Management of spent fuel from power and research reactors: International status and trends

Storage facilities are being expanded, as most countries are deferring decisions on final disposal and reprocessing options

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Spent fuel management has always been one of the most important stages in the nuclear fuel cycle, and stands among the most vital problems common to all countries with nuclear reactors.

It begins with the discharge of spent fuel from a power or a research reactor and ends with its ultimate disposition, either by direct disposal or by reprocessing. Two options exist at present — an open, once-through cycle with direct disposal of the spent fuel, and a closed cycle with reprocessing of the spent fuel and recycling of plutonium and uranium in new mixed oxide fuels.

Direct disposal places the spent fuel in a location and under conditions that do not allow for its retrieval. Reprocessing separates the fissile plutonium and uranium from the waste material for reuse in new fuels. The selection of a spent fuel strategy is a complex procedure in which many factors have to be weighed. They include political, economical, and safeguards issues as well as protection of the environment. Because of the current low uranium prices, recycled uranium and plutonium cost more than newly mined uranium.

Delays in the implementation of the fuel reprocessing option in some countries, the complete abandonment of this option in other countries, and delays in the availability of final spent fuel disposal in almost all countries have led to increasingly long periods of interim spent fuel storage. This "wait and see" approach gives more time and freedom to evaluate the available options and to select the most suitable technology. The problem of spent fuel management has therefore increased in importance for many countries.

The current spent fuel management policies in different countries can be divided into three broad categories:

- A once-through fuel cycle with the focus on interim storage followed by disposal of the fuel;
- The reprocessing option for plants operating or under construction, or where contracts for reprocessing have been placed abroad, and/or some or all of the fuel is returned to the country of origin;
- The "wait and see" option, where spent fuel management programmes are still being evaluated.

Spent fuel in storage

Power plants. In 1992, the spent fuel arising from all types of reactors in nuclear power plants amounted to about 10 000 tonnes of heavy metal (tHM), giving an estimated cumulative total of over 135 000 tHM. Of this, about 90 000 tHM of spent fuel is stored at present.

The quantity of accumulated spent fuel is more than 20 times the current total annual capacity for reprocessing. By the year 2000, the annual amount of spent fuel arising worldwide is projected to surpass 11 000 tHM, increasing from 10 000 tHM in 1992.

Cumulatively, the amount of spent fuel generated is projected to reach 225 000 tHM by the year 2000. *(See graph.)* Assuming that part of this total is reprocessed, the amount to be stored is projected to be about 150 000 tHM. Since the first large-scale final repositories for disposal of spent fuel are not expected to be in operation before the year 2010, "interim" storage will be the primary option for the next 20 years.

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Research reactors. For research reactors, the IAEA does not have a comprehensive database on the amount of spent fuel in storage at present. To rectify this situation, a questionnaire recently was sent to the operators of the research and test reactors and the responses received so far are being evaluated. The United States has exported over 25 000 kilograms of highly enriched uranium (HEU). Of this amount, about 17 500 kg is currently in use or stored as spent fuel in 51 countries. Most of the exported HEU went to the 12 Euratom countries (85%), the remaining amount to 39 other countries.

Many operators of research reactors find themselves in a crisis situation because of spent fuel management problems. This is particularly the case in several Western European countries where operating license extensions are tied to a successful resolution of spent fuel problems. The crisis has been precipitated by the cessation of practices to take back research reactor fuels by the countries where they were originally enriched (mainly the USA and Russia). The crisis has been exacerbated by the Reduced Enrichment for Research and Test Reactors Programme that has left many pools at research reactors filled with HEU, and left a greater throughput of fuels of lower enrichment. Although there are encouraging signs that both the USA and Russia will renew their practices to take back research reactor fuels, any protracted delay in the implementation of these policies could lead to the closure of important research facilities.

