Safety of the nuclear fuel cycle

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The nuclear fuel cycle starts with mining operations, and proceeds through the various steps in the cycle [milling, conversion, enrichment, fuel fabrication, fuel burn-up in the reactor, reprocessing (in some member countries), transport], to the final stages of spent fuel and radioactive waste storage and disposal. Transport is involved between steps in the cycle, and each step in the cycle has its unique safety aspects.

The NEA Committee on the Safety of Nuclear Installations (CSNI) Subgroup on Fuel Cycle Safety (FCS) was created in 1976 to advance the understanding of relevant aspects of nuclear fuel cycle safety in member countries. The subgroup constitutes a forum for the exchange of information and experience in areas related to nuclear fuel cycle safety. It has developed a system for the collection and dissemination of operating experience at the various steps in the fuel cycle, and meets regularly to discuss these events and to analyse in detail some of the more significant events.

The concept of a unified document on the safety aspects of all steps in the fuel cycle materialised about 25 years ago, with the first publication of *Safety of the Nuclear Fuel Cycle* by the NEA. In 1993, the FCS revisited the topic and prepared a new edition. Over the past several years the FCS has been gathering material for another revision and update, which will be published later in 2005.

The nuclear fuel cycle

The nuclear fuel cycle consists of a number of activities which together make up the cycle. The FCS subgroup has chosen to omit two activities of the cycle from the reports on fuel cycle safety. Reactor operation, which is a fuel cycle safety topic, is covered elsewhere in the NEA programme of work, as are the safety aspects of high-level waste disposal. The fuel cycle may be characterised as either once-through (sometimes called "open"), where fuel, after discharge from the reactor, is ultimately taken to a disposal site. By contrast, a closed cycle is characterised by reprocessing and reutilisation of recovered fissile isotopes. Both aspects are covered in the fuel cycle safety reports.

The 2005 update of the *Safety of the Nuclear Fuel Cycle* discusses both the technical and safety aspects of the various steps in the fuel cycle. It also provides a summary of the more significant operational events over the past 50 years and the corresponding lessons learnt.

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Nuclear fuel cycle safety over the past decade

For the most part, since the last update of the *Safety of the Nuclear Fuel Cycle* in 1993, the situation has been relatively stable. While the number of reactors in the OECD area increased by more than 10% (from 321 to 360), some member countries have decided not to build more plants. One development that might play a role in the future of nuclear power in OECD countries is the determination, essentially worldwide, to reduce the consumption of fossil fuel so as to reduce the amount of greenhouse gases and other undesirable byproducts of combustion. Certainly nuclear power could play an important role in the production of electricity without the emission of carbon dioxide and certain other undesirable elements and compounds. Developments over the past decade at various steps in the fuel cycle may be summarised in the following way:

- Nuclear power plants operated with no major safety problem.
- About 60 000 tonnes of uranium were mined each year, purified, converted, enriched (when necessary), fabricated into fuel assemblies and loaded into reactors.
- After use in reactor operation, the fuel was stored (either wet or dry) or shipped to reprocessing plants. At times, these shipments were quite

lengthy, such as by ship from Japan to Europe.

- For the most part these fuel cycle operations were without incident; however, there were two events of note. Fuel cycle operational events of concern included major events at a pilot plant of the Power Reactor and Nuclear Fuel Development Corporation (PNC) in Japan. This involved a bitumen fire. The second event was an inadvertent criticality at a Japan Nuclear Fuel Conversion Company (JCO) facility, which involved loss of life of the operating crew.
- During the past decade, there has been additional interest in continuing the reduction of radiation exposure to workers, and in reducing discharges of radiation to the air and in water.
- Another factor of safety interest that grew and matured over the last decade was in the area commonly called "human factors" and its related topic, "safety culture". These developed into matters of interest to regulators and owners alike, as the human element plays an important role in fuel cycle safety.

Evolution in the nuclear fuel cycle

Developments, both technical and geopolitical, since the 1993 version of the fuel cycle - safety report have contributed to the evolution in fuel cycle technology.

Mining and milling: There are several methods for mining uranium. One method, called *in situ* leaching (ISL), has received increased interest because it does not result in a large deposit of mill tailings after closure of the mine. ISL is not always possible, as it depends on an acceptable rock strata, and the traditional surface and underground mining methods remain predominant modes. In some countries, notably in the United States, in European countries, and to a degree, in African ones, mining has essentially ceased. This is due to several factors, including the low grade of uranium in those countries, the relatively static nature of demand, the low price of uranium for nearly two decades up until 2001, and the availability of enriched uranium (after downblending) from the weapons programme of the former Soviet Union.

Enrichment: Traditionally the enrichment method of choice was gaseous diffusion. Gaseous diffusion has the ability to produce a large quantity (throughput) of enriched uranium, but it consumes a large quantity of electricity in doing so. Most gaseous diffusion plants are quite old. Centrifuge plants are now considered the favoured technology. Over the past ten years, considerable efforts have been made to develop laser enrichment. However, after expenditures of more than one billion dollars, this concept is not yet viable.

Fuel fabrication: Evolution in fuel fabrication technology has not been significant over the past decade or so. Ceramic oxides are still used for fuel, and zirconium alloys are still the cladding of choice. Advancements in reprocessing have made the use of mixed-oxide fuel pellets (both uranium and plutonium) more widespread.

Reprocessing: Several additional reprocessing plants have opened in the United Kingdom and Japan. Plants at La Hague, France are operating at capacity.

Decommissioning: Decommissioning, one of the steps in the fuel cycle, is proceeding at a number of facilities around the world. No significant safety problems in this step have been reported.

Transport: Transport is a necessary step in the fuel cycle, and connects other steps. There have not been any significant developments in transport during the past decade. However, there is continuing interest in the consequences of a severe crash, involving either a truck or a train, during the transport of spent fuel. Research is continuing in this area, as well as in the more recent area of interest concerning the potential for a terrorist attack on fuel shipments.

Event reporting

The FCS subgroup has maintained an event reporting system known as the Fuel Incident Notification and Analysis System (FINAS). This database now contains more than 100 events involving the various steps in the fuel cycle. This system provides a means for furthering the exchange of information, including on the all-important corrective actions and lessons learnt. In 2004, the NEA and the International Atomic Energy Agency (IAEA) agreed to convert FINAS into a jointly operated system. Among other things, this will result in a computer-based search and retrieval system for events, such as the one now used for events in commercial nuclear power plants.

Conclusions

Based on the record of the last decade, it can be said that the fuel cycle has truly matured. Significant improvements in technology and safety have been incorporated at various steps in the fuel cycle. The collection and dissemination of operating experience throughout the fuel cycle is improving significantly in style and format, and will now reach the member states of the IAEA. The FCS subgroup continues to provide a prominent forum for the exchange of safety information and, by publishing the 2005 update of the *Safety of the Nuclear Fuel Cycle*, will further advance the cause of nuclear safety. ■