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IAEA Activities in the Back-end of the Nuclear Fuel Cycle

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Abstract

This paper concerns recent outcomes from the IAEA's activities in the area of the nuclear fuel cycle, particularly focusing on the back-end of the fuel cycle. It includes spent fuel management, plutonium utilization and burnup credit. In the area of spent fuel management, worldwide prospects and status of the spent fuel arising, storage and reprocessing are presented. In the area of plutonium utilization worldwide, only MOX fuel fabrication is described. Finally, the worldwide status of the burnup credit implementation is described.

1. Introduction

The International Atomic Energy Agency, IAEA, has assisted Member States having or planning nuclear fuel cycle activities in developing and maintaining appropriate approaches, policies, strategies and technologies, with due regard to efficiency, safety, environmental soundness and sustainability of these approaches, by facilitating the transfer and exchange of information and technology. In the back-end of the Nuclear Fuel Cycle Programme the IAEA has two sub-programmes for activities on the spent fuel management and the issues and databases related to it. The sub-programme concerning spent fuel management includes four projects: (1) spent-fuel arising, storage options and practices; (2) internationally agreed practices of spent fuel storage; (3) handling and storage of spent fuel from research reactors; and (4) technical developments in the back-end of the nuclear fuel cycle. The Regular Advisory Group on Spent Fuel Management has advised and promoted these activities continuously since 1984. Recently, the Advisory Group conducted technical reviews on spent fuel management and the implementation of burnup credit in spent fuel management systems. The International Symposium on Storage of Spent Fuel from Power Reactors to be held in Vienna in November 1998 was proposed by the Advisory Group. For the other sub-programme on the nuclear fuel cycle, i.e. related issues and databases, three projects are being implemented; (1) nuclear fuel cycle issues of which a main activity is the functioning of the International Working Group on Nuclear Fuel Cycle Options, (2) plutonium inventory and emerging problems, in which the International Symposium on MOX Fuel Technologies for Medium and Long-Term Deployment planned in Vienna in May 1999 will be a key activity, and (3) nuclear fuel cycle databases. In the framework of this sub-programme, the International Symposium on Nuclear Fuel Cycle and Reactor Strategies: Adjusting New Realities was held in 1997 to cover issues such as plutonium management, future fuel cycle strategies, safety, non-proliferation and safeguards aspects.

2. Spent Fuel Management

In the early era of the nuclear energy, it was considered that the nuclear fuel cycle in combination with recycling plutonium separated by reprocessing was the most useful application of nuclear power. Since those early days, however, new realities have emerged which were the main theme in the International Symposium on Nuclear Fuel cycle and Reactor Strategies: Adjusting to New Realities[1]. Currently, countries with nuclear power programmes adopt one of three different approaches which are: the nuclear fuel cycle including reprocessing, direct disposal of the spent fuel or deferred decision.

Spent fuel management encompasses the safe storage of spent fuel from the time it is discharged from the power reactor until it is finally disposed of either directly after a period of interim storage, or until it is reprocessed and the waste disposed of in a suitable repository. The Agency has conducted activities on spent fuel management following the of advice of the Regular Advisory Group on Spent Fuel Management, which consists of 13 Member States and OECD/NEA. The Advisory Group meeting on Spent Fuel management has been held biannually since 1984 and the last meeting was held in September 1997.

In order to look at future trends concerning spent fuel management, the IAEA has developed computer codes, CYBA[2] and VISTA[3]. Both codes calculate spent fuel arising, actinide generation, stockpiles of separated plutonium and other information related to the back-end by using input data gathered worldwide from NPPs, projected electricity generation, reprocessing capacities and the reprocessing ratio, which is the ratio of reprocessed fuel to the total arising. CYBA is useful for the open cycle, while the VISTA calculates results for the closed cycle where recycle of the separated fuel materials is taken into account.

