

# Uranium Supply and the Nuclear Option

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## Introduction

The nuclear industry have traditionally argued that nuclear energy is a reliable source of energy in the longer term [WNA 2003], but for how long? There are many technical issues, related to the choice of reactor and the operation of the fuel cycle, which affect the longevity of the uranium resource. Potentially these choices could limit the viability of the uranium resource to a few decades.

To decide how valid an option nuclear energy is we must understand the limitations on the availability of uranium, and the current state of reactor technology. There are many uncertainties about how the nuclear industry might develop in the future, but it is possible to conclude that the supply of uranium, at a level that could support large-scale power generation, might only be viable for a matter of decades. Potentially, could a shortage of uranium be the Achilles-heel of the nuclear industry that, so far, the anti-nuclear lobby have missed?

## Uranium Resources

Uranium is a resource that is as common as tin or zinc. Some analysts argue that the production processes of the uranium mining industry, and the nuclear industry's use of uranium, mean that we should evaluate the supply of uranium in a similar manner to the evaluation of metal resources [MacDonald 2003]. It is the quality, not the quantity, of the resource that we must concentrate upon.

According to the 'Red Book' [NEA 2004], the OECD Nuclear Energy Agency's statistical study of world uranium resources and demand, in 2002 the world consumed 67,000 tonnes of uranium. Only 36,000 tonnes of this was produced from primary sources. The balance came from a variety of secondary sources, in particular the ex-military inventory of uranium which is being released as nuclear weapons systems are run down. The availability of cheap uranium from the military has been one of the contributing factors to the shrinkage of capacity within the uranium mining sector over the last decade [Combs 2004]. It also entails that at some point between 2010 and 2020 the uranium mining industry must dramatically expand to meet future demand [Bertel 2002].

Estimating the available reserves of uranium is a little difficult as various agencies interpret the availability of uranium resources using different methodologies. If we add together all potential sources of uranium, including 'unconventional' sources such as sea water, the amount of uranium that is accessible around the globe is in excess of 17 million tonnes [Price, 2002]. Most estimates, which consider known reserves and reasonable estimates of other high grade sources of uranium ore, put the figure at around 4 to 5 million tonnes. Some authorities take a more sceptical view. For example the European Commission's Green Paper on Energy [EC 2001] discounts speculative sources and quotes only the known uranium resource (2 to 3 million tonnes).

Generally uranium reserves are classified according to the cost of recovery as a dollar value. Clearly this is an imprecise measure given that it does not reflect the net value of the energy produced from uranium less the

energy used in its mining and processing and in the generation of power. Below a certain concentration the recovery of uranium will take more energy than it produces. The most productive uranium ores contain 1,000 to 20,000 parts per million of uranium (ppmU) [WNA 2004]. Other potential sources, such as igneous rocks, have concentrations of uranium of around 4ppmU. Sea water, also quoted as a future source of uranium, has an average uranium content of 0.003ppmU. In the 1970s Peter Chapman [Chapman 1975] calculated the cut-off value, at which the energy used to extract uranium from the ore exceeds the energy produced from the nuclear plant, at around 20ppmU. Even with advances in processing and reactor design this is unlikely to fall far below 10ppmU. This puts a limitation on the theoretical size of the uranium resource because a number of the potential sources fall below this level.

## Fuel Cycles and Uranium Consumption

The world's nuclear capacity is based upon 'thermal' fission reactors that split uranium atoms and produce heat. The problem with this type of reactor is that it can only split atoms of one isotope of uranium – uranium-235 ( $^{235}\text{U}$ ). As  $^{235}\text{U}$  only constitutes around 0.7% of the uranium resource the amount of energy that nuclear energy systems can generate, using current technologies, is very limited.

The bulk of the uranium resource, made up of the isotope uranium-238 ( $^{238}\text{U}$ ), does not take part directly in nuclear fission. However some of the  $^{238}\text{U}$  is converted to plutonium-239 ( $^{239}\text{Pu}$ ) whilst inside the reactor and this is also fissioned to produce additional energy. The only way it is possible to use the majority of the uranium resource is to adopt a different reactor technology – the 'fast breeder' or 'fast' reactor. This exploits the conversion of  $^{238}\text{U}$  into  $^{239}\text{Pu}$  by 'fast' neutrons in order to produce  $^{239}\text{Pu}$ , and following reprocessing of the nuclear fuel the  $^{239}\text{Pu}$  can be substituted for the  $^{235}\text{U}$  for future energy production.

The primary difference between the thermal reactor system and the fast breeder reactor system is the way that the nuclear fuel cycle operates. Thermal reactors operate a 'once through' cycle. Nuclear fuel is used to generate energy and then it is put into indefinite storage. Some nuclear fuel is reprocessed in order to recover the plutonium, but at the moment the recycling of plutonium back into the fuel cycle operates at a minimal level – through the production of 'mixed oxide' (or MOX) fuel. Switching to a system where fast reactors are used more widely, in order to operate a more 'closed' cycle, would allow a greater proportion of the uranium resource to be utilised. However, it would also require that the world's nuclear reprocessing capacity were dramatically increased as the closed cycle cannot operate without these reprocessing facilities. The requirement to significantly expand fuel reprocessing, far beyond the world's current capacity, also brings with it unknown factors in relation to the consequential increases in releases of persistent and bioaccumulative radioactivity into the environment.

