RESEARCH REACTOR SPENT FUEL STATUS

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Abstract

In recent years the problems of spent fuel from research reactors have received increasing attention as concerns about ageing fuel storage facilities, their life extension and the ultimate disposal of spent fuel loom larger. The overall scope of these problems can be gauged by examination of the databases compiled and maintained by the IAEA. Data compiled in the research reactor spent fuel database are used to assess the status of research reactor spent fuel worldwide. Fuel assemblies, their types, enrichment, origin of enrichment and geological distribution among the industrialised and developing countries of the world are discussed. Some projections of spent fuel inventories to the year 2006 are presented and discussed.

Fuel management practices in wet and dry storage facilities and the concerns of reactor operators about long-term storage of their spent fuel are presented and some of the activities carried out by the International Atomic Energy Agency to address the issues associated with research reactor spent fuel are outlined.

It is clear that more exposure of the problems and concerns and more international co-operation will be necessary to resolve the outstanding issues. It is also clear that take-back programmes of foreign research reactor fuels, if and when they are implemented, will not continue indefinitely. At some stage in the not too distant future (in 2006 for foreign research reactors with US-origin fuel), research reactor operators will be faced with having to find their own solutions regarding the permanent disposal of their spent fuel. For countries with no nuclear power programme, the construction of geological repositories for the relatively small amounts of spent fuel from one or two research reactors is obviously not practicable. For such countries, access to a regional interim storage facility and eventually a regional or international repository for research reactor fuel would be an ideal solution. The time is ripe for serious discussion of regional or international solutions and to begin planning for the day when neither take-back programmes nor the reprocessing option might be available.

1. INTRODUCTION

Activities in the area of management, interim storage and ultimate disposal of spent nuclear fuel from research and test reactors are dominated at the present time by two important programmes. The first is the Reduced Enrichment for Research and Test Reactors (RERTR) programme, and the second is the take-back of spent research reactor fuel by the country where it was originally enriched. In the minds of most research reactor operators, especially those with fuel enriched in the United States, these two programmes are closely linked because a spent fuel take-back programme is the only tangible benefit to be gained from the conversion of their reactor cores from burning highly enriched uranium (HEU) to low enriched uranium (LEU), other than the altruistic goal of non-proliferation. The RERTR programme has already limited and will, if it becomes global, eventually eliminate all trade in HEU for research reactors to the ultimate benefit of all mankind.

At the time of writing, there is only one take-back programme of spent research reactor fuel by a supplier country in operation. During February 1996, the United States Department of Energy (DOE) issued its Final Environmental Impact Statement (EIS) on a Proposed Nuclear Weapons Non-proliferation Policy Concerning Foreign Research Reactor Spent Nuclear Fuel (the Policy). This was followed on 13 May 1996 by the publication of a favourable Record of Decision on the Policy, which has since allowed the resumption of the take-back programme by one of the world’s two major supplier countries, the United States of America. It is hoped that other supplier countries and partners in RERTR will follow suit and implement their own take-back programmes for foreign research reactor spent fuel.

Although the IAEA has been involved with and has fully supported RERTR since its inception through its Department of Research and Isotopes, it was not until 1993 that the Division of Nuclear Fuel Cycle and Waste Technology extended the scope of its spent fuel management programme to include programmes which focused specifically on spent fuels from research and test reactors. These activities cover the collection, analysis and dissemination of information on storage, management and related experience with spent fuels, formulation of norms and provision of technical assistance to developing Member States. A number of concerns were immediately apparent at the beginning of 1993. Many research reactors were in a crisis situation or rapidly approaching a crisis situation and in every case, this was due to spent fuel storage and management problems and the constraints of national laws. It was clear that the capacity for spent fuel storage had been reached or was close to the limit at many research reactors and there were concerns from a materials' science point of view about ageing materials in ageing storage facilities. The IAEA's activities in this area have been formulated to address these concerns, but the first step was to obtain an overall picture of spent fuel management and storage worldwide. This has been attempted by the circulation to research reactor operators of questionnaires specifically designed to form the input to the Research Reactor Spent Fuel Database (RRSFDB). Construction and maintenance of this database is an ongoing activity and this report provides a snapshot at the time of writing of the salient information gleaned from the relatively new RRSFDB supplemented by information from the more established Research Reactor Database (RRDB).