2.1. Spent Fuel Arising and Storage

According to IAEA's survey[4] 437 nuclear power reactor units were operated in 32 countries with a total electric generating capacity of 350 GWe worldwide as of December 1997. The spent fuel arising from these nuclear power plants was about 10,500 tHM in 1997 which contains 75 tonnes of plutonium[5]. The VISTA code calculation can predict the worldwide and regional spent fuel arising. This prediction was made using the scenario that the capacity of nuclear electricity generation grows from 352 GWe in 1997 to 541 GWe in 2020[5] and half of the spent fuel is offered for reprocessing (50 % reprocessing ratio).It is likely in the near future that the annual spent fuel arising from 1990 up to the year 2015 slightly increases. With respect to the regional trends, the annual arising from Western Europe decreases, that from America remains mostly constant while those from Asia and Africa (South Africa) and from East Europe increase in this same period (Fig. 1) These trends are mostly compatible with perspectives of nuclear power generation in the individual regions[4].

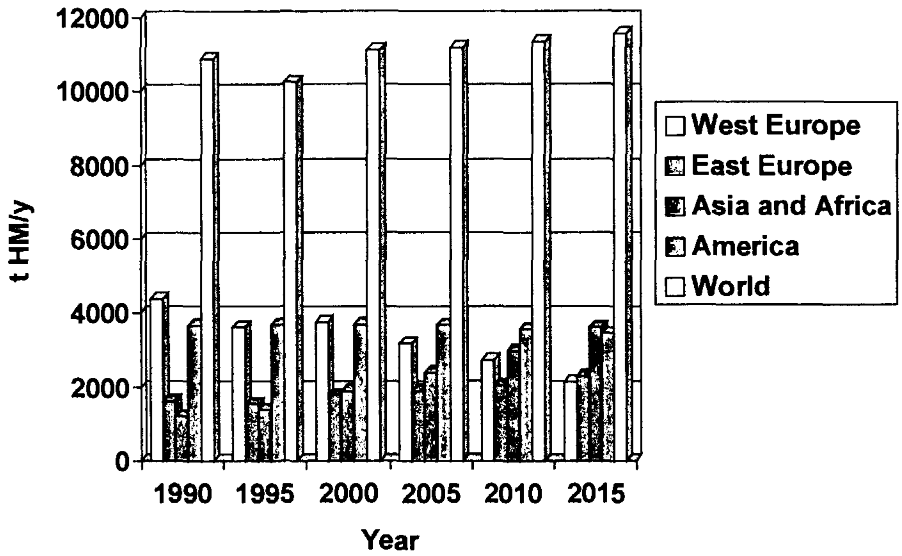

Fig. 1 Projection of regional and worldwide spent fuel arising.

The cumulative amount of spent fuel arising at the end of 1997 was 185,000 tHM worldwide, while the projected cumulative amount of the spent fuel arising in the year 2010 may surpass 340,000 tHM.

The worldwide inventory of the spent fuel stored which is obtained by subtracting the amount reprocessed from the cumulating amount of spent fuel increases steadily from year to year(see Fig. 2). The regional trend indicates that the inventories in any region except for Western Europe will increase. A sharp increase of the stockpiles in North and South America reflect the fact that the USA and Canada are taking the direct disposal option. In contrast, the decrease in Western Europe is caused by a decrease of spent fuel arising and steady increase of amounts reprocessed in several countries in the region.

