COMPARISON OF NATIONAL PROGRAMS AND REGULATIONS FOR THE MANAGEMENT OF SPENT FUEL AND DISPOSAL OF HIGH-LEVEL WASTE IN SEVEN COUNTRIES

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ABSTRACT

This paper describes programs and regulatory requirements affecting the management of spent fuel and disposal of high-level radioactive waste in seven nations with large nuclear power programs. The comparison is intended to illustrate that the range of spent fuel management options is influenced by certain technical and political constraints. It begins by providing overall nuclear fuel cycle facts for each country, including nuclear generating capacities, rates of spent fuel discharge, and policies on spent fuel reprocessing. Spent fuel storage techniques and reprocessing activities are compared in light of constraints such as fuel type. Waste disposal investigations are described, including a summary of the status of regulatory developments affecting repository siting and disposal. A timeline is provided to illustrate the principal milestones in spent fuel management and waste disposal in each country. Finally, policies linking nuclear power licensing and development to nuclear waste management milestones and R&D progress are discussed.

INTRODUCTION

Those nations of the world which generate electricity by means of nuclear power are grappling with the challenges of nuclear waste management in differentways. Some reprocess used fuel elements to recycle uranium and plutonium, producing high-level liquid wastes which are stored or vitrified for disposal, while others are planning direct disposal of spent fuel. Some are developing disposal repositories now, whereas others are deferring this effort to allow the cooling down of waste materials and the continued development of a capability for safe disposal. Also, a variety of techniques are utilized throughout the world for storing discharged fuel elements. In order to understand how spent fuel is managed and what plans have been drawn for the disposal of high-level waste, this paper seeks to compare programs and regulations in seven countries: the United States, France, Japan, the Federal Republic of Germany, the United Kingdom, Canada and Sweden. The seven were selected for comparison because, first, they are among the largest producers of nuclear energy in the world today and have aggressive programs for spent fuel management and waste disposal, and second, because they present a spectrum of technical and political constraints which influence the choice of spent fuel management strategies.

It is particularly important in a comparison of diverse international systems to clarify some semantics. In this paper, the term "spent fuel management" is used to refer to the storage, transportation, and reprocessing of spent fuel. The term "high-level waste disposal" refers to the encapsulation and disposal of nuclear fuel waste regardless of whether the disposed material is in the form of spent fuel or high-level wastes from reprocessing. That is, whatever materials go into a waste repository in a given country are referred to as high-level waste.

OVERVIEW

With nearly 100 reactors licensed for operation, the United States currently has the largest nuclear power program in absolute terms, generating electricity at a rate of over 80 GWe and producing approximately 1,900 metric tons of spent fuel (almost entirely light water reactor fuel) per year. These figures are presented in Table I and compared with similar data for the other six countries listed in order of current nuclear generating capacity. As a group, the natural uranium-fueled reactors (the gas-cooled reactors in France and the UK and heavy water reactors in Canada) generate substantially more spent fuel than light water reactors, due to their lower burnup, as shown by comparing the data in the last column of Table I with generating capacities in the third column. Among either the natural or the enriched uranium-fueled group, spent fuel discharge rates are generally a function of electrical generating capacity.

Interest in reprocessing of spent fuel varies substantially among these countries. France and the United Kingdom currently operate commercial scale facilities for reprocessing their own spent fuel and provide reprocessing services to other countries. Both are currently constructing additional reprocessing services to other countries. Both are currently constructing additional reprocessing capacity. The FRG and Japan now operate only pilot scale reprocessing plants and ship most of their spent fuel to France and the UK for reprocessing. However, both have selected sites and will soon begin construction of commercial scale reprocessing facilities. Table II shows the reprocessing capacities available and under construction in these countries.