2. GENERAL OVERVIEW

Most of the information presented in this section is taken from the RRDB, specifically from the IAEA publication "Nuclear Research Reactors in the World" December 1998 Edition [1]. The RRDB was first published in 1989 and has been maintained ever since. As of December 1998 there was information on 601 reactors stored in the RRDB. Of these, 256 were operational, 8 under construction, 8 planned, 222 shut-down, 106 decommissioned and 1 for which the information was not completely verified.

The distribution of the number of countries with at least one research reactor vs time peaked for developing countries in 1985 but remained almost constant for industrialised countries from 1965 to the present. The IAEA divides the world into six regions and those countries with at least one research reactor are listed by region in Table I.

Table I. Countries with Research Reactors

North America	Western Europe	Eastern Europe	Asia - Pacific	Latin America	Africa & Middle East
CANADA	AUSTRIA	BELARUS	AUSTRALIA	ARGENTINA	ALGERIA
USA	BELGIUM	BULGARIA	BANGLADESH	BRAZIL	EGYPT
	DENMARK	CZECH REPUBLIC	CHINA	CHILE	GHANA
	EUROPEAN UNION	GEORGIA	INDIA	COLOMBIA	IRAN, ISLAMIC REP. OF
	FINLAND	HUNGARY	INDONESIA	JAMAICA	IRAQ
	FRANCE	KAZAKHSTAN	JAPAN	MEXICO	ISRAEL
	GERMANY	LATVIA	KOREA, DPR	PERU	SOUTH AFRICA
	GREECE	POLAND	KOREA, REP.	URUGUAY	SYRIAN ARAB REP.
	ITALY	ROMANIA	MALAYSIA	VENEZUELA	DEM. REP. CONG
	NETHERLANDS	RUSSIAN FEDERATION	PAKISTAN		
	NORWAY	SLOVENIA	PHILIPPINES		
	PORTUGAL	UKRAINE	TAIWAN, CHINA		
	SPAIN	UZBEKISTAN	THAILAND		
	SWEDEN	YUGOSLAVIA	VIETNAM		
	SWITZERLAND				
	TURKEY				
	UNITED KINGDOM				

The age distribution of operational research reactors in the RRDB peaks in the range of 30 to 40 years. In fact, 19% of the reactors are in the age range of 20 to 29 years and 49% in the range 30 to 39 years.

A large fraction, 46%, of operational research reactors operate at a thermal power of 100 kW or less. Almost all of these 118 reactors have fuel for life and will not have spent fuel problems until they permanently shut down.

More details of the information compiled in RRDB are presented in the paper in this symposium by Dodd [2].

Although the RRDB has a section on fuel, it dose not address the details of spent fuel storage and management. For this reason, a questionnaire on spent fuel management and storage was designed and circulated to research reactor operators for the first time in February 1993. Responses to this first questionnaire and subsequent revisions sent to selected research reactors revealed a number of deficiencies in the design of the questionnaire, which have been rectified in the current version. This latest version was circulated to research reactor operators worldwide in February 1999. An overview of the responses received up to date, compiled in the RRSFDB, is presented in the next section.