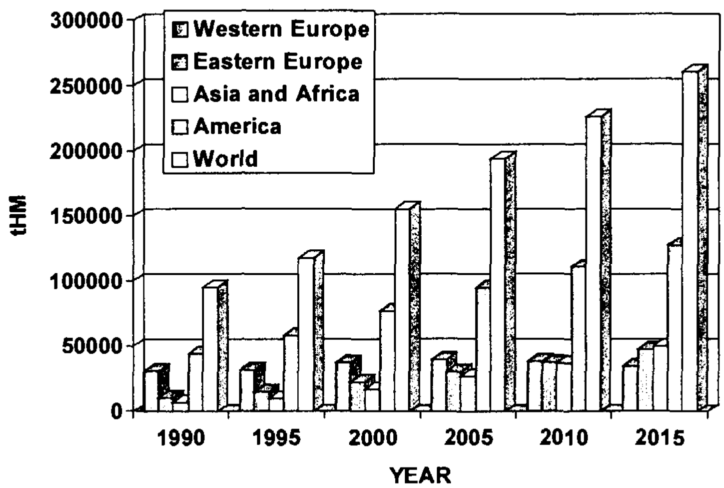

Fig. 2 Projected total amount of spent fuel stored

A comparison of amounts of spent fuel stored and storage capacities is shown in Fig. 3. The storage capacities are deduced from the information that the IAEA gathered in a survey on the status of spent fuel storage as of 1997 and the VISTA code calculation of predicted capacities in the future. The amount of spent fuel stored is calculated by the VISTA code using the same scenario as mentioned above. This data predicts that the storage capacities will have about 100,000 tU surplus over the total amount of spent fuel stored until 2015. However, it should be noted that the situation regarding storage capacity can be radically different in different countries; some countries, for example those in Western Europe, have enough capacity, while others are hard up.

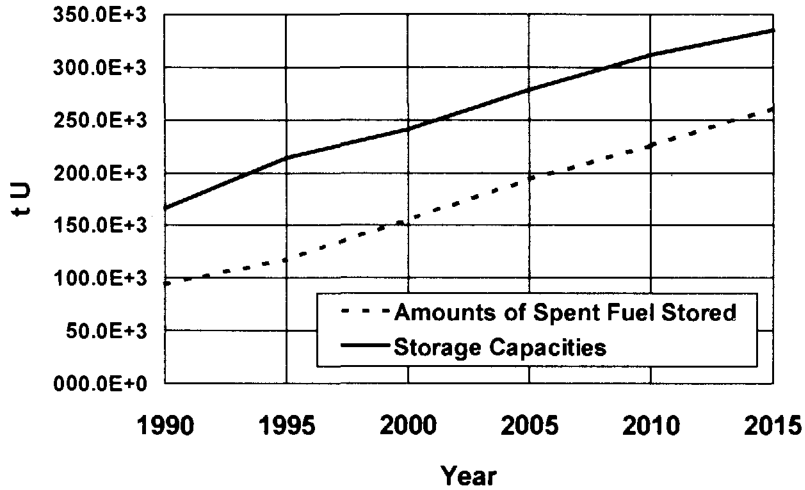

Fig. 3 Comparison of amounts of spent fuel stored and storage capacities world wide.

2.2. Reprocessing

To-date, the civil reprocessing has evolved to an industrial scale in several countries. In September 1998, the IAEA convened a consultancy on spent fuel treatment to survey the worldwide trend of reprocessing. Table 1, which includes updated information from the consultancy, lists the status of the current and projected reprocessing capacities, including the plants under operational, already closed in the past and planned worldwide. At present, France is successfully operating the reprocessing plants in La Hague for LWR spent fuels with a capacity of 1600 t HM/y and has already reprocessed 12,000 t HM of LWR spent fuel, while the United Kingdom now operates two plants with a capacity of 2700 t HM/y, with the deployment of THORP in 1994. The Sellafield B205 plant for the GCR fuel is projected to close its operation some time after the year 2010. In Japan construction work on the Rokkasho-mura reprocessing plant with a capacity of 800 t HM/y continues, but delays have caused it to be several years behind schedule. Russia (former Soviet Union) planed in around 1980 to commission a second large scale reprocessing plant (RT-2) at Krasnoyarsk at the beginning of the next century, 2005, but it has been canceled for financial reasons. India is commissioning the Kalpakkam plant with a capacity of 100 t HM/y for PHWR, and it will be put into operation soon. The Chinese government is planing to operate a pilot reprocessing plant at Jiuqua in 2001, followed by the second large scale plant by the year 2020. The total projected reprocessing capacity worldwide increases over the period 1998-2010 due to the deployment of new plants in Japan, and India, but after 2010 it will probably change due to likely closure of the Sellafield plant (B205) and the deployment of the second Chinese plant.

