

Nuclear fuel resources: Enough to last?

The need to meet ever-growing energy demands in an environmentally sustainable manner has turned attention to the potential for nuclear energy to play an expanded role in future energy supply mixes. One of the key aspects in defining the sustainability of any energy source is the availability of fuel resources. This article shows that available nuclear energy fuel resources can meet future needs for hundreds, even thousands, of years.

Uranium availability

The 2001 edition of the NEA publication on *Uranium: Resources, Production and Demand* (popularly known as the “Red Book”) provides official estimates of uranium resources worldwide.¹ Traditionally, these resources are categorised based on their economic attractiveness and on the confidence in their existence.

Conventional resources

The most readily accessible resources, i.e. resources that are known to exist and are inexpensive to exploit using conventional mining techniques, are classed as “known conventional resources”. These resources are categorised into two sub-groups: reasonably assured resources (RAR) and estimated additional resources category I (EAR-I). Known conventional resources are normally reported in terms of the amount of uranium recoverable, taking into account mining and milling process losses. They are reported in cost categories of resources recoverable at less than USD 40/kilogram of uranium (kgU), less than

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Table 1: Estimated uranium resources

Resource type	Estimate (1 000 t)
Known conventional resources	
Reasonably assured resources (RAR)	2 850
Estimated additional resources cat. I (EAR-I)	1 080
Undiscovered conventional resources	
Estimated additional resources cat. II (EAR-II)	2 330
Speculative resources (SR)	9 940
Secondary sources	
Commercial inventories	220
Surplus defence inventories	250
Re-enrichment	440
Sub-total	17 110
Unconventional resources	
In phosphates	22 000
In seawater	4 000 000
Total	4 039 110

USD 80/kgU and less than USD 130/kgU. It should be noted that the current market price for uranium is about USD 20-30/kgU.

Resources believed to exist and to be exploitable using conventional mining techniques, but not yet physically confirmed, are classed as “undiscovered conventional resources”. These resources include estimated additional resources category II (EAR II), uranium resources that are expected to be located in well-defined geological trends of known ore deposits, or mineralised areas with known deposits; and speculative resources (SR), uranium resources that are thought to exist in geologically favourable, yet still unexplored areas. Almost all EAR-II and SR are reported as *in situ* resources, that is without providing for mining and milling losses. A number

A note on generating costs

The nature of nuclear energy generating costs allows for significant increases in the costs of uranium before the costs of generating electricity significantly increase. For example, a 100% increase in the cost of uranium would only result in approximately a 5% increase in the cost of nuclear electricity using current reactor technology, and even less if fast reactors were used.

of countries, including Australia, did not report undiscovered conventional resources in the 2001 edition of the Red Book, although these countries are considered to have significant resource potential in sparsely explored areas.

Unconventional resources

There are additional resources classified as unconventional, in which uranium exists at very low grades, or can be recovered as a minor by-product. Unconventional resources include the uranium contained in phosphate deposits and in seawater. The technology to recover the uranium from phosphates is mature and has been utilised in the past; it is only the high costs of recovery that limits the desirability of recovering these resources. Research has hinted that it is possible to tap the vast resources of uranium contained in the world's oceans. At present, only laboratory-scale quantities have been extracted and as yet the cost to extract uranium from seawater is estimated to be very high, approximately five to ten times the cost of conventionally mined uranium. This technology would require additional time and investment to bring to deployment. Given the current low cost of uranium, with low-cost resources sufficient for several decades at current demand rates, it is doubtful that any significant funding will be made available in the foreseeable future.

Secondary sources

Secondary sources of uranium, though small compared with the resources described above, play a significant role in supplying current nuclear fuel requirements and are expected to continue to do so through the near future.² Important secondary sources of uranium are:

- Inventories of previously mined uranium held by both government and commercial organisations. These include strategic stocks, pipeline

inventory and excess stocks available to the market.