3. SPENT FUEL MANAGEMENT AND STORAGE

At the time of preparing this paper, the RRSFDB contains 213 entries. Of these research reactors, 48 are permanently shut down, 15 are temporarily shut down for refurbishment, 4 are planning shut down, 2 have unverified information on status and the remaining 144 are operational. Spent fuel is usually an ongoing liability after a reactor is shut down and the IAEA would like to include details of spent fuel, if it has not been reprocessed, from all of the known 222 shut-down reactors reported in RRDB. In addition, there is a large discrepancy between the 256 operational reactors in RRDB and the 144 operational reactors that have so far responded to the questionnaires for RRSFDB. Although most research and test reactors with substantial turnover of fuel and, hence, significant inventories of spent fuel, are included in RRSFDB, clearly, some research reactor operators have lost interest in filling-in questionnaires, especially if they cannot see the usefulness of the end result. Nevertheless, it is essential for the IAEA to get a clear and accurate picture of the problems faced by research reactor operators and their concerns about management, storage and ultimate disposal of spent fuel, in order to be able to address them and to exert pressure internationally for the implementation of spent fuel take-back programmes by supplier countries and to begin a dialogue about possible regional repositories as an ultimate solution for countries with no nuclear power programme.

The remainder of this section is divided into two parts. The first deals with numbers of fuel assemblies, their types, enrichment, origin of enrichment and geographical distribution among the industrialised and developed countries of the world. The second is devoted to fuel management practices in wet and dry storage facilities and the concerns of reactor operators about long-term storage of their spent fuel.

Accumulated spent fuel

Cross-sections of the main western research reactor fuel assembly types may be found in [3], while the cross-sections of the main Russian types are shown in Figures 1 to 4 of the paper by N.V. Arkhangelsky [4]. The western assembly types include MTR box-types containing 10-24 fuel plates per assembly, involute core assemblies containing 280 plates (High Flux Reactor, Grenoble France), tubular fuel assemblies with 4-6 fuelled tubes per assembly (BR-2, Belgium and Dido, UK), TRIGA fuel rod clusters with 1-25 rods per cluster (TRIGA, Republic of Korea - single rods, TRIGA, Romania - 25 rods per cluster), and pin assemblies with 1-12 pins per assembly (Slowpoke, Canada - single pins, NRU, Canada - 12 pins). All of these assemblies are about 60-90 cm long, except for

NRU (275 cm) and Slowpoke fuel pins (30 cm). In Russian designed research reactors, a large variety of fuel assembly geometries have been used. Four of the more important types are shown in Figures 1 to 4 of Reference [4] and can be divided into two groups; multi-tube assemblies (IRT-3M and WWR-M) and multi-rod assemblies (CM-2 and RG-1M). The active parts of these assemblies vary in length from 35-200 cm.

Most research reactor fuels are shipped in assembly form. For this reason, in RRSFDB spent fuel numbers are recorded in assemblies, where a fuel assembly is defined as "the smallest fuel unit that can be moved during normal reactor operation or storage". Even so, questions regarding numbers of fuel assemblies obviously caused confusion to respondents to the questionnaires. Consequently, the data received has been reviewed and corrected by a panel of experts who know the details of the various fuel assembly designs. At any particular facility, several different spent fuel types or spent fuels of different enrichments are usually stored. For example, the store may contain one or more types of HEU from prior to core conversion and one or more types of LEU following conversion.

Several facilities report more than three types of spent fuel and for this reason the records in RRSFDB store up to ten fuel types per facility. Strictly speaking, fuels enriched to ≥ 20% ^{235}U are classified as HEU. Since many facilities with LEU cite a nominal enrichment of 20%, we have modified the definition of LEU to be ≤ 20% ^{235}U for the purposes of RRSFDB. Since any fuel with exactly 20% enrichment before irradiation will have <20% enrichment after significant burnup, this does not violate the accepted definition.

The distribution of fuel types among the reactors in the RRSFDB is shown in Table II. Although the majority are of MTR, TRIGA or standard Russian types, a significant percentage (28%) are classified as other types which underlines the fact that many experimental and exotic fuels exist at research reactors around the world, posing problems for their continued storage, transportation and ultimate disposal.