Fig. 4 shows a comparison between worldwide reprocessing capacities and projected reprocessing requirements calculated by the VISTA code. Calculation involves two scenarios concerning the reprocessing ratio; S1(see the figure) increases gradually from 50% and reaches 100 % in the year 2005, while S2, assumes 100% up to 2020. With respect to the scenario for electricity generation growth, it is the same as the former. Up to the year 2020 capacities of reprocessing are enough to meet the requirements in the scenario of 50% reprocessing, but only if the projected reprocessing facilities are put into operation on schedule. However, the capacity would be short if operation of the new facilities are delayed and fall behind schedule. The 100% reprocessing scenario is unlikely nowadays.

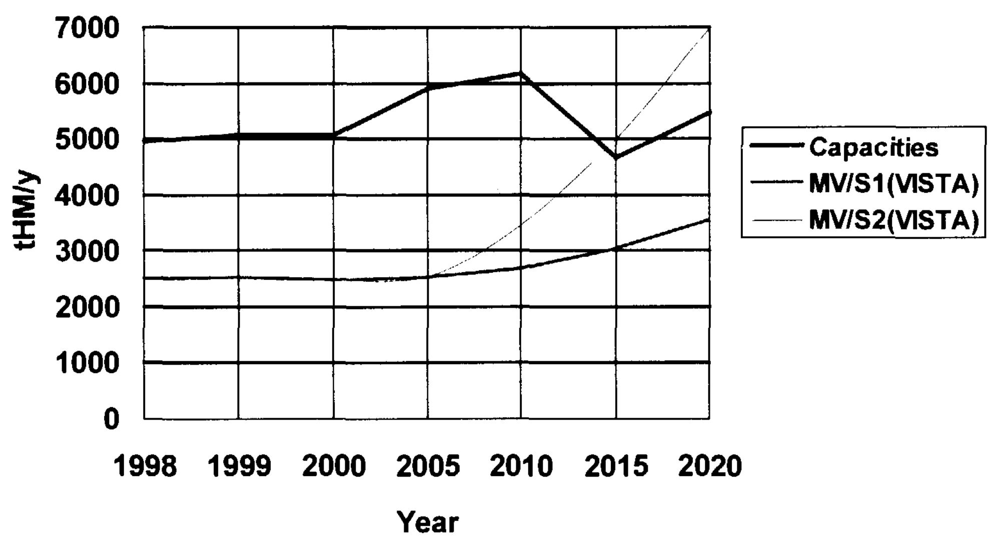

Fig. 4 Comparison between worldwide reprocessing capacities and anticipated reprocessing requirements calculated by the VISTA code

With regard to international co-operation and agreement, the French UP3 and the UK's THORP plants undertake commercial reprocessing under contract with other countries. Similar agreements exist between Russia and Central European countries, although the spent fuel volume concerned is not as large. France and the UK are also offering a guaranteed MOX reprocessing service(6).

The reprocessors have made efforts to improve the international market for reprocessing by helping customer's respond to domestic waste management pressures. The UK is now offering overseas customers the option to substitute a small quantity of high level waste that is radiologically equivalent to the large volume of intermediate waste that would be returned to them under contractual agreements. Such substitution would result in large resource savings and reduced waste transport. With similar objectives, France is planing to return waste to customers in single form containers that can accept both high and intermediate level waste[6].

