CHAPTER 3

SPENT NUCLEAR FUEL AND HIGH-LEVEL WASTE DISPOSAL PROGRAMS IN OTHER COUNTRIES

As in the United States, other countries that use nuclear power are establishing long-term programs for the safe management and disposal of spent nuclear fuel and high-level radioactive waste. Such programs include adopting a national strategy, assigning the technical responsibility for research and development activities to designated agencies, selecting disposal strategies and development activities, and setting the appropriate regulatory standards to protect public health and the environment. Management strategies may include spent nuclear fuel storage at and away from reactor sites, spent nuclear fuel reprocessing, high-level waste vitrification and storage, partitioning and transmutation of the waste into short-lived or stable forms, and disposal in deep geologic media. Typically, the objective of such geologic disposal programs is to immobilize and isolate radioactive waste from the environment for a sufficient period of time under conditions such that any radionuclide releases from the repository will not result in unacceptable radiation exposure of the public. This strategy takes advantage of the geology surrounding the disposal site to act as a passive barrier to radionuclide releases and eliminates many surface factors, such as sabotage, hurricanes, theft, and flooding, which could compromise an above ground facility.

As discussed in Chapter 1 of the BID, deep geologic disposal is considered by many in the scientific community to be the most promising method for disposing of long-lived nuclear waste. Consequently, several nations have begun activities associated with disposal of spent nuclear fuel and high-level waste by isolation in deep geologic formations. These countries envision emplacing solidified high-level waste in a deep geologic formation located within their borders.

Only the United States and Germany have identified candidate locations for disposal of high-level waste, i.e., the Yucca Mountain site in Nevada and the Gorleben site in Germany[9]. Other countries are, to varying degrees, engaged in technical evaluations of the potential suitability of indigenous geologic formations for disposal. Some nations, such as France, have several geologic formations, such as clay and granite, that might be used for disposal, and each

[9] As will be discussed in Section 3.5.2, the suitability of the Gorleben site has been questioned by the new German government which was elected in 1998.

alternative is being evaluated. Others, such as Canada, have focused on one type of geologic formation. (Canada is evaluating a crystalline rock formation in a setting with low seismic activity.) In addition, several countries, such as Canada and Sweden, have established underground research laboratories (URL's) and extended their research programs to include participation by other nations with similar candidate geologies. For example, the Swedish research facility is in a crystalline rock formation and its research program has included participation by Japan, Spain, Finland, Switzerland, the U.S.[10], and Canada.

The disposal strategies for all nations assume that waste isolation will be maintained by reliance on a combination of engineered and natural barriers between the emplaced waste and the environment. Currently, the United States is considering a potential repository site at Yucca Mountain, Nevada where the disposal facility would be located in an arid environment and wastes would be emplaced in an unsaturated geohydrologic regime.

The geohydrologic features of the Yucca Mountain site, and the fact that most of the spent fuel has not been reprocessed and is hot, allow the use of a thermal loading strategy in which heat emissions can deter water from contacting waste packages for an extended period of time. The combination makes Yucca Mountain unique in comparison with the options available in other parts of the world.

Other countries are generally contemplating colder repositories for reprocessed spent fuel in strata that are saturated with moisture, and thus must contemplate longer-term corrosive contact between water and waste packages.

All countries, including the United States, have evolved toward using more robust engineered barrier systems to compensate for the uncertainties in predicting the performance of natural barriers.

For example, in response to a mandate from the national government in the 1970s, the Swedish commercial nuclear waste program developed an engineered barrier concept involving emplacement of spent nuclear fuel in a copper matrix contained within a highly-robust copper

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[10] The United States no longer actively participates in cooperative R&D programs with other countries. However, the U.S. continues to exchange information with other countries through its bilateral agreements and its representation in international agencies.

canister. The viability of this concept to maintain wastes in isolation for one million years in Sweden's geologic formations must be demonstrated, as required by the governmental directive. Sweden has not, however, committed to the use of this engineered barrier concept.

Various nations and international agencies, in addition to the United States, have begun to give consideration to regulations and regulatory standards for high-level waste disposal. Some nations have developed broad risk or dose criteria, and some have supplemented such criteria with additional qualitative technical criteria concerning features of the disposal system. International organizations, such as the Nuclear Energy Agency in Paris, France, provide opportunities for discussion of regulatory criteria and also provide programs of common interest, such as comparison of performance assessment computer codes. There are, however, no international standards for high-level waste disposal accepted by all nations.

Although the performance standards and criteria for the various national regulations are similar, each nation has established specific requirements to meet its needs. Current information concerning the provisions of national and international criteria and objectives for the safety of long-lived radioactive waste disposal is presented in Table 3-1. As will be clear from the ensuing discussion, regulatory requirements are still evolving and the information Table 3-1 is subject to change.

Characteristics of programs in ten nations with major commitments to nuclear power and existing activities concerning disposal of high-level wastes are summarized below. The descriptions address nuclear power utilization, waste disposal, and regulatory programs. Discussions are provided for programs in Belgium, Canada, Finland, France, Germany, Japan, Spain, Sweden, Switzerland, and the United Kingdom.

3.1 BELGIUM

3.1.1 Nuclear Power Utilization

In 1994, Belgium met about 56 percent of its electrical needs through nuclear power (EIA95). The Belgian nuclear power program relies on seven pressurized light water reactors, all of which are operated by Electrabel, a privately-owned company.

From 1966 to 1974, Belgium reprocessed spent nuclear fuel at its Eurochemic facility. The company Belgoprocess was created as a consortium with foreign firms to reactivate the Eurochemic plant, but these efforts failed in the mid-1980s. Belgoprocess is now responsible for decommissioning the plant. Belgium had previously shipped spent nuclear fuel to France for reprocessing, but stores current inventories in reactor pools and in dry storage facilities pending the results of a future parliamentary debate on whether to continue reprocessing. France will

Table 3-1. National and International Criteria and Objectives for the Disposal of Long-Lived Radioactive Wastes (OEC95a)

Organization/ Country/ Reference	Main Objective/ Objective/Criteria	Other Main Features	Criteria for Judging Human Intrusion (HI) Scenarios	Comments
NEA (1984)	For HLW: max. indiv. risk < 10^{-5}/y (all sources)		Indiv. risk/dose - best criterion to judge long-term acceptability	No consensus on ALARA/ optimization
ICRP (Pub. 46, 1985)	For HLW, for individuals (all sources): 1 mSv/y (normal evolution scenarios); 10^{-5}/y (probabilistic scenarios)	Both probability and dose should be taken into account in ALARA	Future human activities should be treated probabilistically	ALARA useful, notably to compare alternatives, but may not be the most important siting factor
IAEA (Safety Series 99, 1989)	Idem ICRP Publication 46		Future human activities are randomly disruptive events that usually are examined probabilistically	Also includes qualitative technical criteria on disposal system features and role of safety analysis and quality assurance
CANADA (Reg. Document R-104, 1987)	For HLW: max. indiv. risk objective: < 10^{-6}/y	Period of time for demonstrating compliance: 10^4y No sudden and dramatic increase for times > 10^4y	Main criteria applicable to all exposure scenarios; no criteria specific to HI scenarios	Additional qualitative, non-prescriptive requirements and guidelines in regulatory documents
FINLAND (Decision of the Council of State, 1991)	For LLW and ILW: max. indiv. dose < 0.1 mSv/y, with max. indiv. dose < 5 mSv/y from accident conditions caused by possible natural events or human actions		Max. indiv. dose < 5 mSv/y from possible human actions	For spent nuclear fuel or HLW, proposed criterion for max. indiv. dose < 0.1 mSv/y
FRANCE (Basic Safety Rule, RFS III.2.f, 1991)	For ILW and HLW: max. indiv. dose < 0.25 mSv/y for normal evolution scenarios; for altered evolution scenarios, risk may be considered (probability of scenario times effect of exposure)	Beyond 10^4 y, dose limit is considered as a "reference" level	Assumptions (French Basic Safety Rule, Appendix 2): Date of HI occurrence > 500 y; Existence of repository and location forgotten; Level of technology same as present day	Technical criteria for siting established in 1987

