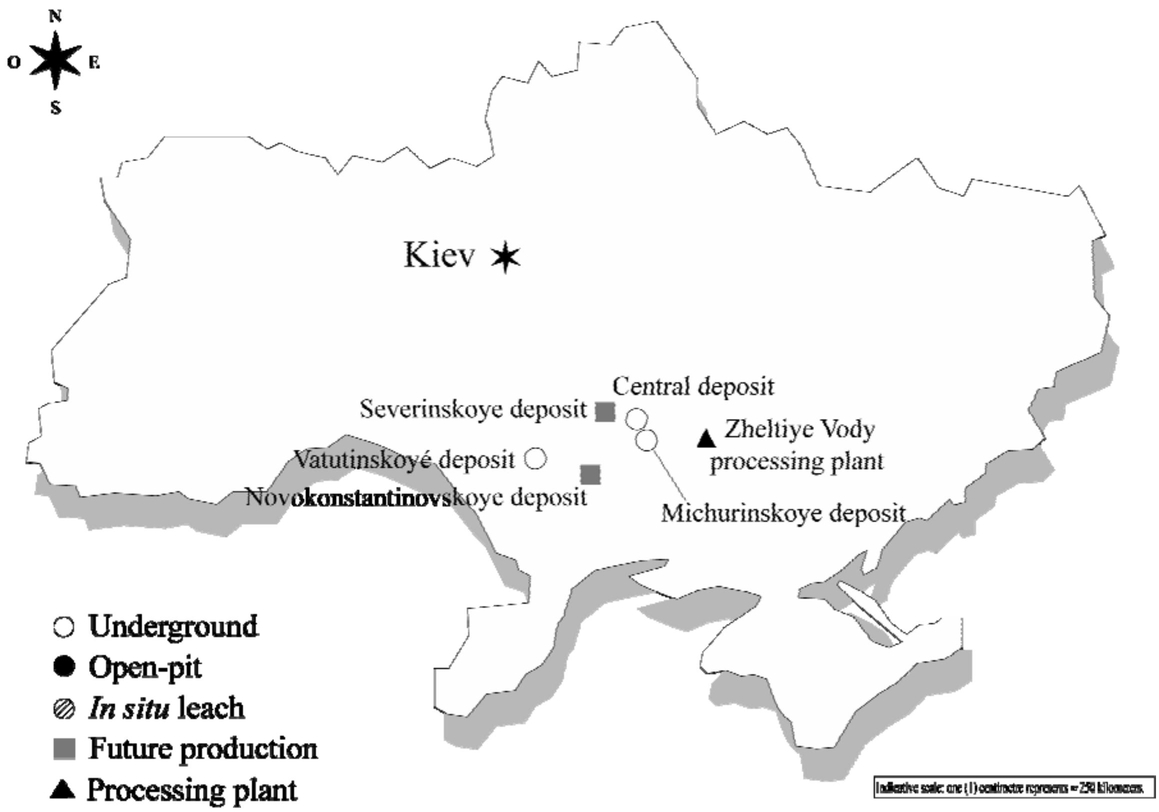


# • United Kingdom •

## URANIUM EXPLORATION

### Historical review

Some uranium mining occurred in Cornwall, as a sideline to other mineral mining, especially tin, in the late 1800s. Systematic exploration occurred in the periods 1945-1951, 1957-1960, and 1968-1982, but no significant uranium reserves were located.

### Recent and ongoing uranium exploration and mine development activities

Exploration in overseas countries is carried out by private companies operating through autonomous subsidiary or affiliate organisations established in the country concerned (e.g., members of the Rio Tinto group of companies).

There were no industry expenditures reported for domestic exploration from 1988 to the end of 2006, nor were there any government expenditures reported for exploration either domestic or abroad. Since 1983, all domestic exploration activities have been halted.

## URANIUM RESOURCES

### Identified Resources (RAR & Inferred)

The Reasonably Assured Resources (RAR) and Inferred Resources are essentially zero. There has been no geological appraisal of the UK uranium resources since 1980.