Spent fuel storage facilities. Spent fuel storage includes all activities related to the storage of fuel until it is either reprocessed or sent for final disposal. Spent fuel storage facilities may be situated at the reactor (AR) or outside the boundary of a nuclear power station at an "away from reactor" (AFR) site, possibly serving as a centralized facility for several reactors. Spent fuel storage facilities may also be classified by the medium of storage, as either "wet" or "dry". "Wet" facilities involve storage of spent fuel in water pools. The spent fuel may be supported within the pool by racks, and/or contained in submerged canisters. "Dry" facilities involve storage of spent fuel in a gas environment, such as an inert gas or air. Dry storage includes spent fuel in casks or vaults. A cask is a massive container which may or may not be designed to be easily transportable. Vaults consist of above- or below-ground reinforced concrete buildings containing arrays of storage cavities suitable for containment of one or more fuel units.

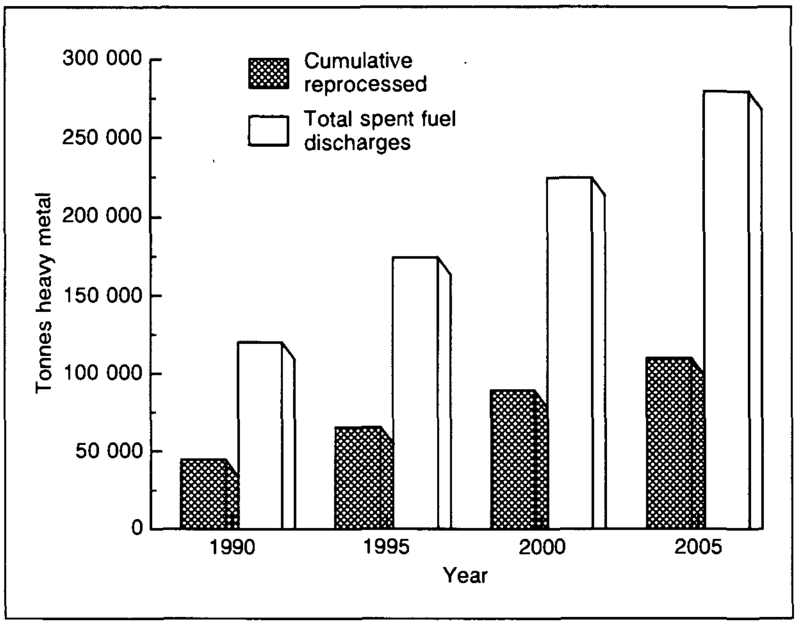
The requirements for interim storage of spent fuel depend on a number of considerations associated with the management option selected. In the closed fuel cycle option, further storage capacity may be required to match the arisings of spent fuel with the available reprocessing plant capacity. For the once-through cycle, storage is required until the final repository has been engineered and is in service. Clearly, for deferred decisions the availability of adequate interim storage is also a key element.

Various types of wet and dry storage facilities are in operation, or being considered by States. An IAEA co-ordinated research programme (CRP) called BEFAST has demonstrated that spent fuel can be safely stored for long periods of time — some spent fuel has now been stored for more than 30 years. Nearly all countries operating nuclear power plants have increased their existing AR capacity by reracking using neutron absorbing materials between the assemblies, or through rod consolidation or simply better distribution of fuel in the storage pools.

Such modifications have resulted in at least a twofold increase in storage capacity. Further capacity increases may invoke the so-called "burnup credit" in calculations of the criticality of irradiated fuels.

In many cases, modifications were insufficient and separate AFR storage facilities had to be constructed. Although the majority of storage facilities are of the wet type (e.g., in France, the United Kingdom, Russia, and Sweden), many countries with large quantities of spent fuel have chosen or are choosing AFR dry storage (e.g., Canada, Germany, Scotland and the USA, while in Russia dry storage is being developed for RBMK fuel). This type of storage has many benefits, including the possibility of passive

Projected cumulative amounts of spent fuel from nuclear power plants



	In operation	Under construction	Planned	Shutdown/ On stand by
Argentina	365			
Belgium				370
Bulgaria	600			
Canada	475	200	12 600	
China			500	
Czech Republic			600	
Finland	1 270			
France	15 000			
Germany	2 150		700	1 500
Hungary			600	
India	523			
Japan	140		3 000	
Korea, Rep. of			3 000	
Russia	10 100	1 900	3 000	
Slovak Republic	600			
Spain			5 500	
Sweden	3 000	2 000	4 000	
United Kingdom	10 350		1 200	
Ukraine	1 900			
United States	900		15 000	
Total	**47 373**	**4 100**	**49 700**	**1 870**

Notes Values are in tonnes heavy metal A number of US reactors have licensed additional dry storage facilities *Source. Data reported to the IAEA*

Away from reactor storage capacities at the end of 1992

cooling, minimal or no maintenance, and a non-corrosive environment.