Table 3-1. National and International Criteria and Objectives for the Disposal of Long-Lived Radioactive Wastes (OEC95a) (Continued)

Organization/ Country/ Reference	Main Objective/ Objective/Criteria	Other Main Features	Criteria for Judging Human Intrusion (HI) Scenarios	Comments
GERMANY (Section 45, para. 1 of Radiation Protection Ordinance, 1989)	For all waste types: max. indiv. dose < 0.3 mSv/y for all reasonable scenarios	Calculation of individual doses limited to 10^4y but isolation potential beyond 10^4y may be assessed		Additional qualitative technical criteria in guidelines and regulatory document
NORDIC COUNTRIES (Basic Criteria Document, 1993)	For all waste types: max. indiv. dose < 0.1 mSv/y (normal scenarios): max. indiv. risk < 10^{-6}/y (disruptive events)	For HLW, additional criterion on "total activity inflow" limiting releases to biosphere, based on inflow of natural alpha radionuclides		Includes other qualitative criteria
SWITZERLAND (Reg. Document R-21, 1993)	For all waste types: max. indiv. dose < 0.1 mSv/y at any time for reasonably probable scenarios; max. indiv. risk <10^{-6}/y for unlikely scenarios	Repository must be designed in such a way that it can at any time be sealed within a few years without the need for institutional control	No criteria for HI scenarios except that for high consequences, probabilities can be taken into account	
UNITED KINGDOM (OECD/NEA Doc. 66-94-041,1995)	For L/ILW: 10^{-6}/y target for indiv. risk from a single facility For HLW: no specific criteria but likely application of principles similar to existing objectives for L/ILW	No time frame for quantitative assessments specified	Main criterion for HI scenarios currently indiv. risk	ALARA to be used to the extent practical and reasonable

soon begin returning to Belgium the high-level vitrified waste created from the reprocessing of Belgian fuel. It is estimated that by the year 2000, Belgium will have produced about 2,500 MTHM of spent nuclear fuel.

In 1985, a vitrification plant, PAMELA, began processing high-level waste from the Eurochemic plant. Vitrified high-level waste will be stored in an intermediate storage facility (recently constructed by the National Agency for Radioactive Waste and Fissile Materials (ONDRAF)) for 50-70 years. Characterization of a potential site for a repository located in a clay formation at the Mol-Dessel site in the northeast corner of the country is progressing.

3.1.2 Disposal Programs and Management Organizations

The Belgian program to establish a radioactive waste repository was initiated in 1974 with the establishment of a government-sponsored research and development initiative. In 1982, the National Agency for Radioactive Waste and Fissile Materials, ONDRAF, was established to implement and manage a multi-year national program addressing the long-term management and disposal of radioactive wastes, including spent nuclear fuel, high-level waste, and other reprocessed waste returned from French facilities. SYNATOM, an agency privatized in 1994, is responsible for uranium procurement, reprocessing spent nuclear fuels, off-site waste management, and disposal of packaged irradiated fuel assemblies. The Nuclear Research Center (CEN), under the Ministry of Economic Affairs, provides technical assistance in basic and applied R&D in nuclear energy and technology.

Belgium's waste disposal program takes a multi-barrier approach, relying significantly upon the low permeability of the Boom Clay formation and the assumption that there are no structural fast paths through the clay. Engineered barriers are anticipated to last no more than a few thousand years, after which the geologic barriers will provide primary containment. For this reason, engineered barriers have been designed to minimize their impact on surrounding geology, and to provide interim public health protection (NWT94).

ONDRAF intends to begin operation of a shallow land-burial facility for low-level waste by the year 2000 and has established an underground laboratory in a clay formation at Mol-Dessel to evaluate the site's suitability as a high-level waste repository. Twenty years of research at Mol-Dessel has led to significant evolution of the design for the planned repository. The clay formation in which the site is situated is the only suitable geological medium that has been identified in Belgium. In 1980, a repository conceptual design was developed for a clay site, and an underground research laboratory at Mol-Dessel (Project HADES) began operation by 1985. In recent years, the repository's design has been altered. The original HADES design was conceived according to the perceived thermal tolerance of the host rock and was intended to allow for retrieval of containers of vitrified waste for a long period of time. The new design does not permit easy retrieval and allows for more homogeneous dispersion of heat. The new design is also believed to be simpler to construct and less damaging to the surrounding clay layer (NWT95).

The underground research laboratory at Mol-Dessel extends to a depth of 224 meters. Research conducted there includes experiments in corrosion properties of containers and engineered barriers, geochemistry and radionuclide migration, backfilling and sealing technology, and near-field effects of heat and radiation on clays. Over the next few years, a preliminary demonstration test for clay disposal (PARCLAY) will be launched at the Mol-Dessel site. PARCLAY will be used to investigate the thermal effects of final disposal on clay and will include the construction of a new 1:1 scale gallery. Based on the outcome of these studies, a larger underground facility might be constructed for a full-scale demonstration project. Assuming that the results of investigations at Mol-Dessel are favorable, repository construction could begin around 2025 and operation around 2030 (OEC95b).

3.1.3 Regulatory Organizations and Their Regulations

Belgium does not currently have specific regulatory requirements or criteria governing the disposal of spent nuclear fuel or high-level waste. In 1994, the Federal Nuclear Inspection Agency (AFCN) was created to oversee inspection and surveillance of Belgium's nuclear facilities under guidance of the Ministry of Employment and Labor and the Ministry of Public Health and the Environment. The King of Belgium has the authority to grant, suspend, reject or withdraw authorization for the construction and operation of nuclear facilities (OEC95c).

3.2 CANADA

3.2.1 Nuclear Power Utilization

In 1994, Canada produced about 19 percent of its electrical needs through nuclear power (22 pressurized heavy-water cooled and moderated "CANDU" reactors (EIA95)). Canadian utilities currently produce a surplus of electric power, and only one new nuclear facility is planned before the year 2005 (OEC95a). Canada's nuclear power is produced by three provincial utilities, Ontario Hydro[11], Hydro Quebec, and New Brunswick Power. As of February 1, 1999 Ontario Hydro had 12 reactors in operation, seven under extended shutdown and one in a laid-up decommissioning mode. The reactors under extended shutdown may be brought back on line in the 2000-2009 timeframe depending on economic conditions, The Hydro Quebec reactor and the New Brunswick Power reactor are both operational (KIN99).

Canada relies on the CANDU reactor design, which uses natural uranium in a once-through fuel cycle. Currently, the program considers only direct disposal of spent nuclear fuel without reprocessing, although the reprocessing option has not been completely ruled out. Until a repository is available, spent nuclear fuel will initially be stored at each reactor site and, later, possibly at a central facility. Estimates indicate that Canada will have produced about 34,000

[11] Ontario Hydro was split into several companies on April 1, 1999 with nuclear power production assigned to Ontario Power Generation Inc.

MTHM of spent nuclear fuel by the year 2000. The country's five existing sites (the Ontario Hydro utility has three sites) have adequate storage facilities for spent nuclear fuel, and there is little urgency to dispose of waste. Current time lines suggest that a disposal facility could be established by about 2025 (OEC95c).

Ontario Hydro fuel has been stored at the Pickering Waste Management Facility since 1995 (KIN99). Dry storage utilizes concrete-filled, steel-shelled vessels which contain 384 fuel bundles each. Currently 600 metric tons of uranium (30,000 fuel bundles) are in storage at Pickering. Ontario Hydro has filed an application to construct the Bruce Waste Management Facility with planned operation in 2002, and a similar facility is planned for Darlington in 2005. New Brunswick Power has operated a dry storage facility at its Pt. Lepreau reactor since 1992 where storage is done in concrete steel-lined vessels each containing 540 fuel bundles. Hydro Quebec uses a concrete vault for spent fuel storage at its Gentilly-2 reactor site.