### Undiscovered Resources (Prognosticated & SR)

There are small quantities of *in situ* Undiscovered Resources as well as Speculative Resources. Two districts are believed to contain uranium resources:

- Metalliferous mining region of southwest England (Cornwall and Devon). Uranium occurs in veins and stockworks, often in association with tin and other metals, emplaced in Devonian metasediments and volcanic and related to the margins of uraniferous Hercynians granites. Mineralisation is locally of moderate (0.2-1% U) but of sporadic distribution. Resource tonnages of individual prospects may be up to several hundred tU.
- North Scotland including Orkneys. The Precambrian metamorphic rocks or north Scotland, with intruded Caledonian granites, are overlain by a post-orogenic series of fluviatile and lacustrine Devonian sediments. Uranium occurs in phosphatic and carbonaceous sediments disseminated in arkosic sandstone (Ousdale) and in faults both within the sediments (Stromness) and in underlaying granite (Helmsdale). Resources of a few thousand tonnes of uranium are indicated with an average grade less than 0.1% U.

## URANIUM PRODUCTION

### Status of production capability

The United Kingdom is not a uranium producer.

### Secondary sources of uranium

MOX fuel has been utilised in fast reactor and, on a trial basis, gas-cooled reactor programmes in the United Kingdom in the past. None of the reactors in the United Kingdom currently use MOX fuel and this is not expected to change in the near future. In October 2001, the government announced the approval for MOX fuel manufacture in the United Kingdom. In December 2001 BNFL started the first stage of plutonium commissioning of the Sellafield MOX Plant (SMP), following the granting of licence consent by the UK Health and Safety Executive's Nuclear Installations Inspectorate. The plant manufactures MOX fuel from plutonium oxide separated from the reprocessing of spent fuel and tails of depleted uranium oxide. SMP has a potential annual throughput of up to 40 tHM of MOX fuel manufacture. Detailed programmes for the SMP are commercially confidential.

### Production and/or use of re-enriched tails

Urenco has a long-term contractual agreement to upgrade tails material, but considers this to be commercially confidential.

## ENVIRONMENTAL ACTIVITIES AND SOCIO-CULTURAL ISSUES

There is no uranium mining in the United Kingdom.

## URANIUM REQUIREMENTS

A consultation on the future of nuclear power was published in May 2007 along with a white paper "Meeting the Energy Challenge". The United Kingdom believes that there needs to be as wide a choice of low carbon options as possible so it does not become over reliant on any one form of electricity generation. The consultation ran until October 2007.

Nuclear is an important part of the UK's energy mix supplying 18% of the UK's electricity in 2007. The Government has stated in the Consultation that a decision needs to be taken before the end of 2007 on whether to continue to obtain some electricity from nuclear. It will be for the private sector to undertake, fund, construct and operate new nuclear plants and cover the cost of decommissioning and their full share of long-term waste management costs.

Following the closure of Dungeness A and Sizewell A at the end of 2006 only two Magnox power stations remain operational. The remaining sites, at Oldbury and Wylfa, shall close in 2008 and 2010 respectively. The Advanced Gas Cooled Reactors (AGRs) operated by British Energy at Hinkley Point B and Hunterston B are planned to close in 2011, followed by Hartlepool and Heysham 1 in 2014, Dungeness B in 2018, and Heysham 2 and Torness in 2023. The Pressurised Water Reactor at Sizewell B is expected to remain operational until 2035.

In the near future the uranium requirements of the United Kingdom shall decline but it is difficult to predict what the long term uranium requirements of the UK shall be.

### Supply and procurement strategy

In the US anti-dumping (selling at less than fair value) and countervailing (subsidy) action initiated by USEC at the end of 2000 against imports of low enriched uranium from The Netherlands, Germany and the United Kingdom, Urenco was found not to have been dumping but to have been receiving subsidies. This resulted in a small duty rate of *ca.* 1.5% being levied for the period 2001/2002. The duty rate is now zero, as the deemed benefit of the subsidies ended in 2002 and no further subsidies have been received. Various appeals were filed against the original decisions by the US Department of Commerce and these are still being progressed through the Court of International Trade.

