United States General Accounting Office

GAO

Report to the Honorable
Richard H. Bryan, U.S. Senate

August 1994

NUCLEAR WASTE

Foreign Countries' Approaches to High-Level Waste Storage and Disposal

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GAO/RCED-94-172

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United States General Accounting Office
Washington, D.C. 20548

Resources, Community, and Economic Development Division

B-256826

August 4, 1994

The Honorable Richard H. Bryan
United States Senate

Dear Senator Bryan:

Permanent disposal of highly radioactive waste presents an extremely difficult challenge to countries around the world because the waste will remain dangerous for thousands of years. Long considered the "Achilles' heel" of nuclear power, waste disposal is one of the most controversial aspects of nuclear power production. The United States faces a particularly serious challenge because it has, by far, the largest civilian nuclear power program in the world. The 1982 Nuclear Waste Policy Act required the Department of Energy (DOE) to develop an underground repository for highly radioactive waste. In 1987, the Congress narrowed repository investigations to a site at Yucca Mountain, Nevada. Originally, the Congress expected that a repository might be ready to accept waste by 1998; now, however, DOE's official target opening date is 2010, and that date is optimistic.

Concerned about the Yucca Mountain project, you asked us to (1) compare and contrast the approaches taken by major nuclear countries for managing civilian high-level waste with the approach taken by the United States and (2) identify lessons that can be learned from these countries' approaches. In response to your request, we visited Canada, France, Germany, Japan, Sweden, Switzerland, and the United Kingdom. In each country, we interviewed cognizant waste management officials, such as representatives of the central government, waste management agency, regulatory agency, affected local governments, nuclear industry, and environmental groups. We supplemented our interviews with documentation when available, but we did not audit each country's waste management program to verify the accuracy and completeness of the information we received. Appendix I briefly compares elements of the nuclear waste programs in the countries we visited with elements of the U.S. program, and appendixes II through VIII discuss each country's waste program. Appendix IX contains further information about our objectives, scope, and methodology.

Results in Brief

Some features of other countries' approaches to nuclear waste disposal may offer insights for the United States. However, a myriad of social, economic, political, geographic, and other factors have influenced each country's waste program and must be considered when determining whether these features warrant further exploration and possible adaptation to the U.S. program. Governments around the world support the use of geologic repositories as the best method for disposing of highly radioactive waste, but no country has yet built an operational facility. All of the countries we visited have encountered difficulties with their waste management programs, and most do not plan to have a repository until 2020 or later. Site selection has been a particularly difficult and contentious part of repository development. Germany is the only country we visited that has a potential repository site, but it also faces substantial opposition to its program and may explore alternatives. Several other countries redirected their waste disposal programs after encountering significant opposition to the selection of potential research or repository sites.

Differences exist between the U.S. and foreign approaches to repository development. For example, all of the countries we visited have addressed the issue of temporary waste storage, thereby relieving pressure to quickly construct a repository. In the United States, an ongoing debate over the federal government's and nuclear utilities' responsibilities for waste storage has seriously affected the repository program. Also, other governments, unlike the U.S. government, often involve the nuclear utilities in their repository development programs and generally allow waste managers a relatively high degree of flexibility in developing their technical and engineering repository concepts. Finally, several countries are exploring the use of long-lived engineered barriers (fabricated components, such as waste containers) for containing radiation in the repositories they are designing. DOE, in contrast, plans to rely heavily on the geology at Yucca Mountain to contain radiation and has limited its research on engineered barriers.

Background

Nuclear power generation creates significant amounts of radioactive waste. Highly radioactive waste, which is a small portion of the total waste produced, contains most of the radioactivity. One type of highly radioactive waste is used, or spent, fuel, which is taken from nuclear reactors after it can no longer efficiently sustain a nuclear chain reaction. Some of the seven countries we visited reprocess spent fuel to recover reusable uranium and plutonium and then solidify the remaining highly radioactive waste into glass logs. Since the public must be protected from both spent fuel and the high-level waste generated from reprocessing, all seven countries are temporarily storing these wastes until permanent disposal options have been explored and a selected option has been developed.