Table II. Distribution of Reactors by Fuel Type

FUEL TYPE	REACTORS USING FUEL TYPE	
	NUMBER	PERCENTAGE
MTR	68	32
TRIGA	42	20
RUSSIAN	42	20
OTHER	59	28

The regional distribution of spent fuel, with a distinction made between developing and industrialised countries, is shown in Figure 1. As might be expected, the majority of spent fuel assemblies are stored in the industrialised countries. The origins of the enrichments of the RRSFDB spent fuel inventory is broken down into fuel of US, Russian, and other origin in Figure 2. In this case, others include China, France, UK, South Africa, natural uranium fuels and those cases where the origin of enrichment was not known or simply left blank on the questionnaire. As expected, the US supplied all of the enriched fuel in North America and most of that in Asia-Pacific, while Russia (or the former Soviet Union) supplied most of the enriched fuel in eastern Europe.

The regional breakdown of US-origin and Russian-origin fuel, classified as HEU or LEU, is shown in Figure 3. This involves totals of 6,205 HEU and 7,364 LEU assemblies of US-origin and 8,422 HEU and 16,209 LEU assemblies of Russian-origin. Of interest in this figure is the fact that HEU outweighs LEU in North America, whereas the reverse is true in western Europe. To some extent this is because more research reactors in western Europe have undergone core conversion than is the case in North America. HEU also outweighs LEU in Africa and the Middle East, eastern Europe and Asia-Pacific. It is worth noting that a significant fraction of Russian-origin HEU was originally enriched to only 36%, while most US-origin HEU was originally enriched to ≥90%.

Overall, there are 62,488 spent fuel assemblies stored in the facilities that have responded to the RRSFDB questionnaires to date and another 23,404 assemblies in the standard cores. Of these 62,488, 45,636 are in industrialised countries and 16,852 are in developing countries, while 22,321 are HEU and 40,167 are LEU.

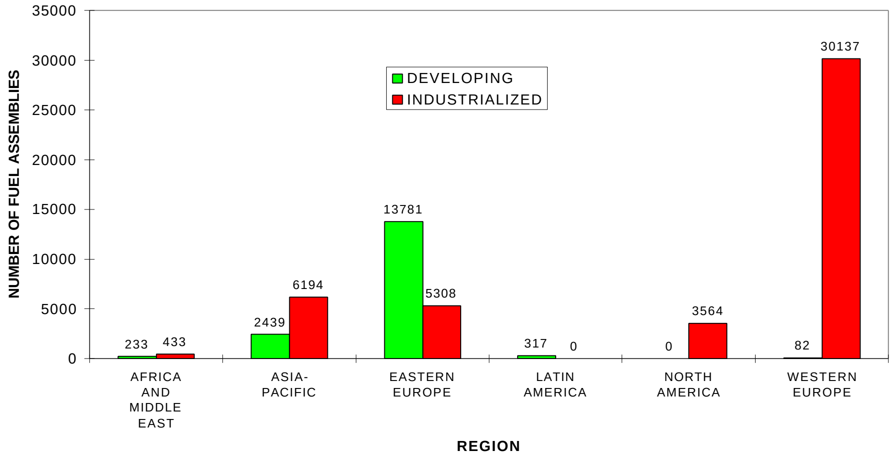

Figure 1. Distribution of spent fuel among developing and industrialized countries.