3. Plutonium Utilization

The IAEA estimates that in 1997 about 10,5000 tonnes of spent fuel was discharged from nuclear power reactors worldwide, which contained about 75 tonnes of plutonium. It is foreseen that the annual plutonium production, as presumed from spent fuel arising in Fig. 1, will remain more or less the same until 2015. The cumulative amount of plutonium in spent fuel from nuclear power reactors worldwide is predicted to be about 2000 tonnes by 2015. It is estimated that about 3000 tonnes of spent fuel discharged from power reactors were offered for reprocessing in 1997, which corresponds to about 30 % of the total. About 24 tonnes of plutonium were separated in reprocessing plants. So far the stockpile of the separated plutonium is estimated to be about 200 tonnes, with France, UK, USA and Russia being the major countries holding this civil plutonium[7].

Plutonium fuels have been designed and developed principally to use in FBR in the closed fuel cycle system. However, in the 1950s, it was anticipated that reprocessing capacities would be enough to supply the requirements for feeding FBR prototypes for a period of 20 years[8]. In addition, there is another factor because exploitation of commercial FBRs was delayed contrary to past anticipation. A MOX fuel assembly was loaded in BR-3 in 1963 as the world's first plutonium recycle in LWR. Since then, plutonium has been recycled in the form of MOX fuel in thermal reactors for more than thirty years. The number of the thermal reactors loaded with MOX fuel assemblies is 32 in five countries which are Belgium, France, Germany Japan and Switzerland. France and Germany are operating 16 and 10 plants loaded with MOX fuel, respectively.

MOX fuel fabrication is becoming a mature industry activity, particularly in Belgium, France and UK. Fabrication plants for MOX fuel are being operated in Belgium, France, UK, Japan and India(Table 1).

Table 1 MOX FUEL FABRICATION PLANTS AND THEIR CAPACITIES[a] (t HM/y)

Country	Plant	1998	2000	2005	2010
Belgium	Dessel P0	35	40	40	40
	Dessel P1	-	40	40	40
France	Cadarache,CFC	35	40	40	40
	Marcoule,MELOX	120	160	160	160
Japan	Tokai	15[b]	15[b]	5[c]	5[c]
	Rokkasho	-	-	100	100
UK	Sellafield	8	8	8	8
	Sellafield, SMP	-	120	120	120
India	Tarapur	5	10	10	10
Russia	Mayak	-	-	10	50
	Total	218	433	533	573

a) information provided by experts of IAEA Advisory Group Meeting at Vienna in Sept. 1998.

b) for ATR, Fugen and FBRs, Joyo and Monju

c) for FR, Monju

In Belgium, the Dessel P0 plant has been operated with an average production equivalent to 98% of its normal capacity over the last ten years. The design stage of Dessel P1 is complete and the facility could be operational within five years after decision to build, but no decision has been taken so far.

In France, the Cogema plant at Cadarache, which previously fabricated FBR fuel, started fabrication of MOX fuel for PWRs in 1991. The MELOX Cogema plant in, Marcoule which started up in 1995 with the currently licensed capacity of 120 t HM/y, produced 68 t of MOX pellets in 1996 and is planned to reach its full capacity soon. Another new plant for PWR, BWR and FR is planned at La Hague, but the start-up date and capacity are not yet fixed.

JNC (PNC) Tokai pilot plant has fabricated MOX fuel for ATR, Fugen and FRs Joyo and Monju. Japan is considering another large scale plant.

Russia constructed seven small-scale facilities with capacities from several tens to hundreds kg HM/a in the 1980s for providing MOX test assemblies for FBRs(9). A pilot-industrial facility (first line) with a capacity of 5 t HM/a is under construction at PU Majak, Chelyabinsk, for providing MOX fuel for commercial FRs. Subsequently, the second line is under design. The project for the Complex 300 plant which was planned to be constructed at the RT-2 plant in Krasnoyarsk has been canceled for lack of funding along with the reprocessing plant(10).

MDF, the MOX Development Facility in the UK produces both PWR and BWR MOX fuels with a capacity of 8 t HM/a. Construction of SMP, the Sellafield MOX Plant, is complete and start of its operation is anticipated in 1998.