Progress on nuclear waste disposal is widely considered a prerequisite for any future growth of nuclear power. Some governments even stipulated that a feasible waste management system be demonstrated before the use of nuclear power could continue or expand. In the United States, the Nuclear Waste Policy Act of 1982 charged DOE with developing an underground repository for the safe, permanent disposal (meaning no foreseeable intent to recover) of highly radioactive waste. In 1986, the President selected three sites—Yucca Mountain, Nevada; Hanford, Washington; and Deaf Smith County, Texas—for detailed study from among nine sites that DOE had been evaluating. Then, in 1987, the Congress narrowed investigations for a repository to the site at Yucca Mountain. The Congress also authorized DOE to construct a facility, called a monitored retrievable storage facility, for storing a limited quantity of waste until the waste can be disposed of in the repository. However, construction of a storage facility cannot begin until the Nuclear Regulatory Commission has authorized DOE to construct a repository.

Opposition to Geologic Disposal Affects All Countries' Programs

Opposition from various groups has profoundly affected the waste programs in the United States and in all of the countries we visited. National governments generally believe that deep geologic disposal offers the best option for isolating highly radioactive waste. While none of the countries we visited has yet constructed a repository for highly radioactive waste, all but the United Kingdom are actively pursuing this goal. Gaining public support for a potential repository site has, however, proven to be difficult and contentious. Potentially affected populations have opposed the siting of a repository near them, and gaining public acceptance is expected to remain one of the most difficult tasks facing waste managers.

In response to substantial opposition, some countries have redirected their waste programs. Several countries had planned to begin their repository programs by studying specific sites but met with opposition to their efforts at these sites. As a result, waste managers redirected their programs toward developing generic concepts that they believe could later be adapted to the conditions found at specific sites. For example, by first developing a generic repository concept, Sweden, Switzerland, and Canada hope to demonstrate to technical experts, political leaders, and the public that a repository could be located at any one of many sites. In some cases, countries are willing to delay their repository's development schedule in order to gain additional public support. Japanese officials, for example, explained that they would spend 10 to 15 years, if necessary, working to gain public support before moving ahead with the licensing process for a nuclear facility. Similarly, following demonstrations of public concern over preliminary site investigations in France, the Parliament slowed and redirected the program by ordering a 15-year period of waste management research.

Opponents of repository efforts include individuals, groups, and governmental bodies, many of whom are also opposed to nuclear power production. Some opponents live near potential research or repository sites and are concerned that the site may present excessive hazards. Such opposition may pose a particular challenge for countries that are smaller yet more densely populated than the United States. For example, France, which is roughly twice the size of Colorado, has a population density of 259 people per square mile, compared with a population density of 70 people per square mile in the United States; hence, finding an isolated repository site may be more difficult in France than in the United States. Other opponents believe that nuclear power must be stopped before a discussion of waste management alternatives can begin. For many, preventing the disposal of highly radioactive waste is an important part of an overall strategy for stopping nuclear power. These opponents believe that mounting volumes of waste—with no place for disposal—will add force to their argument for shutting down all nuclear power plants. Finally, prominent environmental groups in several countries told us that they are concerned that geologic repositories may not safely isolate waste over the time required. These groups generally advocate long-term, aboveground storage as the "least-worst" option for holding waste while disposal methods, including the use of repositories, are explored further.

Germany is the only country we visited that, like the United States, is investigating a potential repository site and is encountering opposition to its efforts. Germany, however, may redirect its current program. In Germany, the affected state government welcomed the repository research effort when it was proposed in the 1970s. Subsequently, however, the political makeup of the state government changed, and the current government opposes nuclear power. The state is responsible for deciding whether to license the repository, and if the current government remains in power, the state may deny the license or prolong the licensing process indefinitely. Germany's federal government has the authority to overrule the state's licensing decision if it determines that the state's objections are political rather than technical. A recent report indicates that, partly because of opposition, Germany may be reconsidering the current project in favor of long-term interim storage and the exploration of additional potential repository sites.