The U.S., Canada and Sweden are all currently planning for direct disposal of spent fuel, although future reprocessing has not been completely dismissed from consideration. Canada is developing technologies for immobilization of both spent fuel and high-level reprocessing wastes to maintain options to dispose of either waste form. Sweden has moved the closest to committing to direct disposal of spent fuel, with a Parliamentary decision in 1980 to phase out nuclear power by 2010. About 10% of Sweden's total expected spent fuel discharge was contracted in the 1970's for foreign reprocessing prior to this Parliamentary decision. It is not certain to what extent these services will actually be used.

The following sections give a brief description of spent fuel management activities in each of the seven

TABLE I

Nuclear Power Capacities and
Spent Fuel Generation Data (thermal reactors only)

Country	Fuel Type	Total Generating Capacity, MWe (operating/under construction)	Number of Reactors (operating/under construction)	Spent Fuel Produced to Date (MTHM)	Current Spent Fuel Discharge Rate (MTHM/year)
US	oxide (LWR*)	84,800/35,000	96/30	13,000	1,900
France	oxide (PWR)	35,500/23,700	38/19	2,600	630
	metal (GCR)	2,300/0	8/0	16,500**	400 (est.)
Japan	oxide (LWR*)	24,600/12,700	33/12	4,500	800
FRG	oxide (LWR)	16,900/13,000	16/12	2,700	400
UK	oxide (AGR)	5,600/3,300	9/5	700	120
	metal (GCR)	5,200/0	26/0	25,000**	1,300
Canada	oxide (HWR)	10,100/5,100	16/6	9,000	1,500
Sweden	oxide (LWR)	9,400/0	12/0	1,500	250

* Small amounts of additional spent fuel are generated at the Fort St. Vrain (US) and Tokai (Japan) gas-cooled reactors and are not included here.

** Data for France and the UK may include spent fuel from the military production reactors. The US figures do not include fuel discharged from military production reactors.

TABLE II

Spent Fuel Reprocessing Facilities

Country	Facility	Primary Fuel Type	Year of Operation	Capacity (MTHM/year)
France	Marcoule: UP1	Metal	1958	500
	La Hague: UP2	Metal	1967-1986	250*
		Oxide	1976-1991	250-350*
	UP2-800	Oxide	1991	800
	UP 3	Oxide	1989	800
Japan	Tokai Mura	Oxide	1977	150
	Rokkashomura	Oxide	1995	800
FRG	Karlsruhe	Oxide	1971	20
	Wackersdorf	Oxide	1992	350
UK	Sellafield	Metal	1964	1250
	THORP	Oxide	1990	600

* UP2 has been used to reprocess oxide (LWR), metal (graphite reactor), and breeder fuels but is gradually being dedicated to LWR fuel only. Its capacity for LWR fuel only will be 400 MTHM/year.

countries, in the order that they are listed in Table I. Table III provides a comparison of the spent fuel management strategies in each country. Figure 1 shows some of the major program milestones in spent fuel management and high-level waste disposal in each country. Following these sections, high-level waste disposal criteria are addressed, and stipulations linking power reactor licensing and development to nuclear waste R&D progress are discussed.

TABLE III

Summary of Spent Fuel Storage Methods

United States -	At-reactor storage with reracking. Plans to utilize rod consolidation, transshipments, and dry storage.
France -	Offsite transfer to reprocessing facility within one year of discharge. Wet storage only.
Japan -	Offsite transfer to reprocessing facility (mostly foreign) within 2 to 3 years of discharge. Interim storage under study with emphasis on dry storage.
FRG -	Offsite transfer to reprocessing facility (mostly foreign) within one year of discharge. Will extend to 5 years and utilize 3 away-from-reactor dry storage facilities in preparation for use of German reprocessing plant in 1990's.
UK -	Offsite transfer of GCR metal fuel to reprocessing facility within one year of discharge. Mostly wet storage; one plant has dry vault. AGR oxide fuel wet-stored at reactor for 1 to 2 years, then shipped to THORP site for reprocessing beginning in 1990.
Canada -	Onsite wet storage. Expanded at-reactor or centralized storage under consideration of both wet and dry design.
Sweden -	Centralized wet storage facility will accept all spent fuel for 40 year storage. At-reactor storage for six months or more.