The Nuclear Decommissioning Authority was set up as an executive Non departmental Public Body (NDPB) under the Energy Act 2004. The NDA assumed its full set of powers on 1 April 2005, including responsibilities for nuclear sites, facilities and installations formerly owned and operated by British Nuclear Group, Westinghouse-Toshiba and the United Kingdom Atomic Energy Authority.

The latest version of the NDA's Lifetime Plans – which detail the commercial operations, decommissioning and clean up programmes of the NDA's 20 sites – now shows an undiscounted total cost of GBR 64.8 billion for cleaning up the UK civil public sector nuclear liabilities.

Additionally the NDA is carrying out a strategic review of options for the management of its nuclear materials stock which will report in the summer of 2007.

## NATIONAL POLICIES RELATING TO URANIUM

No changes to uranium policy have taken place in the United Kingdom. As regards the current policy on participation of private and foreign companies, the UK Atomic Energy Act 1946 gives the Secretary of State for Trade and Industry wide-ranging powers in relation to uranium resources in the United Kingdom, in particular to obtain information (section 4), to acquire rights to work minerals without compensation (section 7), to acquire uranium mined in the United Kingdom on payment of compensation (section 8), and to introduce a licensing procedure to control or condition the working of uranium (section 12A).

There are no specific policies relating to restrictions on foreign and private participation in uranium exploration, production, marketing and procurement in the United Kingdom, nor exploration activities in foreign countries. There is no national stockpile policy in the United Kingdom. Stocks of Uranium Hexaflouride Tails are stored as a zero value asset. Utilities are free to develop their own policy. Current policy is to either recycle them if economically sensible to do so or to de-convert the material to a more stable form starting no later than 2020. Stocks of depleted Uranium derived from reprocessing of Magnox reactors are stored as a zero value asset. Current policy is to recycle this material when it becomes economically sensible to do so.

Exports of uranium are subjects to the Export of Goods (Control) Order 1970 (SI No. 1 288), as amended, made under the Import, Export and Customs Powers (Defence) Act 1939.

## URANIUM STOCKS

The UK uranium stockpile practices are the responsibility of the individual bodies concerned. Actual stock levels are commercially confidential.

## URANIUM PRICES

Uranium prices are commercially confidential in the United Kingdom.

**Mixed-oxide fuel production and use**
(tonnes of natural U equivalent)

| **Mixed-oxide (MOX) fuels** | **Total through end of 2003** | **2004** | **2005** | **2006** | **Total through end of 2006** | **2007** (expected) |
|---|---|---|---|---|---|---|
| Production | NA | NA | 11 | 22 | NA | 11 |
| Use | 0 | 0 | 0 | 0 | 0 | 0 |
| Number of commercial reactors using MOX | NA | 0 | 0 | 0 | NA | 0 |

**Reprocessed uranium use**
(tonnes of natural U equivalent)

| **Reprocessed uranium** | **Total through end of 2003** | **2004** | **2005** | **2006** | **Total through end of 2006** | **2007** (expected) |
|---|---|---|---|---|---|---|
| Production | ~ 50 000 | NA | 1 270 | NA | ~ 51 270 | NA |
| Use | ~ 15 000 | NA | NA | NA | ~ 15 000 | NA |

**Re-enriched tails production and use**
(tonnes of natural U equivalent)

| **Re-enriched tails** | **Total through end of 2003** | **2004** | **2005** | **2006** | **Total through end of 2006** | **2007** (expected) |
|---|---|---|---|---|---|---|
| Production | NA | NA | NA | NA | NA | NA |
| Use* | NA | NA | NA | NA | NA | NA |