The situation in the United States is somewhat similar to that in Germany. During the 1970s, the state of Nevada encouraged the federal government to consider DOE's Nevada Test Site (which encompasses part of Yucca Mountain) for the "storage and processing" of nuclear material under certain conditions and the exploration of potential uses of solar energy. In more recent years, however, Nevada has opposed the selection of Yucca Mountain as a potential repository site. After the President recommends a site for a repository, the Nuclear Waste Policy Act authorizes the state to submit a notice of disapproval. The Congress may override such a notice of disapproval by passing a resolution that becomes law.

Other Countries Have Addressed Interim Storage Needs

The countries we visited have decided, for the foreseeable future, how they will store their waste until disposal. In contrast, interim waste storage remains a pressing issue in the United States. In most of the other countries, the waste producers—the nuclear utilities—are responsible for storing the waste until a disposal facility is available. Interim storage methods vary, but all serve to contain waste and free waste managers to address waste disposal. For example, France and the United Kingdom routinely ship spent fuel from their nuclear reactors to their reprocessing plants. During reprocessing, uranium and plutonium are recovered for reuse, and the highly radioactive waste is solidified into glass logs, which are then easily stored at the reprocessing facilities.

In contrast, Sweden and Canada do not reprocess their spent fuel and, therefore, plan to store the spent fuel until a repository is available. The waste management company formed by the Swedish nuclear utilities has constructed a storage facility near an existing nuclear power plant to hold all of the spent fuel generated by the country's 12 nuclear plants until a repository is built. Utilities in Canada plan to store all of their spent fuel at the country's five reactor sites until a repository has been developed. Regardless of the storage method used, officials in all of the countries we visited indicated that they were generally satisfied with their country's interim storage arrangements.

In the United States, waste storage remains a pressing issue with serious ramifications for the repository program. Inability to resolve this issue is largely due to the debate over the roles and responsibilities of the nuclear utilities and the federal government with respect to interim storage. The 1982 act authorizes DOE to enter into disposal contracts with waste producers; these contracts must provide that (1) following commencement of operation of a repository, the Secretary of Energy must take title to utilities' high-level waste or spent nuclear fuel as expeditiously as practicable upon request of the generator or owner and (2) in return for the payment of fees, the Secretary, beginning not later than January 31, 1998, will dispose of these wastes.[1] Some have interpreted these provisions to mean that DOE is obligated to begin accepting spent fuel from the nuclear utilities in 1998. DOE has made a preliminary determination that it does not have a clear legal obligation under the act to accept waste in the absence of an operational repository or other facility. According to DOE, however, the Department may have created such an expectation through the implementation of its waste disposal contracts with nuclear utilities, some of which are reaching the limits of their existing storage capacities. However, DOE will have neither a repository nor a temporary storage facility available by 1998.[2]

Waste storage in the United States is further complicated by the fact that highly radioactive waste is stored in more than 30 states—at over 70 nuclear plant sites, other nuclear facilities, and three federally owned sites. Although virtually all utilities should be able to store their spent fuel through their plants' licensed lives and beyond, some will need to expand their existing storage capacity to do so. As we concluded in May 1993, until the issue of temporary waste storage is separated from that of repository development and is fully addressed—as has been done in the countries we visited—DOE's repository program may be unable to proceed in an orderly fashion.[3]

[1]The Standard Contract for Disposal meshes these requirements into one clause. It combines the requirements to (1) take title and (2) dispose under the umbrella term "services." The contract states that disposal "services" shall begin "after commencement of facility operations, not later than January 31, 1998," but does not specify which clause controls if a facility is not in operation by 1998.

[2]DOE issued a Notice of Inquiry on May 25, 1994, to address concerns of affected parties over the continued storage of spent fuel at reactor sites beyond 1998. One of the issues DOE requested comment on was its preliminary view that it does not have a statutory obligation to accept spent nuclear fuel in the absence of an operational repository or a suitable storage facility. In June 1994, a number of utilities, states, and state utility commissions filed two separate suits in federal court asserting that DOE has not complied with the Nuclear Waste Policy Act of 1982, as amended. The parties seek, among other things, a declarative ruling that the act imposes on DOE an unconditional obligation to begin accepting radioactive waste by January 31, 1998, in return for the payment of fees, and that the decision of DOE not to begin accepting waste by that date was not in accord with the law.

