes triuranium octoxide
tUnat	Tonnes natural uranium equivalent
TVA	Tennessee Valley Authority
TVEL	TVEL Fuel Company
TVO	Teollisuuden Voima Oyj
TWh	Terawatt-hour
U	Uranium
UCIL	Uranium Corporation of India Limited
UDEPO	World Distribution of Uranium Deposits database (IAEA)
UEC	Uranium Energy Corporation
UG	Underground
USEC	United States Enrichment Corporation
USGS	US Geological Survey
US EIA	US Energy Information Administration
VostGOK	Vostochnyi Mining-process Combinat (Ukraine)
VVER	Water-water energetic reactor
WNA	World Nuclear Association

Appendix 5. **Energy conversion factors**

The need to establish a set of factors to convert quantities of uranium into common units of energy has become increasingly evident with the growing frequency of requests in recent years in relation to the various types of reactors.

Conversion factors and energy equivalence for fossil fuel for comparison

1 cal	=	4.1868 J
1 J	=	0.239 cal
1 tonne of oil equivalent (TOE) (net, lower heating value [LHV])	=	42 GJ * = 1 TOE
1 tonne of coal equivalent (TCE) (standard, LHV)	=	29.3 GJ* = 1 TCE
1 000 m^3 of natural gas (standard, LHV)	=	36 GJ
1 tonne of crude oil	=	approx. 7.3 barrels
1 tonne of liquid natural gas (LNG)	=	45 GJ
1 000 kWh (primary energy)	=	9.36 MJ
1 TOE	=	10 034 Mcal
1 TCE	=	7 000 Mcal
1 000 m^3 natural gas (atmospheric pressure)	=	8 600 Mcal
1 tonne LNG	=	11 000 Mcal
1 000 kWh (primary energy)	=	2 236 Mcal **
1 TCE	=	0.698 TOE
1 000 m^3 natural gas (atmospheric pressure)	=	0.857 TOE
1 tonne LNG	=	1.096 TOE
1 000 kWh (primary energy)	=	0.223 TOE
1 tonne of fuelwood	=	0.3215 TOE
1 tonne of uranium: light-water reactors	=	10 000-16 000 TOE
open cycle	=	14 000-23 000 TCE

* World Energy Council standard conversion factors (from WEC, 1998 Survey of Energy Resources, 18th Edition).

** With 1 000 kWh (final consumption) = 860 Mcal as WEC conversion factor.

Appendix 6. **List of all Red Book editions (1965-2020) and national reports**

Listing of Red Book editions (1965-2020)

OECD/ENEA[1]	World Uranium and Thorium Resources, Paris, 1965
OECD/ENEA	Uranium Resources, Revised Estimates, Paris, 1967
OECD/ENEA-IAEA	Uranium Production and Short-Term Demand, Paris, 1969
OECD/ENEA-IAEA	Uranium Resources, Production and Demand, Paris, 1970
OECD/NEA-IAEA	Uranium Resources, Production and Demand, Paris, 1973
OECD/NEA-IAEA	Uranium Resources, Production and Demand, Paris, 1976
OECD/NEA-IAEA	Uranium Resources, Production and Demand, Paris, 1977
OECD/NEA-IAEA	Uranium Resources, Production and Demand, Paris, 1979
OECD/NEA-IAEA	Uranium Resources, Production and Demand, Paris, 1982
OECD/NEA-IAEA	Uranium Resources, Production and Demand, Paris, 1983
OECD/NEA-IAEA	Uranium Resources, Production and Demand, Paris, 1986
OECD/NEA-IAEA	Uranium Resources, Production and Demand, Paris, 1988
OECD/NEA-IAEA	Uranium Resources, Production and Demand, Paris, 1990
OECD/NEA-IAEA	Uranium 1991: Resources, Production and Demand, Paris, 1992
OECD/NEA-IAEA	Uranium 1993: Resources, Production and Demand, Paris, 1994
OECD/NEA-IAEA	Uranium 1995: Resources, Production and Demand, Paris, 1996
OECD/NEA-IAEA	Uranium 1997: Resources, Production and Demand, Paris, 1998
OECD/NEA-IAEA	Uranium 1999: Resources, Production and Demand, Paris, 2000
OECD/NEA-IAEA	Uranium 2001: Resources, Production and Demand, Paris, 2002
OECD/NEA-IAEA	Uranium 2003: Resources, Production and Demand, Paris, 2004
OECD/NEA-IAEA	Uranium 2005: Resources, Production and Demand, Paris, 2006
OECD/NEA-IAEA	Uranium 2007: Resources, Production and Demand, Paris, 2008
OECD/NEA-IAEA	Uranium 2009: Resources, Production and Demand, Paris, 2010
OECD/NEA-IAEA	Uranium 2011: Resources, Production and Demand, Paris, 2012
OECD/NEA-IAEA	Uranium 2014: Resources, Production and Demand, Paris, 2014
OECD/NEA-IAEA	Uranium 2016: Resources, Production and Demand, Paris, 2016
OECD/NEA-IAEA	Uranium 2018: Resources, Production and Demand, Paris, 2018
OECD/NEA-IAEA	Uranium 2020: Resources, Production and Demand, Paris, 2020