3.2.2 Disposal Programs and Management Organizations

Responsibility for the management and disposal of Canada's nuclear waste was allocated in 1978 under the Canadian Nuclear Fuel Waste Management Program. Ontario Hydro (owner of 20 out of the country's 22 total nuclear power units) assumed the responsibility for interim storage and transportation of nuclear fuel waste[12]. The Federal corporation, Atomic Energy of Canada Limited (AECL), took responsibility for research and development on deep repository disposal, with support given by Ontario Hydro.

The Canadian disposal concept involves siting a repository at a depth of 500-1000 m in a granitic formation located in the Canadian Shield, which is a large region of geologically old rocks that is tectonically quiescent and centered around the Hudson Bay. It stretches east to Labrador, south to Lake Ontario, and northwest to the Arctic Ocean. The repository would be located at a depth between 500 and 1,000 meters. Spent nuclear fuel canisters would be inserted into floor cavities located in excavated disposal rooms and surrounded with a mix of bentonite and silica sand. A mix of glacial rock clay and crushed granite aggregate, along with engineered barriers, would be used to seal most of the remainder of the vault (OEC93).

[12] One additional reactor is owned by Hydro Quebec and one by New Brunswick Power.

AECL submitted an Environmental Impact Statement (EIS) evaluating the planned disposal program to the Federal Environmental Assessment Review Panel in 1994. AECL estimated that siting, licensing, and construction of a disposal facility will take 25 to 30 years and that the facility could, therefore, be in operation by 2025. The Environmental Assessment Panel reported in early 1998 that the AECL concept for deep geologic disposal did not enjoy broad public support and that a number of steps were required to achieve such support (EAP98). Until revised management and public participation procedures were put in place and broad public support was obtained, no work to search for a specific site should proceed. In the course of seeking public support, the AECL repository concept may emerge as the most acceptable approach but that issue must remain open until other policy issues have been resolved.

In response to the report of the Environmental Assessment Panel, the Canadian government set forth its position in December 1998 (KIN99). In its response the government asserted that it expects producers and owners of nuclear fuel to establish, as a separate legal entity, an organization to manage and coordinate the full range of activities relating to the management of the fuel waste including disposal. The producers and owners of the fuel are also expected to establish a fund to develop and compare waste management options, design and site the preferred approach for long-term management, implement the preferred approach, and decommission the waste management facilities. Ontario Hydro has assumed the lead in investigating how best to establish and separately fund the waste management entity.

In 1986, AECL established the Whiteshell underground research laboratory in undisturbed granitic rock at a depth of 240 meters at Lac du Bonnet in the Province of Manitoba. The AECL has since deepened the facility to 440 meters. The purpose of the laboratory is to conduct large-scale, in-situ experiments in the type of rock envisioned under the Canadian disposal concept, demonstrating some of the components of the disposal concept (the facility is not a candidate repository site). AECL is developing methodologies and analytical techniques to evaluate the geomechanical and geohydrological properties of granitic rock. The underground research laboratory was also recently used to study the possible effects of microbial activity in a disposal system. Other studies conducted at the laboratory include large-block radionuclide migration studies, container corrosion studies, and an alternate post-closure assessment case study.

As the result of a government-wide Federal Program Review begun by Ottawa in 1995, in response to a large national budget deficit, AECL's responsibilities have been pared back considerably. The AECL will now focus on a core mission of developing and vending CANDU reactor technology. The AECL's Whiteshell facilities, including the Underground Research Laboratory, may be privatized. In 1997, the Canadian government was in final negotiations to sell these facilities to Canadian Nuclear Projects Ltd., a consortium led by British Nuclear Fuels, Ltd. and Wardrup, a large Canadian engineering firm. However, the deal fell through and the government is looking for other economic opportunities for this site. In the meantime, AECL continues to operate the Underground Research Laboratory.

3.2.3 Regulatory Organizations and Their Regulations

Regulation of nuclear matters in Canada is handled under the Atomic Energy Control Act. The Atomic Energy Control Board (AECB) is currently the lead regulatory agency in Canada for assessing the long-term performance of the disposal facility. The AECB also develops and issues policy statements and regulatory guidance for the eventual licensing of the high-level waste repository. Other provincial and Federal agencies operate under AECB in the regulation of some activities in the nuclear fuel cycle.

In 1987, the AECB issued a policy statement containing objectives, requirements, and guidelines on nuclear waste disposal and high-level waste repository siting (AECB87). The overall objective expressed in these documents is to ensure that there is only a small probability that radiation doses to the public associated with the repository will exceed a small fraction of natural background radiation doses. Under this policy, predicted radiological risk of death to individuals from a waste repository must not exceed 1×10^{-6} annually. For the purpose of demonstrating compliance with the individual risk requirement, the time period need not exceed 10,000 years (AEC87). However, Canada does not have any nuclear-waste-specific regulation at the present time (KIN99).

Canada is in the process of replacing the Atomic Energy Control Act with the Nuclear Safety and Control Act (NSCA) and the new law is expected to be in place in mid-1999. Under the terms of the NSCA, the AECB will be replaced with an expanded Canadian Nuclear Safety Commission (CNSC). The NSCA will provide the framework under which licenses for site preparation, construction, operation, decommissioning, and abandonment of nuclear waste facilities are obtained. One of the tasks allocated to the CNSC is the preparation of regulatory guidance documents. Any application to build a nuclear waste facility would initiate a requirement to prepare an environmental assessment under the Canadian Environmental Assessment Act (KIN99).

3.3 FINLAND

3.3.1 Nuclear Power Utilization

Currently, Finland has four nuclear power plants in operation. These facilities are owned and operated by two separate utilities. Two 445 MWe PWR units, located at Loviisa on the southern coast of Finland, are run by Imatran Voima Oy (IVO). Two 710 MWe BWR units, located at Olkiluoto on the western coast of Finland, are run by Teollisuuden Voima Oy (TVO). The possibility of a fifth reactor has been under consideration for a number of years in Finland. The Technical Research Centre of Finland (VTT) also operates a small (250 kW) Triga research reactor at its Reactor Laboratory (VTT93).

In the past, the two utilities had different waste management strategies. Until recently, IVO has shipped its spent fuel to Russia with no return of reprocessing wastes to Finland. Spent fuel generated was allowed to cool for a period of four to five years at the IVO reactor site before being shipped. However, this practice is no longer allowed. TVO's strategy involves disposing of its spent fuel in Finnish bedrock. No plans exist for reprocessing the spent fuel from TVO's reactors, although this option remains open (VTT93).

In May 1995, TVO and IVO agreed to cooperate for the final disposal of spent fuel and a new company, Posiva Oy, was established. This company, which is jointly owned by TVO and IVO, took over TVO's program on spent fuel disposal. The total amount of spent fuel to be disposed of in Finland is now estimated to be about 1,700 MTHM of BWR fuel from TVO's reactors at Olkiluoto and 740 MTHM of PWR fuel from IVO's reactors at Loviisa (OEC96).

3.3.2 Disposal Programs and Management Organizations

In 1983, the Finnish government set general targets and schedules for research and development of a nuclear waste management program. Based on these guidelines, TVO conducted preliminary site investigations for a spent fuel repository at five sites: Olkilouto in Eurajoki; Kivetty in Konginkangas (now a part of Aanekoski); Romuvarra in Kuhmo; Syyry in Sievii; and Veitsivaara in Hyrynsalmi. Technical plans for managing and disposing spent fuel were also developed. In addition to these activities, extensive research has been conducted on the phenomena and processes affecting the safety of long term disposal of spent fuel. Several Finnish research institutes, universities, and companies made R&D contributions, including the

Technical Research Centre of Finland, the Geological Survey of Finland, and the Department of Radiochemistry at the University of Helsinki. Finland has also drawn upon the expertise of other countries, particularly the Swedish Nuclear Fuel and Waste Management Company (SKB) (YJT92).

