IAEA Overview of global spent fuel storage

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Abstract. Spent fuel storage is a common issue in all Member States with nuclear reactors. Whatever strategy is selected for the back-end of the nuclear fuel cycle, the storage of spent fuel will contribute an imminent and significant part thereof. Notwithstanding considerable efforts to increase the efficient use of nuclear fuel and to optimise storage capacity, delays in realizing geological repositories in most countries or in implementing reprocessing in some countries entail in increased spent fuel storage capacity needs in combination with longer storage durations over the foreseeable future. An overview of global and regional spent fuel arisings and storage capacity is presented in this paper. Some trends are identified and recent Agency activities in the subject area discussed.

1. Introduction

Used or spent nuclear fuel is discharged from operating reactors and temporarily stored at the reactor pool. After a certain cooling time, the spent fuel will be moved from the at-reactor (AR) pool to away-from-reactor (AFR) storage facilities, either on or off reactor site, based on utility practice.

For the ultimate management of spent fuel discharged, the following options are being implemented or under consideration:

- the once-through cycle, i.e. the direct disposal of the spent fuel in a geologic repository;
- the closed cycle, i.e. the reprocessing of the spent fuel, recycling of the reprocessed plutonium and uranium, and disposal of the wastes from the reprocessing operations;
- the so-called “wait and see” policy, which means first storing the fuel and deciding at a later stage on reprocessing or disposal.

This wait and see policy, against the backdrop of delays in geologic repositories programmes in most Member States and in implementing reprocessing in some Member States, has entailed an increase of the amount of spent fuel to be stored and prolongation of storage duration. As a consequence, expansion of spent fuel storage capacity has been needed over the past decade. This trend will continue in the near future.

The situation is further complicated by today’s reliance on higher enrichment, higher burnup fuels as well as on mixed oxide (MOX) fuel, to generate electricity at a competitive cost. Given the much higher decay heat levels from these fuels, wet storage will remain the preferred approach for interim storage during the first decade after discharge. After sufficient decay and, especially when long term storage is foreseen (now storage up to and beyond 100 years is envisaged in some Member States), dry storage under inert conditions or in air becomes the preferred option, given the passive nature of dry storage systems.

2. Overview of spent fuel storage situation

2.1. Status of nuclear power

Today the growth in the number of nuclear power plants is at a standstill in Western Europe and North America, while expanding in parts of Asia and Eastern Europe. At the end of last year, 441 nuclear reactors were operating in 31 countries worldwide [1]. They provided about 2 780 TW·h, which is just over 16 per cent of the global electricity supply.

The total net installed capacity was 359 GW(e) and 33 nuclear power plants are under construction with a total net capacity of 27 GW(e). Table I shows the nuclear power status for four world regions, i.e. West Europe, East Europe, America and Asia & Africa.

Table I. Status of nuclear power in world regions

	Operating Reactors		**Under Construction**	
Regions	**No. of Units**	**Total Capacity GW(e)**	**No. of Units**	**Total Capacity GW(e)**
West Europe	146	125.7	0	0
East Europe	67	46.1	10	8.0
America	124	112.4	1	0.7
Asia & Africa	104	74.5	22	18.4
World	441	358.7	33	27.1

Status 1 January 2003 Source PRIS

2.2. Spent fuel arising

Worldwide the spent fuel generation rate, now at about 10 500 t HM/year, is expected to increase to about 11 500 t HM/year by 2010. As less than one third of the fuel inventory is reprocessed, about 8 000 t HM/year on average will need to be placed into interim storage facilities.

At the beginning of 2003, about 171 000 t HM of spent fuel were stored in storage facilities of various types (Table II). Most of this fuel is under water, but dry storage is becoming a commonly used technology with more than 12 000 t HM currently stored in dry storage facilities worldwide.

The total amount of spent fuel cumulatively generated worldwide by the beginning of 2003 was close to 255 000 t HM. Projections indicate that the cumulative amount generated by the year 2010 may be close to 340 000 t HM. By the year 2020, the time when most of the presently operated nuclear power reactors will be close to the end of their licensed operation life time, the total quantity of spent fuel generated will be approximately 445 000 t HM.

Table II. Status of spent fuel stored in world regions

t HM

Region	Amount
West Europe	36 100
East Europe	27 700
America	83 300
Asia & Africa	23 900
World	171 000

Status 1 January 2003

Assuming that current plans are maintained, one can observe the following regional trends (Fig. 1):

- West Europe will have slight decreasing quantities of spent fuel to be stored, due to reprocessing of spent fuel,
- East Europe will double the amount of spent fuel to be stored in the coming ten years,
- America will store all discharged fuel, thus the amount of spent fuel is constantly increasing,
- Asia & Africa like East Europe, will double the amount of spent fuel to be stored in the coming ten years.