- Large inventories of previously mined uranium derived from military applications in both the United States and the Russian Federation are becoming available for commercial applications. Highly enriched uranium (HEU) and natural uranium held in various forms by the military sector could total a few years' supply of natural uranium equivalent. In addition, surplus plutonium is available which, converted to mixed-oxide fuel, displaces the need for fresh uranium.
- Large inventories of depleted uranium, the by-product of the uranium enrichment process, represent a major reserve of uranium that could displace primary production of uranium. As of 1999, the depleted uranium stockpile of 1.2 million tU could provide up to 452 000 tU of equivalent natural uranium.³

Table 1 provides estimates of the various resource categories discussed above, as of the end of 2000. The table highlights that over 75% of the conventional uranium resources are in the undiscovered conventional resources category. Thus, as known conventional resources become exhausted, future production will have to come from new projects. Based on data from the 2001 Red Book, known conventional resources could last about 75 years at the 2000 demand rate. While this is some time into the future, low cost resources will deplete sooner. Because new projects take a long time to reach production level, timely development decisions will be needed to ensure that resources become available when required. For example, the McArthur River deposit in Canada was discovered in 1988 and began production in 1999; eleven years were needed to bring the mine into production. Similarly, the Cigar Lake deposit, also in Canada, was discovered in the early-1980s but production is not expected to start before 2005. Numerous factors can influence the time necessary to develop a new mine project, including regulatory processes, legal challenges and economic conditions.

Geographical distribution and security of supply

Another aspect of resource availability is the distribution of that resource around the world. Oil and natural gas have a fairly limited geographical availability, with the Middle East and the Russian Federation controlling some 70% of world crude oil and natural gas reserves.⁴ Conversely, the

OECD share of known uranium resources is roughly 40%, about the same as its share of coal reserves. This is much higher than its share of oil reserves (about 7%) and natural gas reserves (roughly 12%). Looking to the future, any country with access to the sea could ultimately have access to the vast uranium resources of the planet's oceans.

In addition, OECD countries are self-sufficient in the essential services that turn the uranium raw material into the finished nuclear fuel, that is, conversion, enrichment and fuel fabrication. Thus, nuclear power plants, once constructed, provide a largely if not entirely domestic source of electricity.

Effect of advanced reactor technology and fuel cycles

Advanced technology is particularly important to any discussion on the availability of nuclear fuel resources because of its potential to radically extend the resource base and increase the efficiency of use. Light water reactors make up almost 80% of the reactors in operation worldwide. Most use a “once-through” fuel cycle in which the uranium placed in the reactor to produce energy is removed after a period of time and treated as waste for disposal. In this once-through fuel cycle about 99% of the potential energy content in the nuclear fuel remains unused. Other reactors use recycled fuel which improves the energy yield. Recycling spent nuclear fuel in current plants can save up to approximately 10 to 15% of the initially mined uranium through the use of the remaining uranium and the plutonium created during the fission process in the original uranium fuel. Plutonium is extracted from the spent fuel and recycled in mixed-oxide (MOX) fuel, but the number of recycles is currently limited because of the buildup of undesirable isotopes. After a few cycles the fuel would have to be managed as a waste similar to the once-through cycle. At present only a single recycle is used.

Yet, with already identified advances in technology these resources can be extended so that nuclear fuel resources become virtually unlimited. The introduction and use of fast reactors would provide significant benefits over current thermal reactor technology:

- They permit the more efficient use of fertile materials as nuclear fuel, such as uranium-238 and thorium, thereby expanding the available resource base.
- In a breeder configuration, fast reactors can produce more fuel than they consume, with

Fertile material

A fertile material is a material that is capable of becoming fissile, that is capable of fission, following the capture of a thermal neutron. Important examples are ^{238}U , which can become fissile ^{239}Pu , and ^{232}Th , which can become fissile ^{233}U .

this fuel being recovered and used to produce energy.

For example, fast breeder reactors could use the depleted uranium tails discussed above that have already been refined and are in storage. This by-product of uranium enrichment would therefore become a fuel resource available for producing energy, augmenting natural uranium resources.

Thorium, an abundant and widely dispersed natural resource can also be used as a fuel resource (see Table 2). Existing estimates of thorium resources should be considered conservative for two reasons:

- Data from China, central and eastern Europe, and the former Soviet Union have not yet been published.
- Historically weak market demand has limited the exploration for thorium.