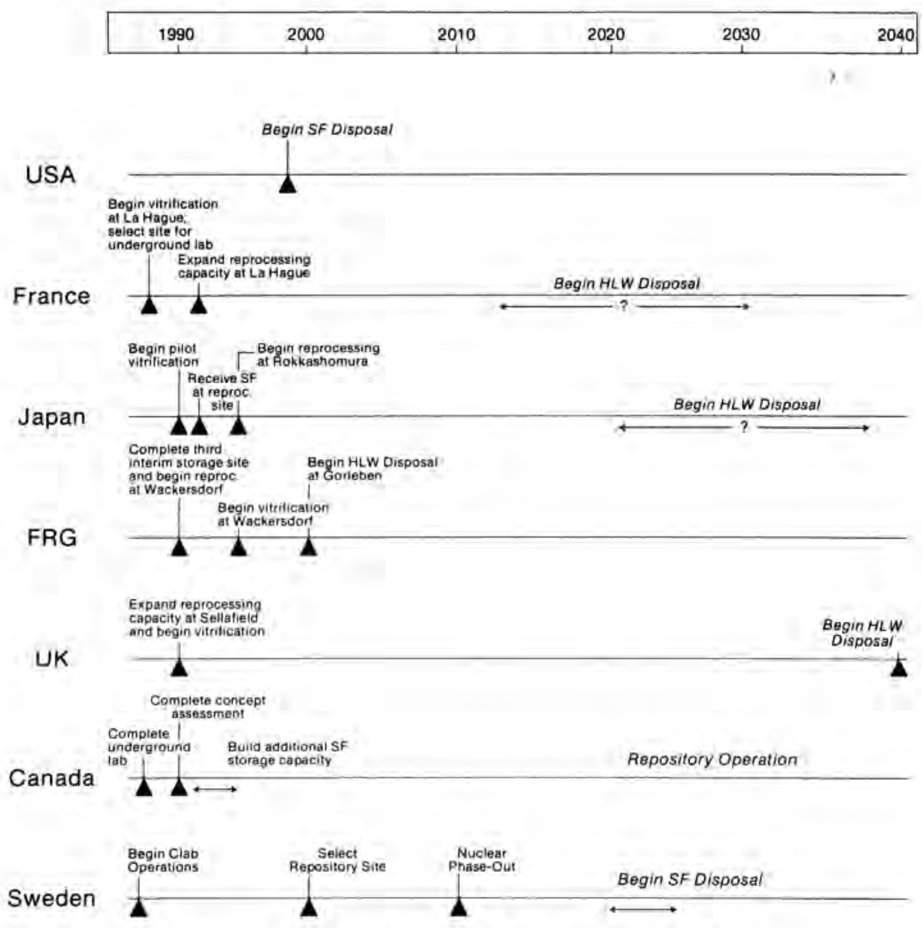

Fig. 1. National Schedules for Spent Fuel and High-Level Waste Management.

PROGRAM DESCRIPTIONS

United States

Activities related to the management of spent fuel and the disposal of high-level waste in the U.S. are governed by the provisions of the Nuclear Waste Policy Act of 1982. The NWPA directs the Department of Energy to select sites and construct and operate two high-level waste repositories. The Act authorizes the construction of a first repository, with a target of beginning its operation by 1998. DOE expects to announce the selection of three candidate first repository sites for detailed characterization in April 1986. Candidate second repository sites are in an earlier stage of screening.