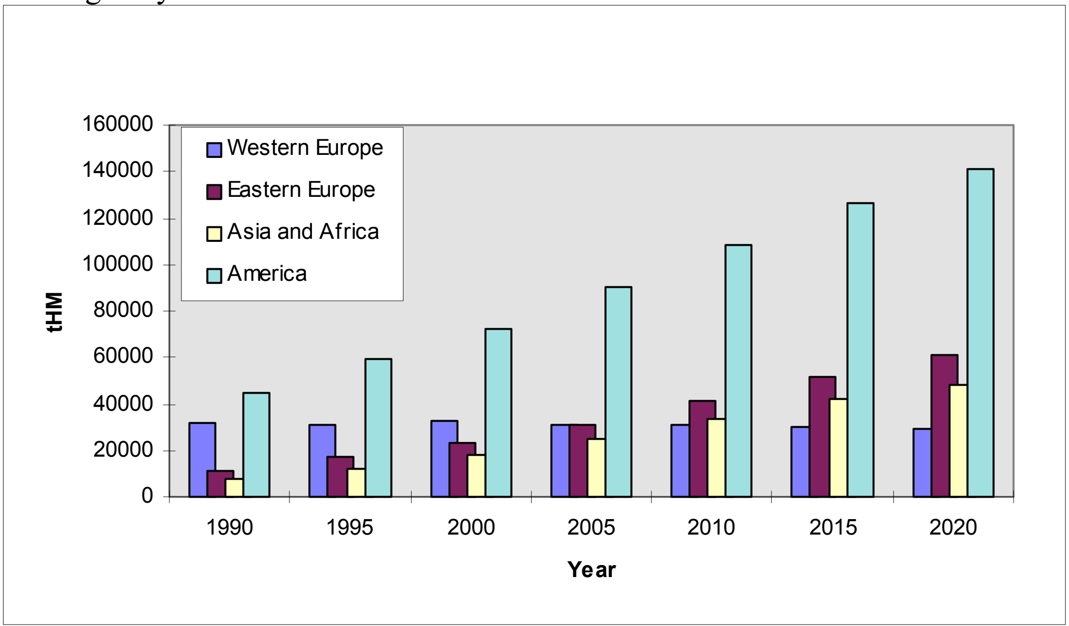

FIG. 1. Spent fuel stored by regions.

2.3. Spent fuel storage capacity

Various types of wet and dry storage facilities are operating in Member States with nuclear power plants (Table III). Early 2002,The global world storage capacity was about 243 000 t HM, with the bulk of storage capacity at reactor pools with 163 000 t HM. Member States operating nuclear power plants actually are or were increasing their existing storage capacity by re-racking the AR storage pools with high-density racks, by implementing burnup credit or by commissioning AFR storage facilities.

Table III. Capacities of operating spent fuel storage facilities

kt HM

Region	AR	AFR wet	AFR dry	Total
West Europe	28.3	32.3	11.3	71.8
East Europe	11.9	20. 8	1.5	34.2
America	94.7	1.7	8.5	104.8
Asia & Africa	27.9	3.3	1.7	33.0
Total	162.8	58.1	23.0	243.8

Status 1 January 2002

The storage capacity of new facilities, under construction in the various regions, are shown in Table IV. The total capacity is 24 000 t HM with 17 500 t HM as dry storage. This indicates that AFR dry storage is getting more and more preference.

Table IV. Capacities of spent fuel storage facilities under construction

kt HM

Region	AFR wet	AFR dry	Total
West Europe	3.0	1.0	4.0
East Europe	3.0	8.9	11.9
America		6.8	6.8
Asia & Africa	0.5	0.8	1.3
Total	6.5	17.5	24.0

Status 1 January 2002

2.4. Balance of spent fuel arising and spent fuel storage capacity

The global world storage capacity is about 244 000 t HM, and thus exceeded, by about 73 000 tonnes, the capacity needed by 1 January 2003. Globally all types of storage facilities have excess capacity available. On a worldwide basis, the spent fuel arising will fill the existing storage facilities and those under construction by around the year 2017, if no other new additional facilities will be built by that time. However, there is no reason to believe that no new construction projects for storage will be launched. Consequently, a storage shortage is not expected globally.