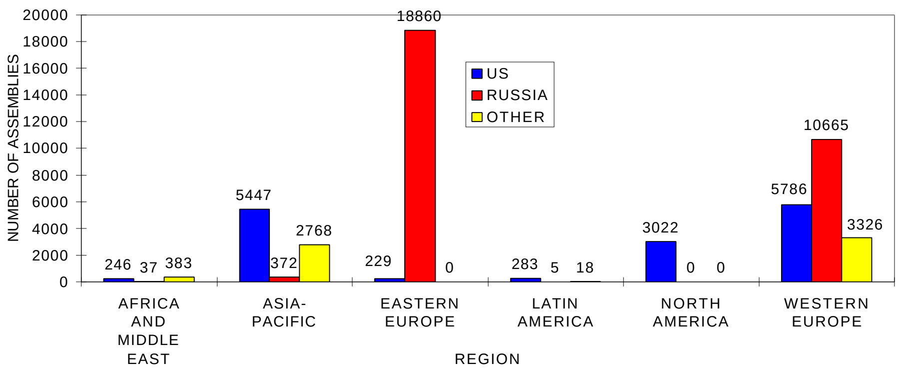

Figure 2. Geographical distribution of spent fuel by supplier country.

The numbers of US-origin and Russian-origin HEU and LEU spent fuel assemblies at foreign research reactors which might be involved in take-back programmes are compared in Figure 4. At present 13,569 spent fuel assemblies of US-origin are located at foreign research reactors, while the equivalent number of Russian-origin is 24,631. As mentioned above, RRSFDB involves only a limited number of the known research reactors in the world, nevertheless these data give an idea of the scope of the problem represented by research reactor fuels. On the basis of these data and a rough knowledge of the numbers of assemblies used each year, it is possible to make projections for the numbers of spent fuel assemblies that will be accumulated in the future. The projections for the total number of assemblies that might be eligible for return to the country of origin by 2006 are also presented in Figure 4. These projections assume no returns in the interim, which will not be correct in the case of US-origin fuel.

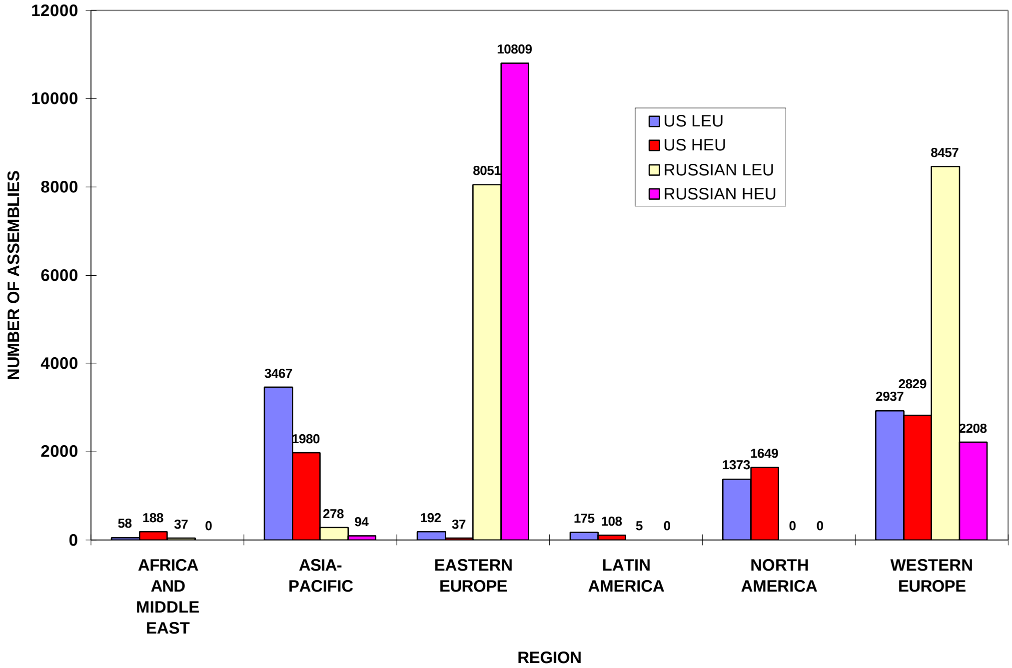

Figure 3. Geographical distribution of US- and Russian-origin fuel by enrichment.