The NWPA does not establish a specific policy on reprocessing, so that it is not known with any certainty what mix of spent fuel and reprocessing high-level waste will be destined for repository disposal. The current Administration has voiced its support for reprocessing, but with no commercial interest in this activity at present, it is becoming more likely that spent fuel will be disposed of, and this is an assumption of the DOE Mission Plan. Repositories will be designed to accommodate both spent fuel and reprocessing waste forms, since the small amount of waste from earlier commercial reprocessing activities and high-level waste from defense activities will be included in the same repositories as the spent fuel, as would any commercial reprocessing wastes which may be produced in the future.

DOE will soon propose to Congress the authorization of a monitored retrievable storage (MRS) facility, a center for consolidation and packaging of spent reactor fuel as well as temporary backup storage up to 15,000 metric tons in the event that start-up of the first repository is delayed. Interim storage of spent fuel until it is accepted by DOE for disposal is the responsibility of the utilities. The strategy for utility storage of spent fuel in the United States is likely to include reracking of fuel in the reactor storage pools, reactor transshipments, rod consolidation, extended fuel burnup, and independent storage in dry casks.

France

In contrast with the U.S. program, the French are firmly committed to the reprocessing of spent fuel and the recycling of extracted plutonium in light water reactors until breeder reactors come into full-scale operation. Storage of spent fuel at reactor sites is very limited because fuel is routinely transported to either the Marcoule (metal GCR fuel) or the La Hague (metal and oxide fuel) reprocessing plants after an initial cooling period of about one year. France has also provided LWR fuel reprocessing services at La Hague to Germany, Japan, and other countries.

The French view storage in fuel pools as a low risk technology which is better established and less costly than dry storage. Therefore, spent fuel pools will be used at the expanded reprocessing facilities. Reracking in reactor fuel bays and dry storage are not foreseen in France, nor is long-term interim spent fuel storage. The exception is at the Superphenix fast breeder reactor site, where a large storage facility is being built in anticipation of the construction of a specialized breeder reactor fuel reprocessing plant at Marcoule.

The French have operated a borosilicate glass plant at Marcoule since 1978 for immobilizing the high-level waste from reprocessing operations. Canisters containing the glass blocks are put in concrete vault storage with initial cooling by forced convection and eventually by natural convection. Vitrification facilities for the La Hague reprocessing plants are also under construction, scheduled for operation in the late 1980's. Vitrified high activity wastes may be stored for several dozen years prior to permanent disposal in deep geologic structures. Selection of a site for an underground research laboratory is anticipated in 1987. After two years of construction and two or three years of study, a determination will be made on the site's suitability as a permanent repository for both transuranic and high-level waste. The site will be developed to be ready for transuranic waste disposal and pilot high-level waste disposal before 2000, and full-scale high-level waste disposal beginning after 2010.

Japan

Japan is also firmly committed to reprocessing its reactor fuel, but depends heavily on reprocessing services provided in France and the UK. As shown in Table II, Japan currently has a small reprocessing capability at Tokai Mura and plans to construct a large reprocessing plant at Rokkashomura, which is expected to begin operating in 1995. The Japanese will use recovered plutonium to fuel fast breeder reactors beginning in about 2010, and will use plutonium in light water and advanced thermal reactors beginning in the late 1990's.

Spent fuel is currently stored in the reactor spent fuel bays for an initial cooling period typically of two to three years. Since all of Japan's fifteen reactor sites are on the coast, offsite transfers of spent fuel are made by ship, whether the fuel is going to European reprocessors or to Tokai Mura. Substantial R&D efforts are underway on interim storage technologies, focusing primarily on dry storage cask technology.

The interim storage approach is attracting increased interest, due to the possibility of delays in operating the large reprocessing facility, the expiration of contracts with European reprocessors in 1990, the later need for plutonium fuel due to slow development of breeder reactors, and the possible economic advantages of interim storage. The planned commercial reprocessing plant will include a storage pool providing 3,000 tons of interim capacity, and is scheduled to start receiving fuel around 1991.