**Net nuclear electricity generation**

| | **2005** | **2006** |
|---|---|---|
| Nuclear electricity generated (TWh net) | 82 | 82 |

**Installed nuclear generating capacity to 2030**
(MWe net)

| **2006** | **2007** | **2010** | | **2015** | |
|---|---|---|---|---|---|
| | | *Low* | *High* | *Low* | *High* |
| 11 900 | 10 500 | 10 500 | NA | 6 000 | NA |

| **2020** | | **2025** | | **2030** | |
|---|---|---|---|---|---|
| *Low* | *High* | *Low* | *High* | *Low* | *High* |
| 3 700 | NA | 1 200 | NA | 1 200 | NA |

**Annual reactor-related uranium requirements to 2030 (excluding MOX)**
(tonnes U)

| 2006 | 2007 | 2010 | | 2015 | |
|---|---|---|---|---|---|
| | | *Low* | *High* | *Low* | *High* |
| 2 165 | NA | 1 700 | 1 900 | 800 | 1 100 |

| 2020 | | 2025 | | 2030 | |
|---|---|---|---|---|---|
| *Low* | *High* | *Low* | *High* | *Low* | *High* |
| 400 | 500 | 300 | 400 | 300 | 400 |

**Total uranium stocks**
(tonnes natural U-equivalent)

| Holder | Natural uranium stocks in concentrates | Enriched uranium stocks | Depleted uranium stocks | 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 |

# • United States of America •

## URANIUM EXPLORATION

### 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 into peaceful atomic energy applications. By late 1957, the number of new deposits being brought into production by private industry and production capability had increased sufficiently to meet projected requirements, and Federal exploration programmes were ended. The government has continued to monitor private-industry exploration and development activities to meet Federal informational needs.

*Appendix 4*

# 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 percent $U_3O_8$ | = 0.848 percent 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.

### a) 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 A.

***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*** 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 A. **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 colspan="3" rowspan="2">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>Russian Federation, Kazakhstan, Ukraine, Uzbekistan</td><td>A + B</td><td>C 1</td><td>C 2</td><td>P1</td><td>P2</td><td>P3</td></tr>
<tr><td>UNFC*</td><td colspan="2">G1 + G2</td><td>G3</td><td>G4</td><td colspan="2">G4</td></tr>
</table>

* United Nations Framework Classification correlation with NEA/IAEA and national classification systems is still under consideration.

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.

***Prognosticated Resources*** 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.

**b) Cost categories**

The cost categories, in United States dollars (USD), used in this report are defined as: <USD 40/kgU, <USD 80/kgU, and <USD 130/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, which uses the exchange rate of 1 January 2007 (Appendix 8).

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.

**c) Relationship between resource categories**

Figure B 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 B. **NEA/IAEA Classification Scheme for Uranium Resources**

| | | IDENTIFIED RESOURCES | | UNDISCOVERED RESOURCES | |
|---|---|---|---|---|---|
| Recoverable at costs | <USD 40/kgU | REASONABLY ASSURED RESOURCES | INFERRED RESOURCES | PROGNOSTICATED RESOURCES | SPECULATIVE RESOURCES |
| | USD 40-80/kgU | REASONABLY ASSURED RESOURCES | INFERRED RESOURCES | | |
| | USD 80-130/kgU | REASONABLY ASSURED RESOURCES | INFERRED RESOURCES | PROGNOSTICATED RESOURCES | |

Decreasing economic attractiveness

Decreasing confidence in estimates

**d) Recoverable resources**

RAR and Inferred Resource 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 Secretariat 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 | 80 |
| ISL (acid) | 75 |
| ISL (alkaline) | 70 |
| Heap leaching | 70 |
| Block and stope leaching | 75 |
| Co-product or by-product | 70 |
| Unspecified method | 75 |

## SECONDARY SOURCES OF URANIUM TERMINOLOGY

**a) 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.

**b) Depleted uranium:** Uranium where the $^{235}U$ assay is below the naturally occurring 0.7110%. (Natural uranium is a mixture of three isotopes, $^{238}U$ – accounting for 99.2836%, $^{235}U$ – 0.7110%, and $^{234}U$ – 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]