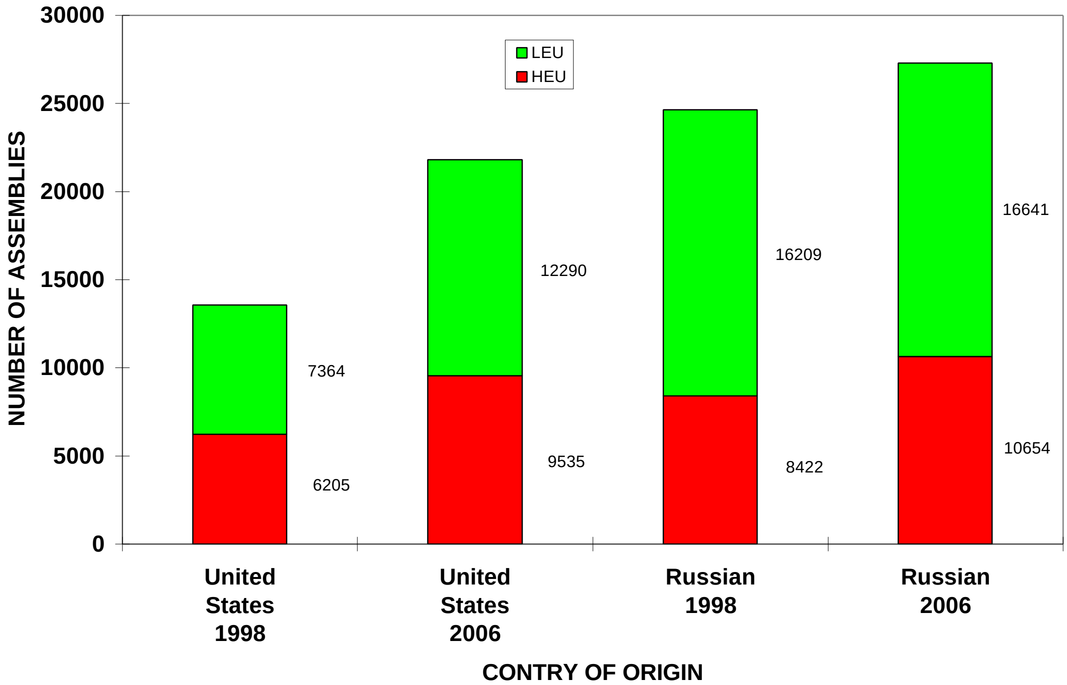

Figure 4. Present and projected spent fuel at foreign research reactors.

Wet and dry storage

As shown in Table III, by far the most commonly used form of spent fuel storage is the at-reactor pool, pond or basin. Since the average age of these facilities in the RRSFDB is 25 years, the success of wet storage where the water chemistry has been well controlled is remarkable. In fact, many aluminium clad MTR fuels and aluminium pool liners show few, if any, signs of either pitting corrosion or general corrosion after more than 30 years of exposure to research reactor water. Also shown in Table III are the many facilities that also have an auxiliary away-from-reactor pool or dry well. At away-from-reactor facilities, the trend is to transfer fuel from wet storage to dry storage, which avoids some of the expense of water treatment facilities and their maintenance.

Table III. Spent Fuel Storage Facilities

STORAGE TYPE	AT REACTOR	AWAY FROM REACTOR
POOL	156	56
DRY WELL	28	29
VAULT	13	9
OTHER	19	8

The parameters typically monitored at wet storage facilities are shown in Table IV. Details of the frequency of monitoring and/or control of these parameters are contained in RRSFDB. They show a remarkable variation from continuous monitoring to "routine" or "occasional".

Similar results for dry storage are shown in Table V. Clearly, dry storage requires less monitoring and maintenance than wet storage and at most dry storage facilities the operators are content to monitor the activity continuously. Several, however, are recognising the importance of assessing the moisture content of dry storage facilities.