A worldwide or regional approach does not imply any problems. On a national level however, a shortage may occur if construction or expansion cannot be financed or licensed. Indeed, nationally the situation differs from country to country and sometimes even from utility to utility. In some cases, the storage pools are fully occupied by spent fuel allowing emergency core unloading only by special measures. Hence, additional storage capacity has to be installed in time, to avoid this problem. In other cases, additional storage capacity has to be installed timely to replace wet storage facilities. In particular in some Eastern European countries, plant operation might be jeopardized if additional local storage capacity cannot be installed in time.

In the past, most of the countries in this region heavily relied on the Soviet Union for their spent fuel management. Spent fuel return agreements signed in the past with the former Soviet Union were amended on a commercial basis. Due to economic constraints most countries did not opt for commercial contracts. As a result, many nuclear power plants in this region are or will be faced with a shortage of spent fuel storage capacity.

3. Trends

This section addresses a few selected trends in spent fuel management, in which the Agency has been active. It concerns the following topics:

- Regional spent fuel storage facilities,
- Long term storage, and
- Burnup credit.

3.1. Regional spent fuel storage facilities

Most Member States with power reactors are developing their own national strategy for spent fuel management, including interim storage. However, several Member States with a small nuclear power programme or only research reactors face the issues of extended interim storage of their spent nuclear fuel. The high cost for interim storage facilities for small amounts of spent fuel accumulated is obviously a handicap and therefore, from an economical point of view, access to an interim storage facility provided by a third Member State would be a solution, at least temporarily.

The safety and economic benefits from the implementation of regional spent fuel storage facilities could be attractive in terms of reduction of the number of spent fuel storage facilities world-wide, enhanced economy due to the scale of storage, and easier safeguarding to ensure non-proliferation.

On the other hand, such concepts involve political and public acceptance issues and therefore require a consensus among countries. The IAEA has assessed factors to be taken into account in the process of such a consensus during meetings in 2001 and 2002 on this task [2].

It appears that the concept of regional spent fuel storage facilities is technically feasible and potentially economically viable, without any obvious institutional deficiencies that would prevent completion of such a project. Storing spent fuel in a few safe, reliable, secure facilities will enhance safeguards, physical protection and non-proliferation benefits. However, political, social, and public acceptance issues are real and difficult to address. The added difficulty due to the regional nature of the facility could well be balanced by the benefits. The State considering hosting such a site and the States considering being customers for such a site will need to make their own decisions on the relative weights to place on these risks and benefits and the final decision on the establishment of a regional spent fuel storage facility.

3.2. Long term storage

The nuclear industry worldwide has accumulated significant fuel storage operating experience over the past 50 years. This experience, however, is largely based on safe and effective wet storage and the effect of time on structures and materials during this limited period of time. The new challenges are to extend the life of existing and new wet and dry storage facilities and guarantee their safe performance for much longer periods of time.

Experts at Agency meetings [3] discussed various topics of relevance to long term storage for defining issues and questions to be addressed through future research and development:

— long term behaviour of spent fuel, fuel assemblies and packages,
— long term behaviour of dry storage systems,
— long term behaviour of wet spent fuel storage facilities, and
— regulatory concerns related to long term spent fuel storage.

The mechanisms that might have the potential to degrade the fuel and fuel structure need to be reviewed to identify possible gaps in knowledge, especially with respect to the long term behaviour of the materials during storage. Cask storage, in comparison to all other storage techniques, presents the greatest challenge (stress/strain) to long term fuel cladding performance, as a result of the high initial operating temperatures during the early years of storage. Stress and strain and the approach to the stress limit are the most important criteria in assessing cladding integrity.

Wet fuel storage is now considered to be a mature technology. In comparison, dry storage is an evolving technology, which has been developed over the past 20 years. Under present boundary conditions, dry storage can also be regarded as an established industrial technology. Unlike wet storage, dry storage can be more sensitive to fuel design changes and burnup increase, because of higher thermal output, which give rise to thermally activated processes.

In wet storage, there exists no urgent questions to be solved with regard to increasing operating life times. However, some recommendations, e.g. in the area of monitoring or technical optimisation were made.

In dry storage, there also exists a certain amount of supporting technical data, covering the burnup of the fuel loaded and the performance of the systems to date. For high burnup and MOX fuel, an extension of the knowledge on the creep behaviour of future cladding materials is needed. Additionally, a surveillance programme could demonstrate the long time behaviour of cask and fuel. For the development of advanced dry storage systems further R&D activities are needed, such as system performance for the perceived duty.

The regulatory objectives are very similar for all member states. Regulatory concerns include aspects of how technology changes are being handled and the extrapolation of material behaviour or performance for increasing storage duration.