**a) 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:

1. IAEA (1984), *Manual on the Projection of Uranium Production Capability,* General Guidelines, Technical Report Series No. 238, Vienna, Austria.

i) **Existing** production centres are those that currently exist in operational condition and include those plants which are closed down but which could be readily brought back into operation.

ii) **Committed** production centres are those that are either under construction or are firmly committed for construction.

iii) **Planned** production centres are those for which feasibility studies are either completed or under way, but for which construction commitments have not yet been made. This class also includes those plants that are closed which would require substantial expenditures to bring them back into operation.

iv) **Prospective** production centres are those that could be supported by tributary RAR and Inferred, i.e., "Identified Resources", but for which construction plans have not yet been made.

### b) Production capacity and capability

**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 EAR-I. The projection is presented based on those resources recoverable at costs <USD 80/kgU.

**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).

### c) 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.

**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 phosphates:** 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-m-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

a) **Reactor-related requirements:** Refers to natural uranium acquisitions *not* necessarily consumption during a calendar year.

## ENVIRONMENTAL TERMINOLOGY[2]

a) **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.

b) **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.

c) **Decontamination:** The removal or reduction of radioactive or toxic chemical contamination using physical, chemical, or biological processes.

d) **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.

2. Definitions based on those published in OECD (2002), *Environmental Remediation of Uranium Production Facilities*, Paris.

**e) Environmental restoration:** Cleanup and restoration, according to predefined criteria, of sites contaminated with radioactive and/or hazardous substances during past uranium production activities.

**f) 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.

**g) Groundwater restoration:** The process of returning affected groundwater to acceptable quality and quantity levels for future use.

**h) Reclamation**: The process of restoring a site to predefined conditions, which allows new uses.

**i) 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.

**j) 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.

**k) Tailings impoundment:** A structure in which the tailings are deposited to prevent their release into the environment.

**l) 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

**a) Uranium occurrence:** A naturally occurring, anomalous concentration of uranium.

**b) Uranium deposit:** A mass of naturally occurring mineral from which uranium could be exploited at present or in the future.

**c) Geologic types of uranium deposits**[3]

Uranium resources can be assigned on the basis of their geological setting to the following categories of uranium ore deposit types (arranged according to their approximate economic significance):

1. Unconformity-related deposits.
2. Sandstone deposits.
3. Hematite breccia complex deposits.
4. Quartz-pebble conglomerate deposits.
5. Vein deposits.
6. Intrusive deposits.
7. Volcanic and caldera-related deposits.
8. Metasomatite deposits.
9. Surficial deposits.
10. Collapse breccia pipe deposits.
11. Phosphorite deposits.
12. Other types of deposits.
13. Rock types with elevated uranium content.

3. This classification of the geological types of uranium deposits was developed by the IAEA in 1988-89 and updated for use in the Red Book.

1. **Unconformity-related deposits**: Unconformity-related deposits are associated with and occur immediately below and above an unconformable contact that separates a crystalline basement intensively altered from overlying clastic sediments of either Proterozoic or Phanerozoic age.

   The unconformity-related deposits include the following sub-types:

   - *Unconformity contact*
     i. Fracture bound deposits occur in metasediments immediately below the unconformity. Mineralisation is monometallic and of medium grade. Examples include Rabbit Lake and Dominique Peter in the Athabasca Basin, Canada.
     ii. Clay-bound deposits occur associated with clay at the base of the sedimentary cover directly above the unconformity. Mineralisation is commonly polymetallic and of high to very high grade. An example is Cigar Lake in the Athabasca Basin, Canada

   - *Sub-unconformity-post-metamorphic deposits*
     Deposits are strata-structure bound in metasediments below the unconformity on which clastic sediments rest. These deposits can have large resources, at low to medium grade. Examples are Jabiluka and Ranger in Australia.