[3]Nuclear Waste: Yucca Mountain Project Behind Schedule and Facing Major Scientific Uncertainties (GAO/RCED-93-124, May 21, 1993).

Other Countries Have Less Ambitious Repository Development Schedules

Largely because they have adequate waste storage facilities and are concerned about the public's acceptance of repositories, the countries we visited are generally pursuing less ambitious repository development schedules than the United States. Waste managers in most other countries said they were under no time pressure to develop geologic repositories, mainly because their storage facilities can hold all of their waste for decades. Perhaps more importantly, some waste managers believe that ample time must be set aside to address the complicated technical issues facing waste managers and to gain public acceptance of waste facilities. Other countries' waste managers generally set their own time schedules, and most do not anticipate opening their geologic repositories before 2020—10 to 30 years after the date planned for the United States. The United Kingdom, for example, has chosen to store its waste for at least 50 years before deciding how to proceed with waste disposal. As table 1 shows, Germany is the only country we visited that plans to open a repository before the 2010 opening date planned for the United States; however, according to a recent report, Germany may redirect its program and delay this date.

Table 1: Repository Development Status and Estimated Opening Dates in Selected Countries

Country	Earliest anticipated repository opening date	Status
Germany	2008	Constructing underground test facility
United States	2010	Constructing underground test facility
Sweden	2020	Searching for suitable site
Switzerland	2020 or later	Searching for suitable site
France	2020 or later	Developing repository concept
Canada	2025 or later	Reviewing repository concept
Japan	2030	Searching for suitable site
United Kingdom	After 2040	Delaying decision until 2040

In contrast to the programs in most other nations, the U.S. program is largely driven by DOE's objectives of accepting waste from utilities beginning in 1998 and disposing of the waste in a repository as soon as possible. Originally, DOE set 1998 as its target date for operating a repository, but later it postponed the opening to 2003 and then 2010. As we have previously reported, DOE is unlikely to meet either of its schedule objectives.

DOE's waste disposal approach has repeatedly been criticized as being schedule-driven. Both the waste management board of the National

Academy of Sciences and the Nuclear Waste Technical Review Board, which was established by the Congress to review the scientific and technical validity of DOE's disposal program, have commented that DOE's schedule objectives are unrealistic and are inappropriately driving the program. The Academy's board recommended, among other things, that the Congress "reconsider the rigid, inflexible schedule embodied in the NWPA [Nuclear Waste Policy Act of 1982] and the 1987 amendments."[4] Furthermore, the Office of Technology Assessment suggested that establishing a repository development schedule that is accepted as feasible and reasonable, rather than "quick," may best promote confidence in a disposal program.[5] Nonetheless, the Office cautioned that an open-ended schedule could encourage continued deferral of the expenditures required to develop disposal facilities because the cost of storing waste is relatively low.

Waste Producers in Other Nations Are Assigned Greater Responsibility

Nuclear utilities in the countries we visited are generally much more involved in their country's waste storage and disposal programs than are their counterparts in the United States. In many of the countries we visited, the government has made the waste producers (primarily nuclear utilities) responsible for managing and ultimately disposing of highly radioactive waste. Because the utilities have generated the waste, many governments take the position that the utilities should be responsible for implementing the disposal programs. Ownership of the nuclear utilities varies from public to private to combinations of both. Regardless of ownership, the nuclear utilities generally participate heavily in their nation's waste management program. Governments oversee these programs through regulatory agencies that ultimately license, or advise their government on licensing, nuclear waste facilities.

Some countries have placed the responsibility for safely managing and disposing of nuclear waste directly on the waste producers. In Sweden and Switzerland, the nuclear utilities have formed organizations that are responsible for designing, building, and operating a repository. In Canada, the primary nuclear utility is owned by the provincial (state) government and is heavily involved in the federal government's waste research program.