In 1992 the AFR storage capacity in operation was 47 373 tHM, made up of 44 833 tHM in wet storage and 2540 t HM in dry storage. *(See table.)* These figures also include the storage pool capacities of reprocessing facilities.

Recognizing the mature status of AFR technologies, changes in the basic principles are not expected in the near future. Nevertheless, factors that may influence future AFR designs are as follows:

- The impact of disposal concepts (when finalized). There may be pressure to place spent fuel in containers amenable to disposal requirements at as early a stage as practicable to minimize the number of handling operations.
- New requirements to store higher burnup fuel and/or advanced fuel types.
- The desire of utilities to claim burnup credits against criticality considerations.
- The desire of utilities to extend storage times. This will influence inspection and maintenance requirements of AFR facilities and put more emphasis on fuel degradation mechanisms.

Changes in the politics and trading relationships of the Eastern European countries are affecting their spent fuel management policies. Russia now requires payment for services in hard currency at a "world price" level. Some legal problems also exist with the transport of Russian-origin fuel and its subsequent reprocessing in Russia. Such factors may lead to changes in the spent fuel management policy of these countries.

Construction of an interim storage facility can be a temporary solution, with the options of reprocessing or direct disposal kept open. For example, in 1992 Hungary decided to build an AFR storage facility at its Paks nuclear plant. An independent group of experts, convened by the IAEA, helped Paks evaluate the various technologies. A dry vault type facility was chosen finally by the operator. This facility is scheduled to be ready by spring 1995. Experts in the Czech Republic decided to construct a dry cask storage facility at the Dukovany site. Other operators of Soviet-designed pressurized-water reactors (WWERs) are also investigating the options available to them for increasing spent fuel storage time. *(See table for an inventory of spent fuel in Eastern European countries.)*

Global needs and IAEA services

In the IAEA's Medium Term Plan, summarized in 1991, spent fuel management is recognized as a high-priority activity. To improve the satisfactory performance of existing storage facilities and, in particular, to offer advice to countries now contemplating construction of new storage facilities, the Agency has implemented the following programmes:

- Preparation of a set of safety documents amounting to international guidelines on the safety of spent fuel storage.
- Advisory programmes on all aspects of spent fuel management.

Safety Series documents on spent fuel storage. At present three documents are being prepared on the safe storage of spent fuel from power reactors. The first is a safety guide on the design of spent fuel storage facilities, the second is a safety guide on the operation of these facilities, and the third is a safety practice document on the preparation of safety analysis reports for spent fuel storage.

These documents are prepared by a series of meetings that bring together world-renowned experts in this field. They are published only after being repeatedly reviewed by the Agency's Safety Series Review Committee. According to the current schedule, the documents will be ready for publication by 1994. It is expected that they will be useful to Member States in establishing their national standards. Preparations also have started for drafting a new safety guide on the design, operation, and licensing of storage facilities for spent fuel from research and test reactors.

Irradiated Fuel Management Advisory Programme (IFMAP). As mentioned previously for both research and commercial reactors, irradiated fuel is being stored for longer than originally envisaged and in larger quantities. While methods of increasing the existing storage capacities, or building additional stores according to modern standards, have been developed in a small number of industrialized countries, information is not always readily accessible outside the country of origin.

In view of the diversity of fuel types, particularly in research reactors, there are benefits to be derived from impartial assessments of technological concepts, operating experience, safety, and regulatory aspects of irradiated fuel management before important decisions are made concerning possible long-term solutions. This information is also important for countries that have operated research reactors extensively over the last 40 years.