It is possible, even likely, that much more thorium exists than has been documented and would be discovered if concerted exploration became warranted.

Implementation of these technological innovations remains for the future and will require considerable research and development effort and investment. Although no commercial deployment of fast reactors is yet planned, they remain a promising opportunity in respect of resource utilisation.

Table 2: Nuclear fuel resources useable in fast reactors

Resource category	Estimate (1 000 t)
Thorium reserves ¹	2 160
Additional thorium resources ¹	2 350
Depleted uranium tails ²	1 200 (758) ³

1. Data from China, central and eastern Europe, and the former Soviet Union not available. *World Energy Assessment*, United Nations Development Program, New York, 2000; German Federal Institute for Geosciences and Natural Resources data bank.
2. At the end of 1999. *Management of Depleted Uranium*, OECD, Paris, 2001.
3. If the depleted uranium tails are re-enriched to the extent possible, about 758 000 tU will remain with 0.06% ^{235}U assay.

Table 3: Effect of technology advances on resource availability

Reactor/fuel cycle ⁱ	Potential energy production – conventional resources only (TWh) ⁱⁱ	Potential energy production – total resources (TWh) ⁱⁱⁱ	Years at 1999 world nuclear electricity generation ^{iv} (conventional)	Years at 1999 world nuclear electricity generation (total)
Current fuel cycle (LWR, once-through)	827 000	21 200 000	326	8 350
Recycling fuel cycle (Pu only, one recycle)	930 000	23 900 000	366	9 410
Light water and fast reactor mixed with recycling	1 240 000	31 800 000	488	12 500
Pure fast reactor fuel cycle with recycling	26 000 000 ^v	630 000 000	10 000	250 000
Advanced thorium/uranium fuel cycle with recycling	43 200 000 ^{vi}	90 200 000 ^{vii}	17 000	35 500

- i. For a fuller description of the technologies listed and their resource requirements, see reference 5 below.
- ii. Conventional resources were calculated using known conventional and undiscovered conventional resources plus secondary sources, from Table 1, for a total of 17 110 000 tonnes.
- iii. Total resources assumes conventional resources plus the phosphate resources, but only 10% of seawater uranium is recovered (400 million t), added together for a total of 439 110 000 t.
- iv. *Key World Energy Statistics*, IEA, Paris, 2001. Total 1999 (latest year data available) electricity generation by nuclear power was 2 538 TWh, rounded to 2 540 TWh.
- v. Assumes use of conventional uranium resources plus 758 000 t of depleted uranium tails remaining after re-enrichment.
- vi. Assumes use of only the thorium reserves base of 2 160 000 t with a matching amount of depleted uranium.
- vii. Assumes thorium reserves base plus resources of 4 510 000 t with a matching amount of depleted uranium. This also assumes that no further discoveries of thorium are made.

Longevity

With these resource estimates and technology options, for how long will we be able to produce nuclear energy? The answer depends on many factors, including levels of electricity demand. Table 3 demonstrates how long estimated resources would be able to produce electricity for various nuclear reactor and fuel cycle technology options. Illustrative assumptions were made as to the resources consumed by each technology as well as the levels of demand. Nevertheless, even at generation rates ten times greater than current levels, there are sufficient resources for many centuries of energy production, and technology developments would greatly extend these periods.

Conclusion

Vast uranium resource potential supplemented by the possible use of fast breeder reactors and thorium-based fuel cycles point to a nuclear energy future that can meet sustained demand.

In considering the question, “Are there enough resources to meet the needs of the current generation without compromising the ability of future generations to meet their own needs?”, that answer has to be yes. Sufficient nuclear fuel resources exist to meet the energy demands of this and future generations well into the future at current and increased demand levels. However, to use this potential, considerable effort and investment will be needed to develop new mining projects and to bring advanced technologies to bear in a timely manner. ■

References

1. NEA (2002), *Uranium 2001: Resources, Production and Demand*, OECD, Paris.
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3. NEA (2001), *Management of Depleted Uranium*, OECD, Paris.
4. US Energy Information Administration (2002), *International Energy Annual 2000*, Washington D.C.
5. NEA (2001), *Trends in the Nuclear Fuel Cycle*, OECD, Paris.