[4]Rethinking High-Level Radioactive Waste Disposal, a Position Statement of the Board on Radioactive Waste Management, National Research Council (National Academy Press, 1990), and Special Report to Congress and the Secretary of Energy, Nuclear Waste Technical Review Board (Mar. 1993).

[5]Managing Commercial High-Level Radioactive Waste (OTA-O-172, Apr. 1982).

In contrast, the Nuclear Waste Policy Act made the federal government responsible for accepting and disposing of waste from the privately owned nuclear reactors scattered throughout the United States. DOE is responsible for all aspects of investigating, siting, constructing, and operating the federal repository facility. Much like several of their counterparts in other countries, the U.S. nuclear utilities pay fees collected from their ratepayers into a government fund earmarked to finance the government's disposal program. However, the U.S. nuclear utilities have no formal role in DOE's program. The Nuclear Waste Technical Review Board believes the Congress effectively removed the utilities from the activities required to develop and operate a waste disposal facility when it placed the responsibility with the government. The Board believes the approach taken abroad—assigning responsibility for disposing of the waste to those that generate it—may encourage greater managerial and financial accountability. In March 1993, the Board recommended reviewing the organizational approaches taken by other countries for ideas about how to restructure the U.S. program.[6]

Other Nations Have Taken a Less Detailed Regulatory Approach

Regulators in most other nations issue general safety goals to protect the environment from radiation in geologic repositories, but they plan to avoid the level of detail embodied in the U.S. approach to regulating geologic repositories. Safety goals, such as limits on the annual radiation dose for those living near a repository site, are set in broad terms and often cover a period of 10,000 years. Government regulators in most countries told us that they are concerned only that the proposed system meet these overall safety goals and expect to leave the details of the repository's design to the designers.

Most foreign regulators stated that they will act as skeptics at various points in the nuclear facility licensing process, evaluating the safety arguments (sometimes called the "safety case") put forth by the waste managers. In France, for example, the regulatory authorities have issued basic safety rules that describe the objectives of deep geologic disposal, and the waste managers are responsible for developing specific methods to meet these basic guidelines. By avoiding detailed criteria, the regulators expect to give the operators the flexibility to respond to the conditions discovered as they proceed with their repository programs.

[6]Special Report to Congress and the Secretary of Energy, Nuclear Waste Technical Review Board (Mar. 1993).

In the United States, the Environmental Protection Agency is developing disposal standards for the U.S. repository program that are similar to other countries' general safety goals. In addition, the Nuclear Regulatory Commission has set specific performance criteria intended to ensure that the waste disposal system at the repository is safe. For example, the Commission requires that

- waste packages (the waste, its containers, and any materials immediately surrounding the containers) remain "substantially complete" for a period to be determined by the Commission of not less than 300 nor more than 1,000 years after permanent repository closure;
- thereafter, the release rates of radioactive material from the engineered barrier system (the waste packages and the underground facility) not exceed limits specified in the regulation; and
- before the waste is emplaced, groundwater travel time from the repository to the accessible environment be at least 1,000 years or such other travel time as may be approved or specified by the Commission.

Some Countries Are Emphasizing Engineered Barriers

While the countries we visited plan to use a combination of natural (geologic) and engineered barriers to isolate waste, some are considering relatively more emphasis on long-lived engineered barriers. In contrast, while DOE will use a combination of barriers, it plans to rely primarily on the natural geology of the Yucca Mountain site to contain radiation. Because of the available geology, the countries we visited expect to build their repositories below the water table; therefore, groundwater is expected to ultimately penetrate the engineered barriers, corrode the waste canisters, and contact the waste. Some waste managers believe that robust engineered barriers can help delay the groundwater's contacting the waste and transporting radiation to the environment.