Table IV. Wet Storage Parameters Monitored

PARAMETER	NUMBER OF FACILITIES
Conductivity	151
Temperature	136
Activity	136
pH	131
Other	39

Table V. Dry Storage Parameters Monitored

PARAMETER	NUMBER OF FACILITIES
Activity	43
Moisture	20
Pressure	16
Temperature	13
Other	7

The concerns expressed by reactor operators about their spent fuel are listed in Table VI. The results of the initial questionnaire indicated that often facilities had more than one concern. This was addressed in the latest questionnaire by requesting the facilities to rank their concerns in order of importance. Not surprisingly, the majority are concerned about the final disposal of their fuel. This is followed by concerns about finance, limited storage capacity, and materials degradation. Surprisingly, finance is of lesser concern now than in the previous responses. Presumably, this is due, at least in part, to the United States Return of Foreign Research Reactor Spent Fuels programme which is paying for the disposal of spent research reactor fuel from the lower income countries possessing fuel of US origin.

Plans for increasing either the number of spent fuel racks, facility size or both are presented in Table VII. These numbers reflect the concerns about storage capacity, interim storage and emergency core unload listed in Table VI.

Finally, 58 facilities (27%) reported the availability of an internal transfer flask.

Table VI. Concerns Expressed by Respondents in Order of Importance

CONCERNS	PRIMARY	SECONDARY	TERTIARY	OTHER
FINAL DISPOSAL	92	21	19	1
FINANCIAL	15	20	16	15
STORAGE CAPACITY	13	12	5	6
MATERIALS DEGRADATION	11	12	12	6
ITERIM STORAGE	9	10	8	4
OTHER	8	1	2	6
CASK AVAILABILITY	7	16	8	2
WATER QUALITY	4	3	5	2
REACTOR SHUT DOWN	4	3	6	7
SELF-PROTECTION OF FUEL	4	7	13	2
AGING OF FACILITIES	3	15	18	9
CORE UNLOAD CAPACITY	3	8	3	1
WASTE RETURN FROM REPROCESSING	2	6	3	1
CRANE CAPACITY	0	0	0	0

Table VII. Planned Expansion of Spent Fuel Facilities

TYPE OF EXPANSION	REACTORS PLANNING STORAGE EXPANSION	
	NUMBER	PERCENTAGE
AT-REACTOR	19	9
AWAY-FROM-REACTOR	14	7

4. IAEA ACTIVITIES ON RESEARCH REACTOR SPENT FUELS

Besides compiling and maintaining the RRSFDB, which is discussed in this paper, and supporting RERTR, the Agency was involved as an observer in almost all of the meetings of the “ad hoc” group of research reactor operators, known as the Edlow Group, which successfully sought to return US-origin spent fuel from foreign research reactors. Towards this same end, the Director General of the IAEA has written to Secretary O’Leary of the US DOE (1 July 1993) and Mr. Victor Michailov, Minister of Atomic Energy of the Russian Federation, (2 February 1995) suggesting that these major partners in RERTR could facilitate the non-proliferation goal of RERTR by taking back foreign research reactor fuel.

To aid the US take-back programme, especially for developing Member States, the Agency has organized activities to help Member States to prepare their spent fuel for shipment back to its country of origin. The main activities in this area were a Training Course held at Argonne National Laboratory, USA, in January 1997 and the preparation of a draft "Guidelines" document entitled "Guidelines Document on Technical and Administrative Preparations Required for Shipment of Research Reactor Spent Fuel to its Country of Origin" given to participants at the Training Course. The Training Course was repeated in May 1999 and the Guidelines Document updated and expanded to included possible shipments of Russian origin research reactor fuel to the reprocessing plant at Mayak. The Guidelines document is a living draft which is updated from time to time as international regulations for shipment and the acceptance criteria of the receiving sites are changed. It is available as a draft document on the Internet (http://www.td.anl.gov/RERTR/RERTR.html).

