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Trends in the nuclear fuel cycle

Economic, environmental and social aspects

Nuclear energy has been part of the world's energy mix for almost fifty years. However, over the past thirty years increased public concern over this form of energy has resulted in socio-political constraints on its use. At the same time, while over these past thirty years the world was able to cope with an increasing energy demand by relying more on fossil fuels, growing consideration for achieving sustainable development and alleviating climate change has led to renewed interest in the potential role of nuclear energy in the world's future energy supply mix.

The role of nuclear energy in a sustainable energy future has multiple facets, a significant number of which relate to the nuclear fuel cycle. Indeed, many sustainability issues are associated with the fuel cycle: use of natural resources, economics, waste arisings, public acceptance, proliferation resistance, to name only a few. In addition, the development of new reactor types with improved characteristics in some of those aspects generally will entail concurrent positive developments in the related fuel cycle.

It is therefore generally agreed that a fresh look at the nuclear fuel cycle options may be worthwhile in order to investigate the possible interactions between the different fuel cycle steps and technology choices. In that respect, the NEA Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (NDC) created an expert group in 1998 to prepare a report on the developments and trends in the nuclear fuel cycle that may improve the competitiveness and sustainability of nuclear generating systems in the medium to long term. The expert group comprised representatives of the nuclear industry, government agencies and research organisations involved in various aspects of nuclear fuel cycle development. The report will be available by the end of 2001.[1]

The nuclear fuel cycle in perspective

The nuclear fuel cycles in use today are the result of four decades of technological development aiming at the establishment of a reliable, secure, safe and cost-effective energy source. However, the basic elements of these fuel cycles were established early in this period, when the "ground rules" and development objectives were different from those existing today. Many decisions made at that time still affect the fuel cycle industry

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today. To meet the needs of an already large military programme, and given the anticipated rapid growth of nuclear production, large fuel cycle facilities were constructed for the mining, conversion and enrichment stages of the fuel cycle, and reprocessing facilities were constructed to provide plutonium for fuelling the expected introduction of breeder reactors. The slowdown in civilian nuclear power programmes that has occurred since the 1980s, together with the agreements reached for reducing nuclear weapons programmes, has led to the current situation where the production capacities of fuel cycle facilities, with the exception of uranium mining, exceed demand.

Current demand for natural uranium amounts to around 60 000 tonnes per year. Stockpiles and known uranium resources could cover some 60 years of consumption by present reactors, and the actual uranium resources are thought to be much larger. Conventional uranium resources are estimated to be about 15 million tonnes, representing some 250 years of present consumption.[2] With such reserve levels and given the uncertain future for new nuclear power plant construction, there is currently little economic incentive to explore for uranium. Additional resources might be found by extracting uranium from seawater (some 4 000 million tonnes), a virtually unlimited supply, provided its development would become economically viable and environmentally acceptable. Less uranium resources would be necessary if use was made of recycling, fast breeder reactors or thorium.

While the availability of uranium may not constitute a constraint to using nuclear energy on a larger scale, other fuel cycle steps, e.g. waste disposal, may become limiting factors and will require fuel cycle choices in the coming decade.

Several technological developments have therefore been initiated over the past decades, both at the front-end and the back-end of the nuclear fuel cycle. Some of these developments are part of a longer term endeavour, such as complete recycling. Other short-term, ongoing industrial development programmes include important elements for further reductions in cost and environmental impact. For example, new uranium mining techniques have been developed and environmental measures adopted to reduce the impacts of the extraction and processing of uranium to very low levels, comparable to natural background radioactivity. In the field of uranium enrichment, the development of centrifuge technology has led to a reduction of costs mainly due to a reduction of the energy consumption by a factor of fifty as compared to gas diffusion technology. This process will likely dominate the enrichment field in the medium term. However, laser enrichment should not be ruled out in the longer term, as it allows for even greater economy and selective re-enrichment of reprocessed uranium.


Energy Resources of Australia Ltd.

Determining ore grade with a radiometric discriminator at the Ranger Mine in Australia.