The decision, in principle, made by the Finnish government in 1983 required TVO to propose suitable areas for more detailed site investigations by the end of 1992. As discussed above, Posiva Oy was established in 1995 and began operation in early 1996. Since its creation, Posiva Oy has continued investigating the three candidate sites originally selected in 1992: Olkiluoto, Kivetty, and Romuvaara. In 1994, TVO also conducted a preliminary feasibility study in Kannonkoski, near Aanekoski. Another feasibility study has been initiated for the island of Hastholmen in Loviisa (OEC96).

Finland plans to select the site for the repository in the year 2000 based on updated technical information on encapsulation and facility design, as well as site-specific safety analyses (OEC96). Detailed construction plans for the encapsulation facility and repository must be presented in 2010 and the repository is to go into operation in 2020. Current plans call for sealing the repository in the year 2050 (YJT92).

3.3.3 Regulatory Organizations and Their Regulations

Finland's Ministry of Trade and Industry is responsible for nuclear power in the country. The Finnish Centre of Radiation and Nuclear Safety is responsible for nuclear safety, including nuclear waste management. This latter organization reviews technical and safety-related license applications (VTT93).

The principles of Finland's waste management policy were originally outlined in the Government's policy decision of 1983. The nuclear energy law of Finland includes specific directives concerning nuclear waste management. Each nuclear waste producer is responsible for the safe handling and management of its waste, including final disposal. This responsibility extends to the financing of such operations. No governmental organizations are envisioned for waste management operations. The utilities contribute to future waste management activities through the Nuclear Waste Management Fund established by the Finnish Ministry of Trade and Industry (VTT93).

In developing its radiological and safety criteria for nuclear waste disposal systems, Finland is closely following the international efforts of the International Atomic Energy Agency (IAEA), the International Commission on Radiological Protection (ICRP), and the Nuclear Energy Agency of the Organization for Economic Cooperation and Development. In addition, the Nordic governments published joint recommendations in 1993 in a document entitled *Disposal of High Level Radioactive Waste, Consideration of Some Basic Criteria* (OEC96).

3.4 FRANCE

3.4.1 Nuclear Power Utilization

In 1994, France met approximately 75 percent of its electrical needs through nuclear power, having the highest per capita installed capacity in the world (OEC95c). The French nuclear power program relies on 56 units, the vast majority of which are light water reactors. Older gas cooled reactors are being phased out, while research and development activities and demonstration projects focus on an alternate reactor designs (liquid metal fast breeder reactor) for power production. France plans to continue building nuclear power plants, although some will serve as replacements for old facilities. The overall contribution of nuclear power to the country's electricity production is not expected to exceed 80 percent (GAO94).

The French radioactive waste disposal program is based on a closed fuel cycle involving spent nuclear fuel reprocessing and recovery and re-use of plutonium in breeder and light water reactors. From 1976 through 1990, France reprocessed over 20,000 MTHM of metallic and oxide fuel. France has already begun to solidify high-level waste in glass and, ultimately, intends to dispose of it—as well as alpha-emitting transuranic waste—in deep geological formations. Vitrification plants for France’s two reprocessing plants, UP2 and UP3, entered service in 1990 and 1992. France also provides reprocessing services to foreign customers; in 1993, the international component comprised an estimated one-third of the country's reprocessing business.

3.4.2 Disposal Programs and Management Organizations

The French nuclear waste program has been entrusted to the National Radioactive Waste Management Agency (ANDRA). ANDRA was formed in 1979 as an arm of the French Atomic Energy Commission (CEA), but 1991 legislation made it an independent entity. ANDRA is responsible for all radioactive waste disposal activities and long-term waste management. Other organizations with key roles in the management of the country's high-level waste include Electricite de France (the national electric utility) and COGEMA (operator of spent nuclear fuel reprocessing and high-level waste immobilization and storage facilities).

In 1987, ANDRA identified four geological media for potential high-level waste disposal— clay, salt, granite, and schist—and began investigative work at a site in each medium. An underground research laboratory was to be established at one or more of the candidate sites; if found suitable, and one of these sites was to have been converted to an operating repository to receive transuranic waste by 2000 and high-level waste by 2010. However, in light of the serious public protests at three of the sites under investigation, former Prime Minister Michel Rocard declared a one-year moratorium on siting activities to allow a reassessment of France's overall waste management strategy. The moratorium began in February of 1990, and, in January 1991, the Parliamentary Office for the Assessment of Technological Options published a report that recommended major changes to the program.

On December 30, 1991, the Parliament enacted a new Law on Radioactive Wastes. The 1991 law requires the government to submit a report to Parliament after 15 years that assesses the results of studies on partitioning and transmutation of actinides, the retrievable or permanent storage of high-level waste in deep geologic formations including the use of underground laboratories, and the technologies for waste conditioning and surface storage. (Work on the first and third options is coordinated by CEA while work on the second option is the coordinated by ANDRA.) The report must also propose a bill authorizing an underground waste repository. At this time, no schedule has been set for developing such a repository. Instead, the Parliament will reassess the program based on the results of the 15-year research phase. The law states that, once the underground research laboratory is built, only research-level quantities of waste may be emplaced into it until the Parliament votes to convert the laboratory into a repository. While no direct disposal of spent nuclear fuel is envisioned, the law also requires that the government perform research on direct spent nuclear fuel disposal options. Annual progress reports and the final report on the three technological areas are to be prepared by a National Evaluation Commission composed of eminent scientists (JOR99).

The new law allowed the government to resume site selection efforts for underground research laboratories. A waste “negotiator” or “mediator” was appointed to discuss proposed investigations with local and regional officials. About 30 localities subsequently expressed interest in hosting a laboratory. In 1994, the government's Bureau of Geological and Mineral

Research (BRGM) investigated these regions and eliminated those with adverse geology. In early 1994, the negotiator announced the selection of four new regions as candidates to host a repository: (1) the southern region of the Vienne "departement," in west-central France; (2) the area surrounding Marcoule in the Gard departement; (3) the Meuse departement, bordering south-eastern Belgium; and (4) the northern Haute Marne departement, north of Dijon. Two other localities were selected as secondary choices because their local governments had not voted on their candidacy; the four primary localities all voted in favor of their candidacy.

The Meuse and the Haute Marne sites were subsequently merged and designated as the East site. Since two years of geophysical examination and drilling revealed no prohibitive factors at any of the sites, ANDRA proposed in 1997 to proceed with underground laboratories at each location. Whereas ANDRA had previously considered four types of potential host rock, the selected regions represent only two: clay and granite. The National Evaluation Commission supported selection of the East site and the Gard site which are in clay but noted confinement problems with the granitic host rock at the Vienne site (JOR99). On December 9, 1998 the French government authorized construction of underground laboratories at the East site in clay and at a new site in a granitic formation to be located by ANDRA.

The 1991 law includes additional provisions designed to ease public concern about France's high-level waste management program, including the creation of a policy of openness concerning the country's high-level waste disposal program and a requirement that government grants and jobs for the host municipality accompany the underground research laboratories.

3.4.3 Regulatory Organizations and Their Regulations

Agencies with regulatory responsibilities include the Directorate for the Safety of Nuclear Installations (DSIN) within the Ministry of Industry; the CEA and its subsidiary, the Institute for Nuclear Protection and Safety (IPSN); the BRGM; and SGN (architect and engineering services).

DSIN, France's principal nuclear regulatory authority, issued Fundamental Safety Rule III.2.f. (DSI91) pertinent to high-level and alpha waste disposal, on June 10, 1991. The rule requires that:

- The impact of a deep geologic disposal facility on radiation exposures be as low as reasonably achievable

- Individual dose equivalent due to the facility be limited to 0.25 mSv (25 mrem) per year for likely events
- The stability of geologic barriers be demonstrated for at least 10,000 years
- High-level waste packages prevent the release of radioactive contents during the period when short- and medium-lived radionuclides dominate total radioactivity

In preparation for the underground laboratory phase, the IPSN, within CEA, is independently preparing facilities to evaluate the long-term safety requirements of a repository on behalf of the regulatory authority DSIN.