In 2003, the Massachusetts Institute of Technology produced a detailed study of the future of nuclear power [MIT 2003]. This provides a wealth of data on the various types of nuclear fuel cycle that might operate in the future, and how much uranium these different fuel cycles consume. On the MIT analysis, the effect of switching from a 'once through' to a 'closed' cycle (where a mixture of thermal and fast reactors are used and the plutonium is recycled through fuel reprocessing) is to nearly halve the consumption of uranium per unit of energy produced. However, despite the fact that using fast reactors would reduce uranium consumption, and allow a greater proportion of the uranium resource to be utilised, no viable commercial design for a fast reactor has yet been produced. The major fast breeder projects have been curtailed by technical flaws, principally related to the problems associated with cooling the core of the fast reactor system. This impasse seems unlikely to change in the future given that the new (Generation III) reactor designs currently being tested, and most of the future (Generation IV) reactors that are being designed, are thermal not fast reactors.

## The Lifetime of Uranium Resources

The nuclear industry often expresses the contribution of nuclear energy in terms of electricity generation, but it's more realistic to look at its contribution in terms of global energy supply. This is because, as fossil fuels become scarce [Mobbs, 2004], nuclear energy would have to displace the energy currently supplied by fossil fuels. Although nuclear energy provides 16% of the world's electricity supply [WNA 2005], recent estimates put the contribution to the world's total energy supply at between 6.1% [BP 2004] and 6.6% [UNDP 2000].

At the current level of uranium consumption (67,000 tonnes per year) known uranium resources (2.8 million tonnes of uranium) would last 42 years – a fact highlighted by the European Commission in their Energy Green Paper [EC 2001]. The known and estimated resources plus secondary resources (such as the military inventory), a total of around 4.8 million tonnes, would last 72 years. Of course this assumes that nuclear continues to provide just a fraction of the world's energy supply. If capacity were increased six-fold then 72 years would reduce to 12 years. This is because nuclear energy, in terms of global energy supply, must increase by a factor of four to eight to make any significant difference to the use of fossil fuels around the globe. Consequently the expected lifetime of the uranium resource would fall by a similar factor.

The actual lifetime of the uranium resource will depend upon the technologies adopted as part of any new nuclear capacity. New reactor designs are more thermally efficient (up to 45% to 50% rather than 30% to 35%) which could extend the lifetime of the uranium resource by a factor of 1.7. Introducing a number of fast breeder reactors, to increase the efficiency of uranium consumption, might increase the lifetime of the uranium resource by a factor of 2. Even so, taking these two factors together alongside a six-fold increase in capacity, the lifetime of the known and estimated uranium resource would still be less than 50 years.

This stark problem, if one reads many papers on uranium resources produced by the nuclear industry, is an issue that is recognised but seldom explored. It was highlighted in OECD research six years ago, which noted that if the nuclear option were adopted without a radical change in technology then known uranium supplies would only last 'about a decade' [OECD 1999]. The recent MIT study briefly acknowledges the matter but, perhaps due to the USA's large indigenous uranium reserves, discards it. Others have acknowledged the short term problems of capacity in the uranium industry, especially the problems that might arise if mining capacity does not expand before the military inventory is exhausted [Del Frari 2001/Connor 2003], but do not look to the longer-term lifetime of the resource. A very few portray a wholly unrealistic scenario, that forecasts hundreds or thousands of years of nuclear energy [Price 2002]. This is because they do not take into account the need for the nuclear industry to grow massively in order to displace fossil fuel use, or that a significant part of the globe's entire theoretical supply of uranium may be unusable (because its extraction and use would take more energy than it would provide).

## Conclusion

To make a significant contribution to energy supply nuclear energy would have to expand by such a scale that the lifetime of the uranium resource, along with issues such as the management of radioactive waste and the control of fissile materials, are always going to be problematic. Unlike plant safety or the emission of radioactivity, which can be controlled through better engineering or management, the basic issue of how much energy can be produced from nuclear sources is limited by physical laws and the scale of current global energy demand.

There are clear shortcomings in the current methodology for assessing uranium resources because they are based entirely on the economic costs of production, not the net energy value of the resource once the costs of extraction and use are taken into account. This has important implications, which vary according to the selection of the fuel cycles and reactor technologies used, on the lifetime of the uranium resource. Until the net energy

value of the uranium resource, and different fuel cycles, is taken into account we can have no clear understanding of the productive future of the nuclear industry. It is also difficult to assess the environmental implications of the nuclear option as each technology creates varying environmental impacts.

It would be unwise to advocate adopting the nuclear option when we have no realistic idea of how long the uranium resource will last. Clearly the 'once through' cycle has no future – if the world were to adopt the 'once through' option the world's uranium resources would be exhausted in a few decades. We would very quickly shift from shortages of oil and coal to shortages of uranium [Mobbs 2005]. The principle solution to the problem of the 'once through' cycle, adopting a more 'closed' cycle using fast breeder reactors, is itself fraught with dangers. There is no tried and tested fast breeder technology. In addition the scale of the increase in nuclear capacity required to displace fossil fuel is such that the lifetime of the resource would still be a matter of decades, not centuries. For this reason it may be that the longevity of the uranium resource, quite apart from the issues of waste or radioactivity, could be more significant to the future viability of the nuclear industry.

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