3.3. Burnup credit

Experts explored the progress and status of international activities related to the burnup credit applications for spent nuclear fuel in 2002 [4]. Application of burnup credit to spent fuel management systems consists of implementation of a criticality safety assessment of the spent fuel management system of interest and of the application of the loading criterion.

Criticality safety is demonstrated with the aid of calculational methods verified by comparison to acceptable standards of known quality. Standards for comparison may be experiments, other accepted codes, or recognized standard problems.

The evaluation of the loading criterion is based on application of a criticality safety acceptance criterion to the results of the reactivity calculations. A criticality safety acceptance criterion is based on the safety margin required by the regulations for the application case, includes the biases of the applied calculation procedures as obtained from validation of these procedures and depends on the statistical confidence level chosen to express the impact of all uncertainties due to the applied calculation procedures and due to manufacturing tolerances of the system of interest.

Future issues of burnup credit are its application to long term storage/disposal of spent fuel, high burnup fuel, MOX spent fuel and spent fuel of advanced fuel designs.

4. IAEA activities on spent fuel management

Recent IAEA activities on spent fuel management consist of the following topics:

Dry Spent Fuel Storage Technology
An IAEA Technical Meeting/Workshop "Dry Spent Fuel Storage Technology" was held in June 2002 to give guidance to experts from Central and Eastern European Member States, operating WWER and RBMK nuclear power plants and to exchange information.

Spent Fuel Treatment
A consultancy meeting was held in October 2002, to prepare for a technical document [update to TECDOC-1103] on the subject of emerging technologies for spent fuel treatment. The TECDOC is expected to be published in 2003.

Operation and Maintenance of Spent Fuel Storage and Transport Casks and Containers
This is a new task intending to draw the pool of knowledge that has been accumulated from the industrial experience in the past several decades on the operation and maintenance of spent fuel casks. A Technical Meeting on this subject is planned for later this year.

Technical and Institutional Aspects of Regional Spent Fuel Storage
Meetings held in 2001 and 2002 determined that technical considerations and economic issues may be less significant than ethical and institutional issues for the development of a multinational project. A TECDOC is planned for 2004.

Optimization of Cask/Container Loading for Long Term Spent Fuel Storage
Meetings were held in 2002 and 2003 in preparation for a subsequent technical document on this topic.

Long term Storage of Spent Nuclear Fuel
To address new trends on long term storage of spent nuclear fuel, several meetings were held until 2000 with the results published [3].

Spent Fuel Performance Assessment and Research
Spent fuel storage technology (particularly dry storage) is undergoing evolution, new fuel and material design changes are coming on stream and target burnups are increasing. The report of the Co-ordinated Research Programme on spent fuel performance assessment and research programme (SPAR) has been published [5].

Selection Criteria for AFR Storage Facilities
Based on meetings held in the period 2001-2003, a TECDOC is planned for 2003 to provide guidance on selection criteria and methodology for AFR facilities, together with updated information on technical development and changing circumstance in the relevant area.

Economics of Spent Fuel Storage
Economics is a major factor of consideration in spent fuel storage projects and its significance will be amplified in the future with the increasing amount of spent fuel to be stored and the associated costs for implementation. A meeting held in 2002 served as a key step toward providing a TECDOC on this subject .

Implementation of Burnup Credit in Spent Fuel Management
A TECDOC [4], exploring the progress and status of international activities related to the burnup credit applications for spent nuclear fuel, will be published in 2003, based on a meeting held in 2002.

Data Requirements and Maintenance of Records for Spent Fuel Management
Guidelines on information management are required for long term management of spent fuel. A meeting, planned for next month is expected to lead to a subsequent TECDOC on records management.

5. Conclusions

The following conclusions can be drawn:

- At present, there is sufficient spent fuel storage capacity on a worldwide basis. However, nationally or on a specific site basis, the situation is different and needs urgent attention.
- Wet fuel storage is presently a mature technology and plays a major role in spent fuel storage.
- Under present boundary conditions, dry storage can also be regarded as an established industrial technology.
- The first geological repositories for the final disposal of spent fuel are not expected to be in operation before the year 2010. Many Member States have not yet started specific site investigations. As a consequence, the use of interim storage will be the primary spent fuel management solution for the next decades in many countries.
- Even more spent fuel storage capacity is required if countries defer their decision to open geological repositories.
- The storage duration becomes longer than earlier anticipated, due to the selection of the "wait-and-see" policy chosen by many nuclear power countries. The use of higher enriched fuel with higher burnup results in higher decay heat and longer storage periods.
- With longer storage periods dry storage becomes more and more important.

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