3.5 GERMANY

3.5.1 Nuclear Power Utilization

In 1994, Germany met about 30 percent of its electrical needs through nuclear power (EIA95). The German nuclear power program relies primarily on pressurized light water reactors (14 units) and boiling water reactors (7 units), although research and development activities and demonstration projects are also evaluating alternate reactor designs (high temperature gas-cooled reactors and liquid metal fast breeder reactors) for power production. It is estimated that by the year 2000, Germany will have generated about 9,000 MTHM of spent nuclear fuel. Germany has historically planned to dispose of spent nuclear fuel in deep geological formations only after reprocessing, as stipulated in a 1976 amendment to Germany's Atomic Energy Law. Plans for a domestic reprocessing facility were abandoned in 1989 and German utilities chose instead to ship their spent nuclear fuel to France and Britain for reprocessing. Resulting vitrified waste is currently returned to Germany and stored in metal casks for planned subsequent disposal. A 1994 amendment to its Atomic Energy Law, however, legalized the *direct* disposal of spent nuclear fuel elements as well (Atomic Energy Law, Article 4, amendment of section 9a(1)) (GER94). Since then, German utilities have been considering both management options.

3.5.2 Disposal Programs and Management Organizations

The German government's Institute for Radiation Protection (BfS) is responsible for the design, construction and operation of waste disposal facilities. Vitrified high-level waste returned from foreign reprocessors was targeted for disposal at the Gorleben facility, a salt dome located in Lower Saxony, if the site proves acceptable. Spent nuclear fuel would also be directly disposed at Gorleben. The newly legalized option of direct disposal has required modification of plans at the facility. Until a repository is in operation, vitrified waste will be stored at Gorleben and the Ahaus facility in Northrhine-Westphalia. Expansions at both the Gorleben and Ahaus storage facilities are currently proposed. A former salt mine at Asse, which served until 1978 as a repository for low-level (125,000 containers) and intermediate-level (1,300 drums) radioactive wastes, now serves as an underground research laboratory for high-level waste disposal.

The Gorleben salt dome ranges in depth from 250 meters to 3000 meters. Construction of an underground research laboratory was initiated in 1986, but all work was stopped for over a year in 1987 because of a construction fatality. As of 1995, two shafts had been sunk to depths of 600 and 620 meters (emplacement at approximately 870 meters is anticipated (LOM95)). Current areas of emphasis include hydrogeological investigation and seismic measurements (OEC95b). Construction of the repository could start at the turn of the century, and the facility is scheduled to remain operational for about 50 years. It is anticipated that the site will receive about 550 MTHM of vitrified waste, 200 metric tons of directly disposed spent nuclear fuel, and about 6,690 containers of low-level and intermediate-level waste per year (LOM95).

Repository design emphasizes the role of the surrounding geology as a barrier. It is anticipated that the salt dome's formations will creep over time in response to radiogenic heating and pressure gradients to encapsulate the waste. The use of steel and iron canisters is intended primarily to contain waste in the short-term. The possibility of direct spent nuclear fuel disposal has required additional research and design development.

Federal agencies have been generally positive about the suitability of Gorleben as a repository site. However, while research appears to generally support the suitability of the Gorleben site, the project has faced increasing opposition from the government of Lower Saxony. As a precautionary measure, in 1995 the Federal Institute for Geosciences and Natural Resources prepared two reports identifying other potential sites for a HLW repository in the event that the Gorleben site is found unsuitable (OEC96).

Subsequently, Federal elections in 1998 dramatically altered the direction of German nuclear program. A coalition agreement signed by the Greens and the Social Democrats on October 20,1998 stated that use of nuclear energy would be phased out (BRE99). With regard to waste management, the agreement noted that a single repository in a deep geologic formation is sufficient for all types of radioactive waste and the time-dependent target for HLW disposal is

2030. The agreement further stated that the suitability of the Gorleben salt dome is questionable and work there should be interrupted while potential sites in other host rocks are examined. Emplacement of radioactive wastes at Morsleben (in former East Germany) is to be terminated and the site decommissioned.

3.5.3 Regulatory Organizations and Their Regulations

Key German agencies include the Federal Ministry for Environment, Protection of Nature and Reactor Safety (BMU), the Federal Ministry for Research and Technology (BMFT), the BfS, the Federal Institute for Geosciences and National Resources, and the host state's ministry for environmental protection. As the primary federal supervisory authority, BMU receives advice from two committees of independent experts, the Reactor Safety Commission (RSK) and the Committee on Radiological Protection (SSK).

In Germany, the institutional and legal framework for the regulation of nuclear facilities is based on the joint participation of Federal and state governments. State governments serve as licensing authorities for all nuclear waste facilities, although the Federal government has the authority to override these decisions. The Federal government retains primary responsibility for waste disposal; the Atomic Energy Law and the Radiation Protection Ordinance (GER94) establish the principles and requirements regarding the safe utilization and application of atomic energy and radioactive materials, including the disposal of radioactive waste. Under the Radiation Protection Ordinance, dosage limits are set at 0.3 mSv (30 mrem) per year for "all reasonable scenarios" (OEC95a).

German regulators had been developing safety regulations that the Gorleben facility would be required to meet through a site-specific safety assessment. It is expected that this safety assessment will be required to demonstrate that potential exposure to radiation from disposed waste will be kept within the range of natural radiation for a period of about 10,000 years and that integrity of the repository system will be maintained over a longer period of time (GAO94).

3.6 JAPAN

3.6.1 Nuclear Power Utilization

In 1994, Japan produced about 31 percent of its electrical needs through nuclear power provided by 49 reactors (EIA95). It is anticipated that this figure will increase to approximately 33 percent by the year 2000 and to about 42 percent by the year 2010 (AEC94). The Japanese nuclear power program currently relies primarily upon light water reactors, although research and development activities and demonstration projects are also evaluating alternate reactor designs (gas cooled reactor, heavy-water moderated reactor, and liquid-metal fast-breeder reactor). By 1994, the country's first prototype fast breeder reactor, Monju, had reached criticality (OEC95b), but a December 1995 coolant leak dealt a setback to the project.

Japan's spent nuclear fuel is currently reprocessed in France and England. However, both countries have exercised their option to return vitrified residue to Japan; the first return delivery from France took place in February 1995. Domestically, the Power Reactor and Nuclear Fuel Development Corporation (PNC) has operated a small reprocessing plant since 1977, where roughly 720 tons of spent nuclear fuel had been reprocessed as of 1993. Furthermore, at the Rokkasho site in Aomori prefecture, a private utility consortium, Japan Nuclear Fuel Services Limited (JNFL), plans to begin operating a large commercial-scale plant shortly after the year 2000 (AEC94). It is estimated that by the year 2000, Japan will have discharged about 20,000 MTHM of spent nuclear fuel from its reactors. Vitrified high-level waste will be stored 30 to 50 years for cooling before disposal in a geologic repository.

3.6.2 Disposal Programs and Management Organizations

As noted above, Japan's current waste management strategy includes spent nuclear fuel reprocessing using domestic and foreign facilities, on-site spent nuclear fuel storage, waste solidification followed by long-term storage, and eventual disposal in a suitable deep geological formation. Japanese nuclear utilities are responsible for storing high-level waste and funding its disposal; JNFL is responsible for low-level waste disposal activities at Rokkasho (OEC95c). Two government-sponsored organizations—PNC[13] and the Japan Atomic Energy Research Institute (JAERI)—are responsible for research and development addressing the fuel cycle, waste

[13] On October 1, 1998 PNC was succeeded by the Japan Nuclear Cycle Development Institute (JNC).

management, and disposal. In 1993, the Steering Committee on High-Level Radioactive Waste (SHP) was created to spearhead planning for disposal of the country's high-level waste.