There is continuous improvement towards higher performance, reliability and safety of fuel design and fabrication. Fuel optimisation addresses the integration of front-end and back-end issues together with improving the operational performance of the nuclear power plants. In that respect, innovative fuel forms are in development, partly in the framework of a life-cycle approach, to bring about reductions in spent fuel quantities, and hence long-term liabilities, better resource conservation, and at the same time improvements in plant availability and reductions in fuel cycle costs.

While the economic merit of reprocessing may vary over time, it has the potential of reducing the consumption of uranium as well as the amount of waste to be disposed of and its overall radiotoxicity. Further towards the back-end of the fuel cycle, the waste disposal solutions proposed today are mainly country specific. Several solutions have been proposed for the final disposal of high-level, long-lived waste, reaching a stage of advancement where the scientific and technical experts feel confident in their feasibility and safety. However, limited social and political consensus has postponed the implementation of these solutions.

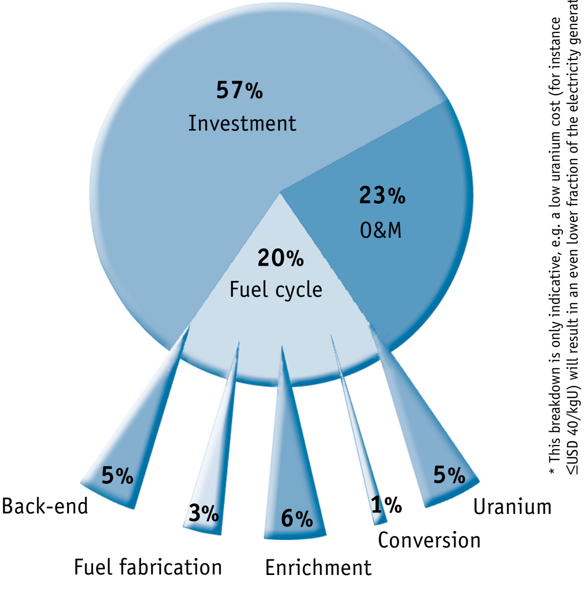
Two additional waste management options often discussed in public and scientific debates today are the extended storage of the waste (rather than irretrievable disposal) and the partitioning and transmutation of the long-lived radionuclides contained within the waste. Partitioning and transmutation involves processing the waste to extract the long-lived radionuclides, especially the minor actinides, which are then irradiated in a nuclear reactor system to yield products with shorter half-lives, thereby reducing the time required for their isolation from the environment. Special industrial facilities would have to be built and operated over long time periods in order to achieve this result. In any case, it is recognised that it would not be feasible to apply this technique to all types of waste, such that some quantities of radioactive materials would still require long-term isolation. Although both options might be components of an overall waste management strategy, and extended storage over a few decades is already planned in some countries, neither option completely avoids the need for some sort of final disposal, such as a geologic repository. Scientists and managers responsible for developing waste management solutions therefore generally remain convinced that progress should continue to be made towards the implementation of permanent disposal.

Dry storage containers for spent nuclear fuel at the Doel nuclear power plant in Belgium.

Electrabel, Belgium

In the context of these fuel cycle developments, it should be noted that nuclear power has a very high degree of long-term stability with respect to the price of the raw material for nuclear fuel (uranium). The cost of the nuclear fuel cycle is about 20% of the total nuclear electricity generating cost, whereas fuel costs may represent up to 80% of fossil fuel electricity generation cost. It is also of particular importance to note that the costs of waste management and disposal, as well as the decommissioning of nuclear power plants and fuel cycle facilities, are already "internalised" in the costs of nuclear electricity production.

Nuclear electricity generation cost breakdown*



* This breakdown is only indicative, e.g. a low uranium cost (for instance ≤USD 40/kgU) will result in an even lower fraction of the electricity generation cost.

Today, much of the current public opposition to nuclear energy is focused on the transport of spent fuel and high-level waste, in spite of the fact that the industry has accumulated more than 40 years of experience in this regard, without experiencing a single accident with radiological consequences to the public or the environment.

Only a small number of accidents with significant radiological consequences have occurred in OECD Member countries during the past 50 years in a few nuclear fuel cycle facilities. These events, while rare, call for continued strict compliance with regulatory requirements as well as quality management at every stage of the fuel cycle.