1. ENEA: European Nuclear Energy Agency; former name of the Nuclear Energy Agency (NEA).

Index of national reports in Red Books

(The following index lists all national reports by the year in which these reports were published in the Red Books)

	1965	1967	1969	1970	1973	1976	1977	1979	1982	1983	1986	1988	1990	1992
Algeria						1976	1977	1979	1982					
Argentina		1967	1969	1970	1973	1976	1977	1979	1982	1983	1986	1988	1990	1992
Armenia														
Australia		1967	1969	1970	1973	1976	1977	1979	1982	1983	1986	1988	1990	1992
Austria							1977							
Bangladesh											1986	1988		
Belgium									1982	1983	1986	1988	1990	1992
Benin													1990	
Bolivia							1977	1979	1982	1983	1986			
Bophuthatswana [2]									1982					
Botswana								1979		1983	1986	1988		
Brazil				1970	1973	1976	1977	1979	1982	1983	1986			1992
Bulgaria													1990	1992
Cameroon							1977		1982	1983				
Canada	1965	1967	1969	1970	1973	1976	1977	1979	1982	1983	1986	1988	1990	1992
Central African Republic				1970	1973		1977	1979			1986			
Chad														
Chile							1977	1979	1982	1983	1986	1988		1992
China													1990	1992
Colombia							1977	1979	1982	1983	1986	1988	1990	
Congo		1967												
Costa Rica									1982	1983	1986	1988	1990	
Côte d'Ivoire									1982					
Cuba												1988		1992
Czech Republic														
Czech and Slovak Rep.													1990	
Denmark (Greenland)	1965	1967		1970	1973	1976	1977	1979	1982	1983	1986		1990	1992
Dominican Republic									1982					
Ecuador							1977		1982	1983	1986	1988		
Egypt							1977	1979			1986	1988	1990	1992
El Salvador										1983	1986			
Estonia														
Ethiopia								1979		1983	1986			
Finland					1973	1976	1977	1979	1982	1983	1986	1988	1990	1992
France	1965	1967	1969	1970	1973	1976	1977	1979	1982	1983	1986	1988	1990	1992
Gabon		1967		1970	1973				1982	1983	1986			
Germany				1970		1976	1977	1979	1982	1983	1986	1988	1990	1992

2. Bophuthatswana is a former republic, dissolved in 1994, in the north-western region of South Africa.

Index of national reports in Red Books (*cont'd*)

1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	
				2002	2004	2006	2008		2012	2014	2016	2018	2020	Algeria
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	Argentina
			2000	2002	2004	2006		2010	2012	2014	2016	2018	2020	Armenia
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	Australia
														Austria
														Bangladesh
1994	1996	1998	2000	2002	2004	2006	2008							Belgium
														Benin
												2018		Bolivia
														Bophuthatswana
								2010	2012	2014	2016		2020	Botswana
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	Brazil
1994	1996	1998					2008	2010						Bulgaria
														Cameroon
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	Canada
														Central African Republic
										2014	2016			Chad
1994	1996	1998	2000	2002	2004	2006	2008		2012	2014	2016	2018	2020	Chile
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	China
	1996	1998					2008							Colombia
														Congo
														Costa Rica
														Côte d'Ivoire
	1996	1998												Cuba
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	Czech Republic
														Czech and Slovak Rep.
	1996	1998			2004			2010	2012	2014	2016	2018	2020	Denmark (Greenland)
														Dominican Republic
														Ecuador
1994	1996	1998	2000		2004	2006	2008	2010					2020	Egypt
														El Salvador
		1998			2004									Estonia
									2012					Ethiopia
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	Finland
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	France
	1996	1998	2000	2002	2004	2006								Gabon
1994	1996	1998	2000	2002		2006	2008	2010	2012	2014	2016	2018	2020	Germany