2. **Sandstone deposits:** Sandstone 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, for example, carbonaceous material, sulphides (pyrite), hydrocarbons and ferro-magnesium minerals (chlorite), etc. Sandstone uranium deposits can be divided into four main sub-types:

   - *Roll-front deposits*: The mineralised zones are convex 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 tonnes to several thousands of tonnes of uranium, at grades averaging 0.05-0.25%. Examples are Moynkum, Inkay and Mynkuduk (Kazakhstan); Crow Butte and Smith Ranch (United States) and Bukinay, Sugraly and Uchkuduk (Uzbekistan).

   - *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 hundreds of tonnes up to 150 000 tonnes of uranium, at average grades ranging from 0.05-0.5%, occasionally up to 1%. Examples of deposits include Westmoreland (Australia), Nuhetting (China), Hamr-Stráz (Czech Republic), Akouta, Arlit, Imouraren (Niger) and Colorado Plateau (United States).

   - *Basal channel deposits*: Paleodrainage systems consist of several hundred metres wide channels filled with thick permeable alluvial-fluvial sediments. Here, the uranium is predominantly associated with detrital plant debris in ore bodies 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 hundreds to 20 000 tonnes uranium, at grades ranging from 0.01-3%. Examples are the deposits of Dalmatovskoye (Transural Region), Malinovskoye (West Siberia), Khiagdinskoye (Vitim district) in Russia and Beverley in Australia.

- *Tectonic/lithologic deposits* occur in sandstone related to a permeable zone. Uranium is precipitated in open zones related to tectonic extension. Individual deposits contain a few hundred tonnes up to 5 000 tonnes of uranium at average grades ranging from 0.1-0.5%. Examples include the deposits of Mas Laveyre (France) and Mikouloungou (Gabon).

3. **Hematite breccia complex deposits:** Deposits of this group occur in hematite-rich breccias and contain uranium in association with copper, gold, silver and rare earths. The main representative of this type of deposit is the Olympic Dam deposit in South Australia. Significant deposits and prospects of this type occur in the same region, including Prominent Hill, Wirrda Well, Acropolis and Oak Dam as well as some younger breccia-hosted deposits in the Mount Painter area.

4. **Quartz-pebble conglomerate deposits:** Detrital uranium oxide ores are found in quartz-pebble conglomerates deposited as basal units in fluvial to lacustrine braided stream systems older than 2.3-2.4 Ga. The conglomerate matrix is pyritiferous, and gold, as well as other oxide and sulphide detrital minerals are often present in minor amounts. Examples include deposits found in the Witwatersrand Basin where uranium is mined as a by-product of gold. Uranium deposits of this type were mined in the Blind River/Elliot Lake area of Canada.

5. **Vein deposits:** In vein deposits, the major part of the mineralisation fills fractures with highly variable thickness, but generally important extension along strike. The veins consist mainly of gangue material (e.g. carbonates, quartz) and ore material, mainly pitchblende. Typical examples range from the thick and massive pitchblende veins of Pribram (Czech Republic), Schlema-Alberoda (Germany) and Shinkolobwe (Democratic Republic of Congo), to the stockworks and episyenite columns of Bernardan (France) and Gunnar (Canada), to the narrow cracks in granite or metamorphic rocks, also filled with pitchblende of Mina Fe (Spain) and Singhbhum (India).

6. **Intrusive deposits:** Deposits included in this type are those associated with intrusive or anatectic rocks of different chemical composition (alaskite, granite, monzonite, peralkaline syenite, carbonatite and pegmatite). Examples include the Rossing and Trekkopje deposits (Namibia), the uranium occurrences in the porphyry copper deposits such as Bingham Canyon and Twin Butte (United States), the Ilimaussaq deposit (Greenland), Palabora (South Africa), as well as the deposits in the Bancroft area (Canada).