The Japanese plan to immobilize high level wastes from reprocessing in borosilicate glass and store the glass canisters for 30 to 50 years prior to deep geologic disposal. A pilot vitrification plant is planned to begin operation in 1990, and a high-level waste storage facility is expected by 1992 for receipt of returned waste from European reprocessors. (Under the contracts for reprocessing of spent fuel from foreign countries, the UK government requires that, if appropriate, the high-level waste shall be accepted back by that country from which the spent fuel originated).

Federal Republic of Germany

German utilities are required by law to demonstrate provisions for spent fuel management in order to obtain a license to operate a reactor (see further discussion below under "Stipulations"). A comprehensive system has therefore been developed including reactor spent fuel pools, centralized dry storage facilities, contracts for foreign reprocessing services, and construction of a German reprocessing plant. As in Japan, a small reprocessing plant is currently operating in the FRG and a commercial scale plant will soon be constructed. In the meantime, German utilities send most of their spent fuel to France and the UK for reprocessing.

Most power plants in the FRG have the capacity for about ten years of spent fuel storage, although little of this capacity has been utilized because of the reprocessing contracts. Offsite transport normally occurs after a cooling period of about one year. In order to build an inventory of spent fuel elements for the future reprocessing plant, it will become necessary to begin using the at-reactor storage capacities and to develop away-from-reactor interim storage facilities. It has been decided to construct three centralized facilities for interim storage of spent fuel in dry storage casks, each with a capacity of 1,500 metric tons. The facilities are located at Gorleben (the site of Germany's planned high-level waste repository), Ahaus, and at the Wackersdorf reprocessing complex, and will begin receiving spent fuel between 1986 and 1990. Utilities will now begin to make maximum use of at-reactor storage, extending at-reactor cooling to about 5 years. Subsequently, spent fuel will be shipped to these facilities and stored in dual-purpose transportation and storage casks.

A vitrification plant is planned at the Wackersdorf site, along with a storage facility for vitrified high-level waste canisters, which will also accept the returned vitrified waste from the reprocessing of FRG spent fuel overseas. A site investigation is underway at the Gorleben salt dome to demonstrate its suitability for a high-level waste repository.) It is intended that operation of the facility will begin before the year 2000.

United Kingdom

The United Kingdom developed a reprocessing capability early, out of necessity. Magnox fuel from Britain's gas-cooled reactors could not be wet-stored for prolonged periods because its magnesium cladding is susceptible to corrosion, and dry storage was not yet developed. Therefore, storage of spent fuel at the 26 Magnox reactors in the UK is minimal, with offsite transport to the Sellafield reprocessing plant generally occurring within 6 to 12 months of reactor discharge. One exception is the Wylfa plants in Wales, where some spent Magnox fuel has been stored in a dry vault. Similarly, oxide fuel from 9 advanced gas reactors (and, in the future, from 5 additional AGRs under construction) is stored at the reactor site for only a short period of 1 or 2 years. The policy in the UK is to store this stainless -steel clad spent fuel in water pools up to a maximum of 10 years. It is presently shipped offsite for wet storage at Sellafield, prior to reprocessing at the thermal oxide reprocessing plant (THORP), which is scheduled for operation in 1990.

As in France, both the metal fuel and THORP reprocessing plants at Sellafield are contracted for reprocessing of foreign spent fuel. LWR fuel from Japan, Germany, and other countries is being stored at the Sellafield site in anticipation of 1990 operation of THORP.

A vitrification plant is under construction at Sellafield for immobilization of high-level waste from both reprocessing plants. It is based on the French design and is scheduled for initial operation in 1989. The vitrified waste will be stored for approximately 50 years in a natural convection-cooled vault prior to geologic disposal. The intended time period for storage of vitrified waste products allows substantial time to site a high-level waste repository and develop a disposal capability. The UK has thus discontinued a research drilling program and has reoriented its disposal R&D towards confirming the applicability to the UK of investigations and findings of research in other countries. Construction of a pilot high-level waste repository, which was originally scheduled for the late 1990's, is no longer considered necessary in the UK.