Index of national reports in Red Books (*cont'd*)

	1965	1967	1969	1970	1973	1976	1977	1979	1982	1983	1986	1988	1990	1992
Ghana							1977			1983				
Greece							1977	1979	1982	1983	1986	1988	1990	1992
Guatemala											1986	1988		
Guyana								1979	1982	1983	1986			
Hungary														1992
India	1965	1967		1970	1973	1976	1977	1979	1982	1983	1986		1990	1992
Indonesia							1977				1986	1988	1990	1992
Iran, Islamic Republic of							1977							
Iraq														
Ireland								1979	1982	1983	1986			1992
Italy		1967		1970	1973	1976	1977	1979	1982	1983	1986	1988		1992
Jamaica									1982	1983				
Japan	1965	1967		1970	1973	1976	1977	1979	1982	1983	1986	1988	1990	1992
Jordan							1977				1986	1988	1990	1992
Kazakhstan														
Korea						1976	1977	1979	1982	1983	1986	1988	1990	1992
Kyrgyzstan														
Lesotho												1988		
Liberia							1977			1983				
Libyan Arab Jamahiriya[3]										1983				
Lithuania														
Madagascar						1976	1977	1979	1982	1983	1986	1988		
Malawi														
Malaysia										1983	1986	1988	1990	1992
Mali											1986	1988		
Mauritania													1990	
Mexico				1970	1973	1976	1977	1979	1982		1986		1990	1992
Mongolia														
Morocco	1965	1967				1976	1977	1979	1982	1983	1986	1988	1990	
Namibia								1979	1982	1983	1986	1988	1990	
Netherlands									1982	1983	1986		1990	1992
New Zealand		1967					1977	1979						
Niger		1967		1970	1973		1977				1986	1988	1990	1992
Nigeria								1979						
Norway								1979	1982	1983				1992
Pakistan		1967												
Panama										1983		1988		
Paraguay										1983	1986			
Peru							1977	1979		1983	1986	1988	1990	1992
Philippines							1977		1982	1983	1986		1990	
Poland														

3. Libya as of 2011.

Index of national reports in Red Books *(cont'd)*

1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	
														Ghana
1994	1996	1998												Greece
														Guatemala
														Guyana
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	Hungary
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	India
1994	1996	1998	2000	2002	2004	2006		2010	2012	2014	2016	2018	2020	Indonesia
		1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	Iran, Islamic Republic of
											2016			Iraq
		1998												Ireland
1994	1996	1998	2000						2012	2014	2016			Italy
														Jamaica
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018		Japan
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	Jordan
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	Kazakhstan
1994	1996	1998	2000	2002	2004	2006	2008	2010						Korea
	1996			2002										Kyrgyzstan
														Lesotho
														Liberia
														Libyan Arab Jamahiriya
1994	1996	1998	2000	2002	2004	2006	2008							Lithuania
													2020	Madagascar
			2000				2008	2010	2012	2014	2016		2020	Malawi
1994	1996	1998	2000	2002										Malaysia
										2014	2016	2018	2020	Mali
											2016		2020	Mauritania
1994	1996	1998	2000						2012		2016	2018	2020	Mexico
1994	1996	1998						2010	2012	2014	2016	2018	2020	Mongolia
		1998												Morocco
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	Namibia
1994	1996	1998	2000	2002										Netherlands
														New Zealand
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	Niger
														Nigeria
	1996	1998												Norway
1994		1998	2000											Pakistan
														Panama
												2018		Paraguay
1994	1996	1998	2000		2004	2006	2008	2010	2012	2014	2016	2018		Peru
1994	1996	1998	2000	2002	2004	2006								Philippines
			2000	2002			2008	2010	2012	2014	2016			Poland