7. **Volcanic and caldera-related deposits**: Uranium deposits of this type are located within and nearby volcanic caldera filled by mafic to felsic volcanic complexes and intercalated clastic sediments. Mineralisation is largely controlled by structures (minor stratabound), occurs at several stratigraphic levels of the volcanic and sedimentary units and extends into the basement where it is found in fractured granite and in metamorphites. Uranium minerals are commonly associated with molybdenum, other sulphides, violet fluorine and quartz. Most significant commercial deposits are located within Streltsovsk caldera in the Russian Federation. Examples are known in China, Mongolia (Dornot deposit), Canada (Michelin deposit) and Mexico (Nopal deposit).

8. **Metasomatite deposits**: Deposits of this type are confined to the areas of tectono-magmatic activity of the Precambrian shields and are related to near-fault alkali metasomatites, developed upon different basement rocks: granites, migmatites, gneisses and ferruginous quartzites with production of albitites, aegirinites, alkali-amphibolic and carbonaceous-ferruginous rocks. Ore lenses and stocks are a few metres to tens of metres thick and a few hundred metres long. Vertical extent of ore mineralisation can be up to 1.5 km. Ores are uraninite-brannerite by composition and belong to ordinary grade. The reserves are usually medium scale or large. Examples include Michurinskoye, Vatutinskoye, Severinskoye, Zheltorechenskoye and Pervomayskoye deposits (Ukraine), Lagoa Real, Itataia and Espinharas (Brazil), the Valhalla deposit (Australia) and deposits of the Arjeplog region in the north of Sweden.

9. **Surficial deposits:** Surficial uranium 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), and they have been found in Australia (Yeelirrie deposit), Namibia (Langer Heinrich deposit) and Somalia. These calcrete-hosted deposits are associated with deeply weathered uranium-rich granites. They also can occur in valley-fill sediments along Tertiary drainage channels and in playa lake sediments (e.g., Lake Maitland, Australia). Surficial deposits also can occur in peat bogs and soils.

10. **Collapse breccia pipe deposits:** Deposits in this group occur in circular, vertical pipes filled with down-dropped fragments. The uranium is concentrated as primary uranium ore, generally uraninite, in the permeable breccia matrix, and in the arcuate, ring-fracture zone surrounding the pipe. 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.

11. **Phosphorite deposits**: Phosphorite deposits consist of marine phosphorite of continental-shelf origin containing syn-sedimentary stratiform, disseminated uranium in fine-grained apatite. Phosphorite deposits constitute large uranium resources, but at a very low grade. Uranium can be recovered as a by-product of phosphate production. Examples include New Wales Florida (pebble phosphate) and Uncle Sam (United States), Gantour (Morocco) and Al-Abiad (Jordan). Other type of phosphorite deposits consists of organic phosphate, including argillaceous marine sediments enriched in fish remains that are uraniferous (Melovoe deposit, Kazakhstan).

12. **Other deposits**

**Metamorphic deposits:** In metamorphic uranium deposits, the uranium concentration directly results from metamorphic processes. The temperature and pressure conditions, and age of the uranium deposition have to be similar to those of the metamorphism of the enclosing rocks. Examples include the Forstau deposit (Austria) and Mary Kathleen (Australia).

**Limestone deposits:** This includes uranium mineralisation in the Jurassic Todilto Limestone in the Grants district (United States). Uraninite occurs in intra-formational folds and fractures as introduced mineralisation.

**Uranium coal deposits:** Elevated uranium contents occur in lignite/coal, and in clay and sandstone immediately adjacent to lignite. Examples are uranium in the Serres Basin (Greece), in North and South Dakota (United States), Koldjat and Nizhne Iliyskoe (Kazakhstan) and Freital (Germany). Uranium grades are very low and average less than 50 ppm U.

13. **Rock types with elevated uranium contents:** Elevated uranium contents have been observed in different rock types such as pegmatite, granites and black shale. In the past no economic deposits have been mined commercially in these types of rocks. Their grades are very low, and it is unlikely that they will be economic in the foreseeable future.