Canada

Canadian utilities have developed extensive at-reactor fuel pool capacity, including auxiliary storage pools at several plants, connected to the primary pools by enclosed corridors or underwater ducts. Natural uranium fuel used in Canada's heavy water reactors is not subject to criticality and can, therefore, be stored at high density, contributing to this large storage capacity. Furthermore, lower burnup reduces heat removal requirements, and the CANDU reactor's short assembly length allows horizontal storage in stacked trays. However, lower burnup is the reason for the much larger volume of spent fuel generated than in enriched uranium-fueled reactors, although the lower burnup material is cooler and less radioactive.

Additional storage capacity will be needed at Canadian reactors by the mid-1990's. With no decision by the government on the reprocessing of spent fuel, utilities are considering additional at-reactor and centralized storage facilities of both wet and dry design. Concrete canisters and convection vaults are expected to have major cost advantages over expanded water pool storage, as well as higher reliability because of passive cooling. The feasibility of a concrete integrated cask suitable for storage, transportation, and disposal is also being assessed.

Canada is now in its sixth year of a ten year R&D program to assess the concept of deep underground disposal. Technologies are being developed for the immobilization of both spent fuel and reprocessing waste, so that options are maintained for the disposal of either waste form. An Underground Research Laboratory is also being constructed as a part of this assessment to allow in-situ testing in granite. It is expected to be completed in 1986. At the end of the decade, a public hearing will be held followed by a government decision on the acceptability of the concept. If accepted, efforts to select a disposal site could then proceed.

Sweden

Following the national referendum on nuclear power in 1980 and the subsequent parliamentary decision to phase out nuclear power by 2010, Sweden has developed a somewhat unique system for managing the spent fuel to be discharged from its twelve reactor units. Under requirements to demonstrate a safe spent fuel management strategy in order to obtain a permit to initially load fuel into a reactor, Swedish utilities have formulated the KBS-3 plan, which formed the basis for licensing the last two reactors in 1984.

KBS-3 provides for a standardized transportation system, a centralized interim fuel storage facility, and a central high-level waste repository. With all reactor sites located on the coast, all spent fuel is transported by ship to the intermediate storage facility, "Clab," which is located adjacent to the Oskarshamn reactor site on Sweden's east coast. The Clab facility was completed in 1985 and has begun to receive spent fuel for storage. The wet storage technique is utilized, emplacing fuel in large stainless-steel lined concrete vats situated in underground caverns with rock cover of at least 30 meters. The facility has an initial capacity of 3,000 metric tons but will be expanded to 7,500 metric tons to accommodate all fuel discharged from Sweden's twelve reactors during their expected lifetimes. After the existing backlog of spent fuel at the reactor sites has been shipped to Clab, future generated spent fuel will be stored at the reactor sites for at least six months after discharge prior to offsite transfer.

It is planned for spent fuel to be stored at Claf for about 40 years prior to shipment for repository disposal. Selection of two or three candidate repository sites for detailed study is expected in around 1990, followed by presentation of a single site for licensing in around 2000. Construction would begin around 2010 and operation around 2020. Spent fuel will be packaged into copper canisters at an encapsulation station located above ground at the site of the repository.

WASTE DISPOSAL REGULATIONS

Not surprisingly, the degree to which high-level waste disposal criteria have been developed in each of the seven countries depends on schedules for repository operation and the need for such criteria (see Fig. 1). In the U.S., where the first repository license application is scheduled to go to NRC in 1991, the criteria are extensively developed. DOE has issued its final guidelines for selecting repository sites, and EPA and NRC have promulgated final environmental radiation protection standards and repository performance criteria, respectively, establishing the complete technical basis for the development of repositories. Similarly, the Federal Republic of Germany has established a licensing basis for high-level waste repositories. Its criteria for final disposal do not include generally applicable quantitative performance criteria, as in the U.S. Instead, they require the demonstration of safety in a site-specific safety analysis. The repository must, however, comply with Germany's generally applicable radiation protection rules.