Index of national reports in Red Books *(cont'd)*

	1965	1967	1969	1970	1973	1976	1977	1979	1982	1983	1986	1988	1990	1992
Portugal	1965	1967	1969	1970	1973	1976	1977	1979	1982	1983	1986	1988	1990	1992
Romania														1992
Russia														
Rwanda											1986			
Senegal									1982					
Slovak Republic														
Slovenia														
Somalia							1977	1979						
South Africa	1965	1967	1969	1970	1973	1976	1977	1979	1982	1983	1986			1992
Spain	1965	1967	1969	1970	1973	1976	1977	1979	1982	1983	1986	1988	1990	1992
Sri Lanka							1977		1982	1983	1986	1988		
Sudan							1977							
Surinam									1982	1983				
Sweden	1965	1967	1969	1970	1973	1976	1977	1979	1982	1983	1986	1988	1990	1992
Switzerland						1976	1977	1979	1982	1983	1986	1988	1990	1992
Syrian Arab Republic									1982	1983	1986	1988	1990	
Tajikistan														
Tanzania													1990	
Thailand							1977	1979	1982	1983	1986	1988	1990	1992
Togo								1979						
Turkey					1973	1976	1977	1979	1982	1983	1986	1988	1990	1992
Turkmenistan														
Ukraine														
United Kingdom						1976	1977	1979	1982	1983	1986	1988	1990	1992
United States	1965	1967	1969	1970	1973	1976	1977	1979	1982	1983	1986	1988	1990	1992
Uruguay							1977		1982	1983	1986	1988	1990	
USSR (former)														1992
Uzbekistan														
Venezuela											1986	1988		
Viet Nam														1992
Yugoslavia					1973	1976	1977		1982				1990	1992
Zaire[4]					1973		1977					1988		
Zambia											1986	1988	1990	1992
Zimbabwe									1982			1988		1992

4. Zaire is the former name – between 1971 and 1997 – of the Democratic Republic of the Congo.

Index of national reports in Red Books *(cont'd)*

1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016		2020	Portugal
1994	1996	1998	2000	2002										Romania
1994		1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	Russia
														Rwanda
												2018	2020	Senegal
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016			Slovak Republic
1994	1996	1998		2002	2004	2006	2008	2010		2014	2016	2018	2020	Slovenia
														Somalia
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016		2020	South Africa
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	Spain
													2020	Sri Lanka
														Sudan
														Surinam
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016		2020	Sweden
1994	1996	1998	2000	2002	2004	2006	2008							Switzerland
1994														Syrian Arab Republic
				2002										Tajikistan
								2010	2012	2014	2016	2018	2020	Tanzania
1994	1996	1998	2000	2002		2006				2014	2016	2018	2020	Thailand
														Togo
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	Turkey
					2004									Turkmenistan
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	Ukraine
1994	1996	1998	2000	2002	2004	2006	2008	2010		2014	2016	2018		United Kingdom
1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	United States
														Uruguay
														USSR (former)
1994	1996	1998	2000	2002	2004	2006			2012		2016	2018	2020	Uzbekistan
														Venezuela
1994	1996	1998	2000	2002	2004	2006	2008			2014	2016	2018	2020	Viet Nam
														Yugoslavia
														Zaire
1994	1996	1998							2012	2014	2016	2018	2020	Zambia
1994	1996	1998												Zimbabwe

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Uranium 2020: Resources, Production and Demand

Uranium is the raw material used to produce fuel for long-lived nuclear power facilities, necessary for the generation of significant amounts of low-carbon electricity and other uses, such as heat and hydrogen production, for decades to come. Although a valuable commodity, major producing countries limited total production in recent years in response to a depressed uranium market. Uranium production cuts have unexpectedly deepened with the onset of the global COVID-19 pandemic in early 2020, leading to some questions being raised about future uranium supply.

This 28th edition of the "Red Book", a recognised world reference on uranium jointly prepared by the Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA), provides analyses and information from 45 producing and consuming countries in order to address these and other questions. The present edition reviews world uranium market fundamentals and presents data on global uranium exploration, resources, production and reactor-related requirements. It offers updated information on established uranium production centres and mine development plans, as well as projections of nuclear generating capacity and reactor-related requirements through 2040.

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