A comparison of MOX fuel production capacities and predicted MOX fuel requirements by 2010 is given in Fig. 5. The requirement was calculated, again using the VISTA code, assuming the moderate growth of electricity generation and a 50 % reprocessing ratio.

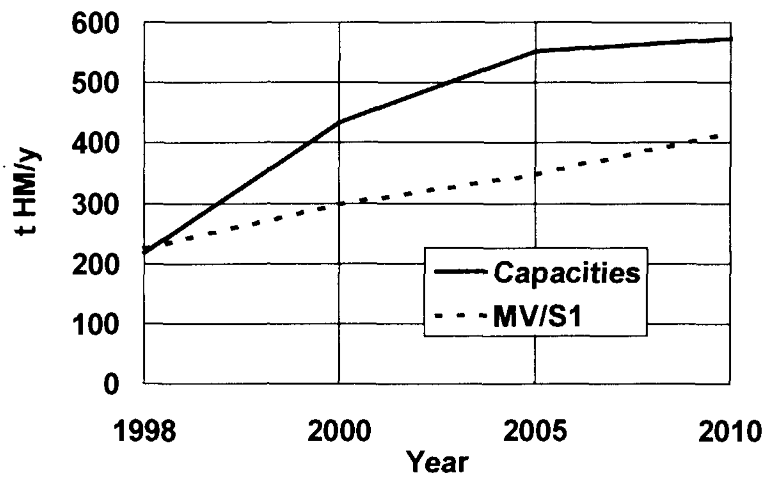

Fig. 5 Comparison between worldwide MOX fuel production capacities and predicted annual MOX fuel requirements calculated by VISTA code.

At present, MOX fuel requirements are near the full production capacities. This current relation in the supply and demand of the MOX fuel reflects the near full capacity prodcution of the commercial plants, as mentioned above for the Dessel P0 plant. However, it is foreseen that the supply will be in excess of demand up to 2010 because of commissioning of the Sellafield SMP, expansion of the MELOX plant capacity and deployment of the Rokkasho plant.

4. Burnup Credit[11]

The Regular Advisory Group on Spent Fuel management recommended in 1995 to identify and clarify areas of burnup credit applications. The first Advisory Group meeting was held in October 1997 in the IAEA. The burnup credit is originally motivated by consideration of economic efficiency, but its additional benefits may be considered to contribute to public health and safety, and resource conservation and environmental quality. Implementation of burnup credit has been envisaged in many countries for such different needs as;

- introduction of higher enriched fuel in the existing storage, reprocessing or transport systems. In this case, application of burnup credit can avoid the need for new installations or extensive modification of existing facilities.
- increase of the storage capacities by allowing smaller distances between the fuel assemblies,
- increase of the cask capacities over current design capacities to reduce the number of shipments.

The IAEA collected information on the status of burnup credit and the prospects of its implementation. The status categorized into storage, transportation, reprocessing and disposal, as of December 1997 is listed in Table 2.

The burnup credit defined by the Advisory Group is considered to be the reactivity associated with the use of the fuel in the reactors. The different levels of burnup credit which are commonly used are described as follows:

- Credit for the net decrease of the fuel fissile content, taking into account both burnup and buildup of the different fissile nuclides (***net fissile content level***)
- Credit for the net fissile content and for the absorption effect of actinides (***actinide only level***)
- Credit for the actinide and the neutron absorption in the fission products (***actinide and fission product level***)
- Credit for the presence of integral burnable absorbers in the fuel design (***integral burnable absorber level***)

Among the above-mentioned various levels of burnup credit, the net fissile content level is generally not used alone and the actinide only level is applied in many countries such as France, Germany, Russia and Switzerland. The status of the application of actinide only level of burnup credit is as follows:

- In France, the actinide only level is approved for wet storage, wet and dry storage and reprocessing of spent PWR fuel.
- In Germany the actinide only level is approved for dry transport of spent BWR fuel in the CASTOR V/52 cask.