France has adopted site selection criteria which apply to both surface and deep geological disposal facilities. Safety criteria for the high-level waste repository are scheduled to be issued in 1987. Requirements for the vitrification process also limit the radioactivity concentration in the glass waste products. Canada has also proposed siting criteria in the form of a regulatory guide, as well as qualitative requirements on the repository which state that following repository closure, there must be a small probability that radiation doses to the public attributable to the repository will exceed a small fraction of natural background radiation doses. More specific disposal criteria are anticipated prior to Canada's concept assessment hearing.

Elsewhere, high-level waste disposal regulations are in a more conceptual stage. It can be expected that these regulations will be consistent with national radiation protection standards, and that a varying degree of specific disposal requirements and siting guidelines will be developed depending on how prescriptive regulatory policies are in each country.

STIPULATIONS

Finally, in some countries the licensing and development of nuclear power have been linked to spent fuel management plans and R&D progress. Two of the countries covered in this study require reactor license applicants to demonstrate a safe spent fuel management strategy in order to obtain reactor construction or operating licenses. In the FRG, this demonstration must initially be made in support of an application for a construction license, and before the first partial operating license is granted, a demonstration must be made that the safe location of spent fuel is assured for the first six years after plant commissioning. This can be accomplished by submitting contracts to reprocess the spent fuel. Reactor licensing in the FRG is also linked to progress in siting both external storage and reprocessing facilities.

In Sweden, to obtain permission to load fuel into a reactor for the first time, a licensee must demonstrate that there is a method for handling and final disposal and spent fuel and derivative waste which is acceptable with regard to safety and radiation protection, and must present an R&D program for the work that is necessary to support this demonstration.

In contrast, when the USNRC completed its Waste Confidence Proceeding in 1984, it determined that there was a reasonable assurance of the feasibility of safe spent fuel management and high-level waste disposal. NRC then issued a rule requiring that, at least 5 years before the expiration of a plant's operating license, the reactor licensee must submit its plans for onsite management of spent fuel until the time when title to and possession of the fuel are transferred to DOE for ultimate disposal. This does not constrain licensing actions in any way. However, controversy in the U.S. over the acceptability of nuclear waste disposal may impact upon the development of nuclear power in another manner. In 1983, the U.S. Supreme Court unanimously upheld a California State law banning the construction of new nuclear power plants until a technology for the safe disposal of high-level waste is demonstrated, and ruled that states may enact such bans so long as they are based on economic grounds. (Radiological concerns are left to the exclusive jurisdiction of the Federal government under the Atomic Energy Act.) At least three other states (Maine, Connecticut and Wisconsin) have also banned reactor construction until a waste disposal strategy is demonstrated.

Japan requires license applicants only to indicate the method of disposition of spent fuel, which in effect means identifying that the spent fuel will be reprocessed. Canada and the UK have both been advised by special commissions not to commit to new nuclear plants until substantial progress is made in high-level waste disposal, but neither government has adopted such a policy. France also does not link reactor licensing to waste disposal planning or R&D progress.

CONCLUSION

Recognition of how others deal with certain challenges is helpful for optimizing one's own approach to meeting similar challenges. This paper has attempted to illustrate that although there is a high degree of flexibility in the manner in which spent fuel management and high-level waste disposal can be approached, there are certain technical and political constraints which have strongly influenced national decisions over whether to reprocess, how to store spent fuel, and when to proceed with high-level waste disposal. Fuel design, scale of national nuclear power programs, and public attitudes towards nuclear power and nuclear waste are key among these considerations. We can all benefit by paying attention to what other countries are doing in these areas, including regulations affecting high-level waste disposal and stipulations on the licensing of new power reactors.