In order to fulfill these requirements, the IAEA has started the Irradiated Fuel Management Advisory Programme (IFMAP). IFMAP will provide advice in the specific area of irradiated fuel storage and on developing national programmes for Member States, particularly developing countries, that request its services.

In 1990 a group of experts visited China to provide advice on the storage of spent fuel from its nuclear power plant. As mentioned earlier, in 1992 an IAEA team assisted with the selection of a spent fuel interim storage option in Hungary. Preliminary discussions also were held in 1992 between the IAEA and specialists in Ukraine and Thailand to assist in the formulation of the spent fuel storage programmes in these countries.

Other related activities. As noted earlier, the IAEA is conducting a co-ordinated research programme known by the acronym BEFAST. Its focus is on the behaviour of spent fuel and storage facility components during long-term storage. Two phases of the programme, which was initiated in 1981, have been completed, with results published by the IAEA.

The third phase started in 1992. It includes 15 research agreements or contracts with participating institutes from 12 countries. The experience of spent fuel storage in these countries will be used to help establish an international database in this area. It is expected that the results will be useful to States, particularly developing countries, because they will provide a unique record of the safety of long-term storage of spent fuel. Data will be especially valuable to those countries designing or licensing interim storage facilities.

Inventory of spent fuel in storage from power reactors in Eastern European countries

	At reactor (AR)	Away from reactor (AFR)	Total
Armenia	30		30
Bulgaria	320	120	440
Czech Republic	170	140	310
Hungary	300		300
Lithuania	800		800
Russia	3900	4950	8850
Slovak Republic	140	440*	580
Ukraine	830	1430	2260

*Includes 140 tonnes scheduled for transfer back to the Czech Republic.
Note: Values are in tonnes heavy metal. *Source: Data reported to the IAEA.*

Spent fuel management approaches in selected countries

	Deferred decision	Direct disposal	Reprocessing
Argentina	●		●
Belgium			●
Brazil			●
Bulgaria	●		●
Canada		●	
China			●
Czech Republic	●		●
Finland	●	●	●
France			●
Germany		●	●
Hungary	●		●
India	●		●
Italy	●		●
Japan			●
Korea, Rep. of	●		
Lithuania	●		
Mexico	●		
Netherlands			●
Pakistan	●		
Russia			●
Slovak Republic	●		●
Slovenia	●		
South Africa	●		
Spain	●		●
Sweden		●	
Switzerland			●
United Kingdom	●		●
Ukraine	●		●
United States		●	

Note: Some countries have different spent fuel management approaches for different fuel types In some countries one spent fuel management approach is presently being followed but future options applying different approaches are being evaluated. *Source: Data reported to the IAEA.*

The IAEA also recently initiated a CRP to study the possible degradation of materials used in spent fuel storage facilities. The topic is important because of the increasing life spans of interim storage facilities. Little is known about the long-term ageing characteristics of many of the construction materials, especially when the degradation mechanisms are either induced or enhanced by irradiation.

To assist specialists in developing countries to strengthen operations at their storage facilities, the Agency further is organizing interregional and regional training courses. Two-to-three week courses are being offered in 1993 and others are planned in years ahead. Separate courses will be tailored for operators of power plants and research reactors.

An aerial view of a concrete canister storage facility for spent fuel in Canada. *(Credit: AECL)*

Future directions

Over the coming decade, it is expected that the long-term storage of spent fuel will become the most common option followed by nuclear operators in the world. So far there are no serious safety problems. However, experience has been limited to less than 40 years while the required length of the storage could be more than twice that long.

A number of areas may require greater attention. These include matters related to the safe storage of high burnup fuels; the storage of damaged, or failed, fuel; the economics of long-term storage; the use of different and new storage technologies; and improvements in the operation of existing technologies. In these areas and others, the IAEA remains prepared to assist countries in responding to problems and finding solutions. ❐

A spent fuel storage pond at the Thermal Oxide Reprocessing Plant at Sellafield in the United Kingdom. *(Credit: BNFL)*