Radioactive waste is managed in accordance with Japan's Long Term Program for the Development and Utilization of Nuclear Energy (AEC94). In 1994, the Atomic Energy Commission (AEC) issued an update to the long-term disposal plan, placing particular emphasis on the disposal of high-level waste and adding new details to the country's plans and timetables for this effort. The 1994 update established a procedure for implementation of a deep geologic repository and provided guidelines on storage, vitrification, and geologic disposal. The plan also added clarity to the roles of Japan's nuclear-related organizations, which can be summarized as follows:

- Government Research and Development Organizations (PNC and JAERI): PNC is the lead organization implementing the research and development program in various areas of the fuel cycle and geologic disposal, while JAERI performs research in support of the government's safety evaluation of geological disposal, as well as research on advanced waste management technologies.

- Utilities and their Consortia: Utilities are responsible for funding high-level waste disposal programs and for contributing to related research and development work.

- Government Agencies: Government agencies are responsible for oversight and overall coordination of disposal. While it has not yet been decided what entity will implement or license the disposal project, the AEC's 1994 update of the country's long-term disposal plan suggests that this duty will be delegated by the year 2000 and that SHP is responsible for studying the matter (SHP has not been designated the implementing entity).

The 1994 plan also laid out a five-step process to develop a high-level waste repository. The first phase, selection of effective formations, was completed in 1984. Subsequent steps as established by the AEC include: (1) establishment of an implementing organization by the year 2000; (2) selection of candidate disposal sites, subject to government cooperation and community acceptance; (3) demonstration of disposal technology at the candidate site, followed by license application; and (4) establishment of necessary laws and policies for the disposal implementation and safety. The plan called for the repository to be operational by 2030 to 2045. Japanese authorities have determined that high-level waste disposal should be possible in any geologic formation excluding unconsolidated media (e.g., soil and sand). Because of geological heterogeneities in Japan, geological characterization is expected to be difficult, causing uncertainties in predicting the performance of natural barriers. Thus, Japan is assigning a major role to the engineered barrier system, while defining a small number of critical natural characteristics for the site which are expected to be achievable in various geological settings.

In April 1997 the AEC issued *Guidelines on Research and Development Relating to Geological Disposal of High-Level Radioactive Waste in Japan*. The Guidelines describe the level of technical reliability which must be demonstrated for a geologic repository. The Guidelines also identify issues which must be addressed to establish the technical basis for selection of potential disposal sites and for the formulation of safety standards. R&D activities to be conducted after 2000 are also identified (MAS99).

Considerable research and development has been underway in recent years. Most research is conducted by PNC (now JNC) and regular plans are submitted to AEC; the most recent progress report (designated H3) was submitted in 1992, and a subsequent report (tentatively designated H12) is expected before the year 2000 (OEC95b)(MAS99). The H12 report (a draft of which was issued in 1998) is expected to more rigorously address the feasibility of the specified disposal concept than did the H3 Report. The H12 report is also expected to provide input for regulatory and siting processes which will be set in motion after 2000 (MAS99).

PNC operates an underground test facility in both sedimentary and crystalline rock environments. The test facility is located in the Tono Uranium Mine in central Japan. Major experiments in the mine include ground water flow investigation; studies on the effects of excavation on the mechanical and hydraulic behavior of the repository; natural analogue studies and evaluations of the chemical durability of simulated waste glasses; and the corrosion rates of candidate overpack materials. Since 1988, PNC has also conducted major tests in the Kamaishi iron ore mine in northern Honshu. Work at this mine is currently guided by a 5-year research plan, submitted by PNC in 1993 and characterized by work in a deeper gallery. Major investigations at Kamaishi have included detailed fracture mapping, cross-hole hydraulic and geophysical testing, drift excavation-effect studies, in-situ stress measurements, single-fracture flow tests, and observations of seismic activity. In December 1995, PNC signed an agreement with local governments to build an underground research laboratory near the city of Mizunami. The laboratory will be used to research ground water and rock mass characteristics for geologic disposal (OEC96).

Several new facilities were started in recent years, including: (1) the Tokai Vitrification Facility (the first vitrification facility in the country, where operation began in 1995); (2) the Nuclear Fuel Cycle Engineering Facility (NUCEF), where construction was completed in 1995; (3) the Recycling Equipment Testing Facility (RETF), begun in 1995 to develop reprocessing techniques for spent nuclear fuel from fast breeder reactors (OEC95b); and (4) the ENTRY facility at the Tokai Research Lab to conduct full-scale engineering tests and non-radioactive simulations of the performance of natural and engineered barriers.

3.6.3 Regulatory Organizations and Their Regulations

The Atomic Energy Basic Law of 1955 established the AEC and the principles and requirements for the safe utilization and application of atomic energy and radioactive materials, including the disposal of radioactive waste. In addition to the AEC, other key agencies or organizations include the Nuclear Safety Commission (NSC), the Ministry of International Trade and Industry (MITI), and the Science and Technology Agency (STA). Regulatory requirements for the high-level waste repository have not yet been established, nor have formal individual dose limits been issued.

3.7 SPAIN

3.7.1 Nuclear Power Utilization

As of December 31, 1990, Spain had a total of nine light water nuclear power plants in operation. A tenth reactor, the graphite-gas Vandellos plant, was expected to begin decommissioning in 1996. Spent fuel from the light water reactors is stored on site in pools specifically designed for this purpose. Spent fuel from the Vandellos 1 plant was sent to France for reprocessing. Spain's radioactive waste is currently managed by the Empresa Nacional de Residuos Radioactivos, S.A. (The Spanish National Radioactive Waste Company - ENRESA) which was established by Royal Decree 1522 on July 4, 1984. Eighty percent of the company is owned by the Spanish Centre for Energy, Environmental and Technological Research (CIEMAT) and 20 percent is owned by the National Institute for Industry (INI) (SMI91).

Two types of high-level wastes will have to be managed in Spain: spent fuel from light water nuclear power plants and the vitrified wastes from reprocessed fuel from the Vandellos 1 plant. At the end of 1990, 974 MTHM of spent fuel were stored at the sites of Spain's nine nuclear power plants. It is projected that approximately 5,200 MTHM of spent fuel will ultimately be managed in Spain. In addition, 180 m^3 of vitrified wastes from the Vandellos 1 plant will require final disposal (SMI91).

3.7.2 Disposal Programs and Management Organizations

ENRESA manages all radioactive wastes in Spain, including low-level, intermediate level, and high-level wastes. The high-level waste program in Spain considers both intermediate storage and final disposal of these wastes. Intermediate storage, which allows the radioactive elements of the waste to cool down and decay, includes both dry storage in casks and vaults and liquid storage in pools. Waste has been stored on-site, although Spain has contemplated a Temporary Centralized Storage option (SMI91).

The goals and objectives of Spain's program to permanently dispose of high-level waste and spent fuel were outlined in its Third General Radioactive Waste Plan. This strategy, which was defined and initiated in 1987, included three areas of work:

- Search for a site for facility construction—Spain considered granites, salts, and clay media
- Acquisition of technology and training of teams required for characterization of the chosen site and construction of the disposal facility
- Development of the basic design for a deep geological disposal facility (SMI91)

Progress is being made in terms of defining the conceptual design of a geological repository in Spain. The development of a preliminary conceptual design for granite and clay was completed in 1992 and for clay in 1994. A non-site specific conceptual design for salt has also been completed. More recently, a probabilistic performance assessment in a generic granite formation was done in 1997 and a similar study in a generic clay formation was done in 1998 (SAN99).

Spain has also adopted its Third Research and Development Plan which covers the period from 1995 through 1999. This plan, which includes all types of radioactive wastes, has as its main objective the support required for the performance of the high-level waste program. The Plan primarily emphasizes verification of site characterization methodologies and preliminary repository designs, application of numerical models, and acquisition of specific data for the performance of long-term safety assessments (OEC96).