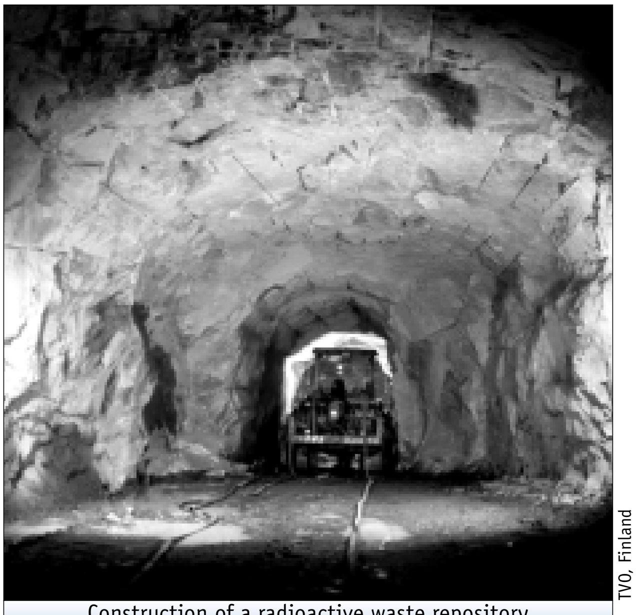
Proliferation risk has also been part of public and political concerns. An institutional safeguards regime has been established to prevent the diversion of material from the civil nuclear fuel cycle for military or terrorist purposes. New developments in reactor and nuclear fuel cycle technologies may also enhance the proliferation resistance of fuel cycle facilities, providing even greater protection from this type of diversion.

Challenges for future development

Given today's market-driven environment, there is limited potential for industry to fund the long-term R&D needed to develop and implement advanced fuel cycles. Political pressure and competing budget priorities have worked to reduce nuclear R&D funding by governments as well. There are some signs that government funding may increase in the near future, but budget constraints are likely to limit the number of fuel cycle options that can be investigated.

Comprehensive planning that includes consideration of economic, environmental and social factors in a well-balanced and integrated comparative assessment of different options will become increasingly important in formulating and taking decisions on long-term R&D programmes and energy policies, including for nuclear power. Nuclear power faces major challenges with respect to the nuclear fuel cycle, including:

- Implementation of advanced reactor concepts and fuel cycles will remain a lengthy and expensive process. Multilateral or international co-operative R&D programmes will therefore become increasingly important in order to pool limited financial resources and obtain the benefits of synergy among R&D activities, thereby shortening the process that spans from concept to industrial reality. Indeed, there already are some examples of such co-operative activities, including the US-initiated Generation IV International Forum (GIF), the IAEA-led International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO), and the multi-national interest in the Pebble Bed Modular Reactor (PBMR).
- Facilities for the final disposal of spent fuel and high-level waste should be put in place in order to demonstrate to the public that the industry is managing its wastes, and that the disposal systems, for which the necessary technologies already exist, can be operated with very limited impact on the environment.
- From a long-term perspective, it is important to further develop advanced reactors and fuel cycles, incorporating full recycling of actinides, in order to reduce the overall amount of waste requiring disposal or to reduce the necessary confinement times, as well as to improve the efficiency of using natural nuclear fuel resources.



TVO, Finland

Construction of a radioactive waste repository at Olkiluoto in Finland.

Conclusion

The different developments, as analysed in the report, show that nuclear power has potential as a sustainable energy source. Governments and industry have already developed environmental protection measures in the nuclear fuel cycle, including transport, and continue to improve those measures. No major technical problems remain in the short term, and current fuel cycles may essentially be seen as a mature business activity with a very low impact on the environment in OECD countries. Ongoing technological developments offer various possibilities for using nuclear energy in a sustainable development context. The final choice essentially depends on socio-political considerations. In this respect, stakeholder participation will need to be improved and consensus sought if this industry is to develop its potential. ■

Notes

1. NEA (2001), *Trends in the Nuclear Fuel Cycle: Economic, Environmental and Social Aspects*, OECD, Paris.
2. NEA and IAEA (2000), *Uranium 1999: Resources, Production and Demand*, OECD, Paris.