The preparation of a Safety Guide on Design, Operation and Safety Analysis Report for Spent Fuel Storage Facilities at Research Reactors has been submitted for publication. During December 1997 the IAEA convened an Advisory Group Meeting on the Management and Storage of Experimental and Exotic Spent Fuels from Research and Test Reactors (IAEA-TECDOC-1080). Also, the Agency offers advice through IFMAP, the Irradiated Fuel Management Advisory Programme, to operators of spent fuel storage facilities and more tangible assistance to developing Member States through the IAEA's Technical Assistance and Co-operation programmes.

Recognising that the degradation of materials, equipment and facilities through ageing is becoming of more concern to many operators, the Agency has organised several activities in the materials' science field. Prominent among these was the preparation of a document on the durability of nuclear fuels and components in wet storage (IAEA-TECDOC-1012). This document contains information on aluminium clad fuels used in research reactors developed as part of a Co-ordinated Research Programme (CRP) on Irradiation Enhanced Degradation of Materials in Spent Fuel Storage Facilities. Another CRP is devoted specifically to research reactor fuel cladding and focuses on the monitoring and control of corrosion in wet storage. It is in the process of developing a Standard Guidelines on water chemistry control to minimize the corrosion of aluminium-clad research reactor fuel.

5. THE FUTURE 2006 AND BEYOND

For countries with US-origin fuel, a serious decision with long reaching consequences will have to be made in the not too distant future: i.e. to shut down prior to the deadline in 2006 and ship their spent fuel and final core back to the US, or continue to operate past 2006 and find their own solutions to the back end of the fuel cycle for their research reactors. For countries with nuclear power programmes the decision is somewhat easier than for those without. Solving the back end problems for the very much larger quantities of power reactor fuel will no doubt eventually lead to satisfactory solutions to the back end problems for research reactors. For countries with no nuclear power programme, the construction of geological repositories for the relatively small amounts of spent fuel from one or two research reactors is obviously not practicable. For such countries, access to a regional interim storage facility and eventually a regional or international repository for research reactor fuel would be an ideal solution, unless the US government can be persuaded to extend its fuel take-back programme.

Since it is probable that many of the currently operational research reactors will shut down in the near future, the extension of the regional facility idea to include a new high-powered, high-flux, multipurpose reactor serving the research needs of regional groups of countries is an interesting idea. Many currently operational reactors are old, under-utilised and incapable of carrying out research at the "cutting-edge" without expensive refurbishment. In fact, more and more state-of-the-art research will be done at the few new and planned high-powered, high-flux, multipurpose reactors which are only affordable to relatively rich countries. Consequently, it would make sense for regional groups of countries to pool their resources in a state-of-the-art research facility which includes interim storage and ultimate disposal of spent fuel and waste. The time is ripe for serious discussion of regional or international solutions and to begin planning for the day when neither take-back programmes nor the reprocessing option might be available.

For countries with fuel enriched in the former Soviet Union or the Russian Federation, and those few countries with fuel enriched in countries other than the US and Russia, in a sense 2006 is right now. However, the Russian authorities have recently agreed to undertake a serious feasibility study of the repatriation of Russian origin research reactor fuel. But, there are two major obstacles to its eventual implementation. One is the current Russian Atomic Law which forbids the importation of radioactive materials, and the other is funding of the programme, which cannot be borne by the Russian Federation or the low-income countries where the fuel is located. Efforts are underway to rectify both of these problems.

Taking an optimistic view, the problems of spent fuel from research and test reactors will be solved in the foreseeable future by repatriation and/or regional facilities. The IAEA will continue to promote and work towards both solutions.

Taking a pessimistic view, interim storage will continue for the foreseeable future. In such a case, it will make sense to transfer aluminium clad research reactor fuel from we to dry storage. Consequently, the IAEA will continue its activities to understand the ageing of materials in spent fuel storage facilities, both wet and dry, and attempt to determine their durability, so that if necessary interim storage can be extended in a safe, reliable and economic way.

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