Public pressure caused a cessation of field work in 1996 and, in response, the Spanish Senate created an Inquiry Committee to provide recommendations to the government on how to develop a radioactive waste management policy (SAN99). The Committee noted that, while deep geological disposal is the basis for most international programs, there is growing interest in partitioning and transmutation of long-lived radionuclides. They stated that decisions needed to have a high and broad level of socio-political consensus which could be obtained only through involvement of a wide range of institutions and administrations. Subsequently, the Spanish government provided further guidance on waste management policy in early 1998 which included the following:

- No decision on disposal of high-level waste will be made before 2010
- No further siting activities will be undertaken before 2010 (After that date, siting activities must be voluntary)
- Deep disposal will continue to be studied but other technologies such as partitioning and transmutation should also be analyzed

ENRESA is modifying its strategy to be congruent with the government guidance and the changes will be reflected a new R&D Plan (1999-2003).

3.7.3 Regulatory Organizations and Their Regulations

The Spanish Nuclear Safety Council (Consejo de Seguridad Nuclear) has officially adopted a level of individual risk below 10^{-6} per year for the long term disposal of radioactive wastes. This risk value equates to a dose to individuals in the critical group of less than 0.1 mSv/year (10 mrem/year) (SMI91).

3.8 SWEDEN

3.8.1 Nuclear Power Utilization

Following a 1980 national referendum, the Swedish Parliament decided to phase out nuclear power plants by the year 2010. Although the Swedish government maintains this commitment, the country remains dependent on nuclear fuel for approximately 51 percent of its electrical power needs (as of 1994). Sweden's nuclear power is produced with nine boiling water reactors and three pressurized water reactors (EIA95).

By 2010, Sweden will have produced nearly 8,000 MTHM of spent nuclear fuel. In the 1970s, Swedish utilities had entered into agreements with other countries to reprocess foreign sources of spent nuclear fuel; however, this approach was abandoned following the 1980 referendum and the utilities have since sold their reprocessing contracts or traded high-level waste from reprocessing for other spent nuclear fuel. A joint utility consortium, the Swedish Nuclear Fuel and Waste Management Company (SKB), manages the disposal of radioactive waste. In 1985, SKB began operating a centralized spent nuclear fuel storage facility (CLAB) that will eventually hold all of Sweden's spent nuclear fuel for about 40 years. As of 1994, this facility was filled to about 45 percent capacity (SKB94). The facility is situated in an underground granite cavern at a depth of 30 meters, near an existing nuclear power plant (Oskarshamn). In 1998 the Swedish government authorized expansion of CLAB and the work is expected to be completed in 2004.

3.8.2 Disposal Programs and Management Organizations

Nuclear waste management activities in Sweden are guided by the Act Concerning Nuclear Activities and the Act Concerning the Management of Natural Resources. Every three years, SKB is required to provide Swedish regulators with a research and development plan for activities related to the management and disposal of the country's radioactive waste. The 1992 plan was approved contingent upon additional details regarding deposition and canister design (SKB94).

As outlined in the 1993 plan, Sweden's reference disposal concept for spent nuclear fuel is to encapsulate it in high-integrity copper canisters and emplace the canisters in a repository built in crystalline rock at a depth of about 500 meters, backfilling the deposition holes with highly-compacted bentonite and the tunnels and shafts with a mixture of sand and bentonite. SKB is evaluating alternative concepts such as deep boreholes and tunnel emplacement, as well as alternative canister designs. Canisters are expected to consist of a steel insert (for mechanical protection) inside of a copper sleeve (for corrosion protection).

SKB’s 1995 R&D Programme (SKB95) set forth the following schedule for establishing a deep geologic repository:

- SKB is currently conducting feasibility studies, planned at a total of five to ten municipalities
- Feasibility studies are expected to be completed by 1997, after which time two municipalities, and locations within both, will be selected for site investigation
- One site will be selected around 2001, and deposition of encapsulated fuel is planned for 2008, when a small portion (approximately 800 tons) of Sweden's nuclear fuel will be deposited

Feasibility studies were completed in Storumann in May, 1995, but a local referendum rejected further research there. A feasibility study at a second municipality, Malaa, was completed in March of 1996. The municipality of Malaa is conducting an independent review of the feasibility study involving local stakeholders and independent experts, and the decision on whether to organize a local referendum on further research will be based on the results of this review (SKB96). Other sites where feasibility studies are underway or being considered include four of the five municipalities with existing nuclear facilities (Varberg, Oskarshamn, Nykoping, and Osthammer). The fifth site with an existing nuclear facility, Kavlinge, is currently not considered a candidate.

However, site selection has not progressed as rapidly as envisioned in the 1995 R&D Programme. The 1998 RD&D Programme calls for feasibility studies at five sites to be completed and two sites to be selected by SKB for site investigations by 2001 (HED99).

The OECD/NEA conducted an international research project in an underground research laboratory at Sweden's Stripa mine from 1980 to 1991 (OEC95b). SKB has recently completed construction of a second laboratory under the island of Äspö, 2 km north of Oskarshamn, at a depth of 450 meters. The Äspö site will be used to test methods of site selection and characterization, and to research disposal technologies for later use in Sweden's deep geologic repository.

3.8.3 Regulatory Organizations and Their Regulations

Key government entities with direct responsibilities in waste management include the Swedish Nuclear Power Inspectorate (SKI), the National Institute for Radiation Protection (SSI), and the Swedish Consultative Committee for Nuclear Waste Management (KASAM). All operate under the supervision of the Ministry of the Environment and Natural Resources. The National Board for Spent Nuclear Fuel (SKN), a former public entity with regulatory responsibilities, was absorbed into SKI in the early 1990s.

As of 1995, safety requirements for management and disposal of high-level waste were in development. These requirements are the responsibility of SSI, in cooperation with SKI. Both SSI and SKI favor a total systems approach, without specifying detailed sub-system quantitative criteria in early phases of repository development. Proposed guidelines for the deep repository would require that:

- Radiation doses to individuals be limited to 0.1 mSv/yr for a reasonably predictable period of time (one million years), after which radionuclide fluxes are to be limited to a level corresponding to naturally occurring fluxes of radionuclides

- A passive multi-barrier approach be used

- Future safety of the facility requires no further controls after the facility is sealed

- The repository be designed to not restrict future attempts to change the repository or retrieve the waste (SKB95)

Established general principles for the management of nuclear waste state that:

- Radiation protection take into consideration issues of biodiversity and natural resource use in addition to human health

- Radiation protection be independent of whether doses arise today or in the future, or whether they originate within or outside the country

- The disposal of nuclear waste pose a risk no greater than that of other portions of the nuclear fuel cycle

- All activities must be justified, protection must be optimized, and the individual must be protected by dose limits (SKB95)

3.9 SWITZERLAND

3.9.1 <u>Nuclear Power Utilization</u>

In 1994, Switzerland's five nuclear power plants supplied about 37 percent of the country's electrical power needs (EIA95). The Swiss nuclear power program relies on a mix of pressurized and boiling light water reactors (three PWRs and two BWRs). Although there is currently a moratorium on construction of new nuclear plants, capacity increases at existing plants have kept supply high, and a 10 percent increase by the year 2000 is planned (OEC95c).

The Swiss estimate that, by the year 2000, they will have produced about 1,800 MTHM of spent nuclear fuel. Switzerland currently ships its spent nuclear fuel to France and Britain for reprocessing but maintains the options of spent nuclear fuel management both with and without reprocessing in the future.

3.9.2 Disposal Programs and Management Organizations

The responsibility for establishing radioactive waste disposal facilities in Switzerland lies with the National Cooperative for the Storage of Radioactive Waste (NAGRA), a joint government and utility cooperative agency. NAGRA was established in 1972 to manage the disposal of radioactive wastes, including spent nuclear fuel, high-level waste and other reprocessed waste returned from the French and British reprocessing facilities. Waste conditioning and interim storage of reprocessed waste, high-level waste and spent nuclear fuel is the responsibility of ZWILAG, a cooperative comprised of nuclear utility operators.