- In Russia the actinide only level is approved for wet transport of spent WWER-440 fuel from Kola Nuclear Power Plant.
- In Switzerland this burnup credit level is approved for dry transport of spent PWR fuel.

Actinide and fission product level of burnup credit is approved for PWR storage in the USA, Korea and Spain, for RBMK wet storage in Russia and Lithuania and for dry storage cask loading in the USA. Credit for the presence of integral burnable absorber is approved for BWR wet storage systems in Germany, Spain, Sweden and Switzerland.

5. Conclusions

The IAEA has played important roles in peaceful use of the nuclear energy by collecting and disseminating state-of-the-art information and providing technical support in the area of nuclear power. This paper describes recent outcomes from the IAEA's activities in the back-end of the nuclear fuel cycle, particularly focusing on the spent fuel management, reprocessing, plutonium utilization and burnup credit. In this paper, the following matters are elucidated or forecast with the aid of VISTA calculations:

-It is foreseen that the spent fuel arising worldwide is not much changed up to 2015. In the regional forecasts, spent fuel arising in Western Europe decreases, while that in Asia and East Europe increases.
-Steady increase of the cumulative spent fuel amount worldwide is foreseen. Inter alia, the growth in North America is outstanding, which reflects the adoption of the open cycle policy without reprocessing. The cumulative amount from Western Europe will decrease.
-It is foreseen that storage has surplus capacity over spent fuel arising up to 2015. However, the spent fuel storage situation is substantially different in different individual countries.
- An update of information on reprocessing facilities, their capacities and projection worldwide is presented.
- It is foreseen that reprocessing capacities are sufficiently surplus to reprocessing requirements, if 50 % of the spent fuel amounts are reprocessed.
-An updated country status on the MOX fuel fabrication is presented.
- It is foreseen that the capacity of MOX production is nearly the same as the MOX fuel requirement at present, but by commissioning of new facilities, the production capacities will eventually become greater than the requirements.
-Updated burnup credit implementation worldwide is presented.

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Table 2 Uses of Burnup Credit: National Practices and Status

COUNTRIES	STORAGE									TRANSPORTATION								REPROCESSING				DISPOSAL			
	WET					DRY				WET				DRY											
	P	B	R	M	W	P	B	M	W	P	B	M	W	P	B	M	W	P	B	M	W	P	B	M	W
BULGARIA					IC				IC				IC				IC								
CZECH REP.					IC				IC								IC								IC
FRANCE	AP			IC			IC	IC		AP	IC	IC	IC	AP	IC	IC	IC	AP	RR	IC					
GERMANY	RR	AP		IC	NO	IC	IC	IC	IC					UD	AP	IC	IC					IC	IC	IC	IC
HUNGARY					NO				IC								IC								
JAPAN	IC	IC		UD		IC	IC	UD		IC	IC		IC	UD	UD	IC		IC	IC	IC					
KOREA, REP.	AP					IC				IC				IC											
LITHUANIA			AP																						
RUSSIAN FED.			AP		IC				IC				AP				IC				IC				
SLOVAKIA					IC				IC				IC				IC								IC
SPAIN	AP	AP				IC	IC							IC	IC										
SWEDEN		AP												IC	IC							UD	UD		
SWITZERLAND	NO	AP		NO		IC	IC	IC						AP	IC	IC									
UK	RR	UD		UD		IC	IC	IC	IC	RR	UD	UD		IC	IC	IC	IC	UD	UD	UD					
USA	AP	IC				RR	IC			RR				RR	IC							RR	RR		

(As of December 1997)

AP=Approved
IC=Interest/Considering or Appricable.
NO=Appricable but not interested.
RR=Regulatory Review
UD=Under Development

P=PWR
B=BWR
R=RBMK
M=MOX
W=WWER

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