    *Rare metal pegmatites*: These pegmatites contain Sn, Ta, Nb and Li mineralisation. They have variable U, Th and rare earth elements contents. Examples include Greenbushes and Wodgina pegmatites (Western Australia). The Greenbushes pegmatites commonly have 6-20 ppm U and 3-25 ppm Th.

    *Granites*: A small proportion of un-mineralised granitic rocks have elevated uranium contents. These "high heat producing" granites are potassium feldspar-rich. Roughly 1% of the total number of granitic rocks analysed in Australia have uranium-contents above 50 ppm.

    *Black Shale*: Black shale-related uranium mineralisation consists of marine organic-rich shale or coal-rich pyritic shale, containing syn-sedimentary disseminated uranium adsorbed onto organic material. Examples include the uraniferous alum shale in Sweden and Estonia, the Chatanooga shale (United States), the Chanziping deposit (China), and the Gera-Ronneburg deposit (Germany).

*Appendix 5*

**ACRONYM LIST**

| | |
|---|---|
| AGR | Advanced gas-cooled reactor |
| AL | Acid leaching |
| ALKAL | Alkaline atmospheric leaching |
| BWR | Boiling water reactor |
| CANDU | ***Can***adian ***d***euterium ***u***ranium |
| CWG | Crush-wet grind |
| DOE | Department of Energy (United States) |
| EC | European Commission |
| EIA | U.S. Energy Information Administration |
| EU | European Union |
| EUP | Enriched uranium product |
| FLOT | Flotation |
| Ga | Giga-years |
| GDR | German Democratic Republic |
| GIF | Generation IV International Forum |
| GNSS | Global Nuclear Services and Supply |
| GWe | Gigawatt electric |
| HEU | Highly enriched uranium |
| HL | Heap leaching |
| IAEA | International Atomic Energy Agency |
| IEA | International Energy Agency |
| INPRO | International project on innovative nuclear reactors and fuel cycles |
| IPL | In-place leaching |
| ISL | *In situ* leaching |
| IX | Ion exchange |
| kg | Kilograms |
| km | Kilometre |
| LEU | Low enriched uranium |
| LWR | Light water reactor |
| MAGNOX | Magnesium oxide |
| MOX | Mixed oxide fuel |
| MWe | Megawatt electric |

| | |
|---|---|
| NEA | Nuclear Energy Agency |
| OECD | Organisation for Economic Co-operation and Development |
| OP | Open-pit |
| ppm | Part per million |
| Pu | Plutonium |
| PHWR | Pressurised heavy-water reactor |
| PWR | Pressurised water reactor |
| RAR | Reasonably assured resources |
| RBMK | Water-cooled, graphite-moderated reactor (Russian acronym) |
| SWU | Separative work unit |
| SX | Solvent extraction |
| t | Tonnes (metric tons) |
| Th | Thorium |
| tHM | Tonnes heavy metal |
| TOE | Tonnes oil equivalent |
| tU | Tonnes uranium |
| TVA | Tennessee Valley Administration |
| TWh | Terrawatt-hour |
| U | Uranium |
| UG | Underground mining |
| USSR | Union of Soviet Socialist Republics |
| VVER | Water-cooled, water-moderated reactor (Russian acronym) |

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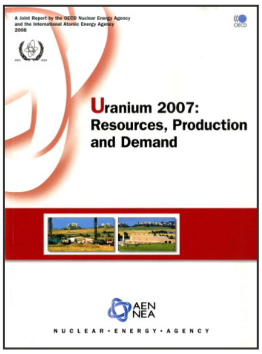


**From:**
# Uranium 2007
## Resources, Production and Demand

**Access the complete publication at:**
https://doi.org/10.1787/uranium-2007-en

**Please cite this chapter as:**

OECD/International Atomic Energy Agency (2008), “United Kingdom”, in *Uranium 2007: Resources, Production and Demand*, OECD Publishing, Paris.

DOI: https://doi.org/10.1787/uranium-2007-43-en