Overall nuclear policy is governed by the Swiss Atomic Law, to which two major changes were proposed in 1994. These proposed revisions were subsequently dropped by the parliament in favor of drafting an entirely new national nuclear energy law. A draft of this law is in development (OEC96). The overall goal of the Swiss program is to establish the viability of a repository in Switzerland by the year 2000, although commissioning of a repository will not occur before 2020 to allow a 40-year spent nuclear fuel/high-level waste cooling period. Participation in any international repository projects that may develop is also under consideration.

The Swiss have historically considered two rock types, crystalline rock and sedimentary rock, as potential host media for a high-level waste repository. In 1984, NAGRA launched studies in crystalline rock by drilling seven deep boreholes into the crystalline basement of northern Switzerland and, subsequently, conducted geological and safety assessment studies. In 1994, NAGRA released a synthesis of this research (Kristallin I), expressing optimism about the use of crystalline rock as a host rock; specifically, NAGRA is considering crystalline rock formations in northern Switzerland as viable sites for a repository and is planning additional field work there (OEC95b). In support of crystalline rock studies, a new three-year Phase IV study was launched at the Grimsel Rock Laboratory in 1994. The Swiss have also considered two sedimentary rock types, Opalinus clay and freshwater molasse, and have conducted field research on both formations. In January 1994, the Safety Inspectorate, NAGRA, and representatives of the relevant government agencies identified Opalinus clay as the preferred sedimentary host rock option (OEC95b). A site in Benten, just north of Zurich, has been identified for seismic survey and the construction of an 800-meter borehole to further examine the feasibility of a repository in clay.

By the year 2000, NAGRA must submit a program—the Siting Feasibility Project—for government approval that demonstrates the feasibility of siting a repository in one or more of the crystalline or sedimentary media under consideration.

3.9.3 Regulatory Organizations and Their Regulations

Key organizations or agencies with direct regulatory responsibilities in waste management include: the Nuclear Safety Division (HSK) of the Federal Energy Office (BEW) within the Federal Department of Transport, Communications, and Energy (EVED); the Federal Commission for the Safety of Nuclear Installations (KSA); the Federal Department of Interior (EDI); and the Institute for Reactor Research (EIR). An interagency working group (AGNEB) was also established to coordinate activities in support of government decisions on the licensing of nuclear waste facilities.

In November 1993, HSK released the current guidelines for management of nuclear waste in the country, entitled Radiation Protection for the Disposal of Nuclear Waste (HSK93). Dosage is limited to 0.10 mSv (10 mrem) per year for reasonably probable scenarios, and annual risk is limited to 10^{-6} for unlikely scenarios. Candidate repositories must produce a system capable of meeting these requirements in order for their application to be considered (GAO94); furthermore, all repositories must be designed to be sealed at any time within a few years, after which it must be possible to dispense with institutional controls.

3.10 UNITED KINGDOM

3.10.1 Nuclear Power Utilization

In 1994, the United Kingdom (UK) met about 26 percent of its electrical needs through nuclear power (EIA95). During the 1960s and 1970s, the UK depended primarily on a series of Magnox (magnesium-clad, uranium metal-fueled) reactors (20 units in operation as of 1995), but began to use advanced gas-cooled reactors (AGRs) during the 1970s and 1980s (14 units in operation as of 1995). One pressurized water reactor (PWR) was commissioned in 1995. Use of a fast reactor was explored as well, but a prototype facility in Dounreay was closed in 1994.

British Nuclear Fuels, plc. (BNFL), a government-owned corporation, reprocesses spent nuclear fuel at its Sellafield facility on behalf of both domestic and foreign utilities. Spent metallic fuel from the country's Magnox reactors is reprocessed at the Sellafield facility at a rate of approximately 400 cubic meters annually (NIR94). In March 1994, BNFL began operating the Thermal Oxide Reprocessing Plant (THORP) at Sellafield to reprocess spent nuclear fuel produced by the country's AGR and PWR reactors and by international customers. THORP is the country's first commercial-scale reprocessing plant for oxide fuels.

In 1994, the Board of Trade and the Secretary of State for the Environment placed portions of the British nuclear program under review. In May 1995, at the conclusion of the review, it was announced that the country's comparatively modern facilities (7 AGR stations and the Sizewell PWR) and all future facilities were to be privatized (nuclear power had been excluded from the 1990 privatization of the electric utility industry). Under privatization, all AGR and PWR stations have been grouped under a new company called British Energy plc. Magnox stations have been transferred to a new company called Magnox Electric plc (Magco), a government-owned company responsible for operation of and liabilities resulting from these stations. It is expected that Magco will ultimately become a subsidiary of BNFL.

Since 1952, over 30,000 MTHM of metal fuel from the Magnox reactors have been reprocessed in the UK. It is estimated that by the year 2000, Britain will have about 4,000 cubic meters of high-level waste destined for storage or disposal due to the reprocessing of some 60,000 metric tons of spent nuclear fuel. High-level waste is currently stored in an air-cooled facility at Sellafield.

3.10.2 Disposal Programs and Management Organizations

The responsibility for managing the storage and disposal of radioactive waste lies with its producers. BNFL has the lead responsibility for management of high-level waste from reprocessing. In 1990, BNFL began operating a vitrification plant at Sellafield. In 1982, the government established the Nuclear Industry Radioactive Waste Executive (NIREX) to develop and operate intermediate- and low-level radioactive waste disposal facilities. NIREX was originally established as a partnership consisting of private firms and governmental agencies. In 1985, NIREX was restructured as an independent legal entity, UK NIREX Ltd.

Historically, the UK's radioactive waste disposal strategy has postponed the development of a high-level waste disposal facility, considering deep disposal of low- and intermediate-level wastes a higher priority. NIREX had been researching a potential disposal site near Sellafield and plans suggested that a repository for low- and intermediate-level wastes could be operational there by the year 2010. A recent governmental review, however, has comprehensively rejected a proposed environmental impact study by NIREX that was necessary to proceed with construction of an underground research laboratory at Sellafield. This rejection has caused NIREX to refocus its program onto more generic issues while continuing to condition and package intermediate-level wastes for eventual disposal (HOL99).

Eventual deep disposal is planned for high-level waste. Current plans call for continued reprocessing of spent nuclear fuel, solidification of high-level waste, and surface storage for about 50 years. Under this schedule, the need for a high-level waste repository is not expected before the year 2040. Vitrified high-level waste would then be disposed in deep geologic media. The UK Department of Environment, Transport and the Regions instituted, in 1997, a two-year review of options for management and eventual disposal of spent fuel. The study, which is nearing completion, is designed to formulate a program for development of a deep repository for HLW and to define the key elements of the required R&D work.

The UK has also adopted a policy of monitoring the results of research activities being conducted by other countries. Depending on the outcome of research being conducted abroad, Britain would then develop a high-level waste disposal and repository strategy using concepts that best fit British needs.

3.10.3 Regulatory Organizations and Their Regulations

The Atomic Energy Act of 1946 establishes the authority and responsibility to control and regulate the development of nuclear power in Britain. The Act has been amended several times to establish new requirements, including those addressing the management and disposal of radioactive waste.

The regulatory functions are performed by the Nuclear Installations Inspectorate, which is part of the Health and Safety Executive; the Radiochemical Inspectorate of the Department of the Environment; the Ministry of Agriculture, Fisheries, and Food; the UK Atomic Energy Authority; and the Secretaries of State of Scotland and Wales. The government also takes advice from several independent experts and advisory committees, including the Radioactive Waste Management Advisory Committee and the National Radiological Review Board.

Exposure limits are based on recommendations of the National Radiological Protection Board. While no current limits pertaining to exposure from spent nuclear fuel and high-level waste have been set, indications are that they will be similar to those set for low- and intermediate-level wastes (10^{-6} per year for individual risk from a single facility (OEC95a)). The British waste management philosophy favors the use of broad safety goals over prescriptive regulatory approaches, placing the burden of compliance upon the operator.

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