Waste managers in some countries expect that emphasizing long-lived engineered barriers will help them establish that the combination of their repository sites and engineered barriers will meet their respective safety goals and may also help them gain public acceptance for the repositories. Sweden, for example, plans to contain waste in copper and steel canisters, which its waste managers believe will remain intact for 1 million years. Although Sweden considers its granite geology to be very stable and suitable for a repository, it is treating its geology as a backup system that will be used to contain the radiation only if the canisters fail. Sweden believes that the public will place greater confidence in the repository if it knows that, from a technical standpoint, all of the repository's safety features have been maximized to prevent the release of radiation.

Japan, Canada, and Switzerland are also exploring the benefits of long-lived engineered barriers. Japan is studying the use of robust engineered barriers partly because of the country's complex geology. Canada has developed a repository concept employing a titanium or copper waste canister that would retain its integrity for at least 500 years. However, Canada is also considering developing a longer-lived canister, in part to help alleviate public concerns about waste disposal. Finally, Switzerland's planned engineered barrier system includes a canister that would provide complete waste containment for 1,000 years and, in the opinion of Swiss researchers, would probably contain waste for at least 100,000 years when used in conjunction with other elements of the engineered barrier system, such as a thick clay packing material.

Germany is the only country we visited that, like DOE, is placing greater reliance on a geologic barrier—a salt dome—than on engineered barriers. Under the current program, the waste will first be placed in steel and cast-iron canisters, then deposited in the repository. Because of its geologic properties, the salt will, over time, surround and encapsulate the waste, thereby isolating it and preventing the release of radiation. For this reason, Germany believes that a robust engineered barrier is unnecessary. Germany's approach is similar to DOE's approach at the Waste Isolation Pilot Plant in New Mexico for disposing of the transuranic-contaminated wastes[7] produced in its nuclear weapons program.

DOE plans to rely heavily on the geology at Yucca Mountain—volcanic rock called tuff—to contain radiation. According to DOE's siting guidelines, "the engineered barriers will be designed to complement the natural barriers, which provide the primary means for waste isolation." As a result, DOE has limited its attention to engineered barriers to compliance with the Nuclear Regulatory Commission's requirements. The Nuclear Waste Technical Review Board, however, has raised questions about DOE's approach and has recommended that engineered barriers be viewed as an integral part of the waste management program and that robust, long-lived waste packages be fully evaluated.

[7]Transuranic waste is discarded material that is contaminated with man-made radioactive elements having atomic numbers greater than uranium. These elements, such as plutonium and americium, decay slowly and remain radioactive for thousands of years.

Observations

Some features of other countries' approaches to nuclear waste disposal may offer insights for the United States. However, a myriad of social, economic, political, geographic, and other factors that have shaped and influenced each country's waste program must be considered when determining whether these features warrant further exploration and possible adaptation to the U.S. program. In the countries we visited, we found pronounced differences from the United States in three key areas: (1) involving waste producers in waste storage and disposal programs; (2) exploring robust engineered barriers; and most importantly, (3) addressing interim storage needs, thereby allowing waste managers to focus on developing realistic repository schedules.

Foreign nuclear utilities generally have more responsibility for waste disposal than their American counterparts. Proponents of this approach believe that placing the burden of developing and implementing waste disposal solutions on the waste producers may encourage better managerial and financial accountability for the program. Further assessments of the management of the U.S. waste disposal program may benefit from exploring greater involvement by utilities.

Other countries have found that the use of robust engineered barriers to contain nuclear waste may offer political as well as technical advantages for repository programs. However, these gains must be balanced against the potential costs of this approach. In other countries, regulators generally allow waste managers to develop the combination of geologic and engineered barriers that the repository designers deem appropriate. In contrast, DOE must meet specific regulatory requirements for both geologic and engineered barriers. Developing engineered barriers that exceed regulatory requirements may cost more in terms of time and expense than is currently envisioned. These considerations, therefore, need to be balanced against potential improvements in safety and public acceptance that could be gained from a more robust engineered barrier design. Under DOE's current approach, however, this evaluation does not appear imminent.

The most significant difference between the approaches of the United States and of the countries we visited is that the other countries appear to have separated the issue of long-term waste disposal from considerations of temporary waste storage. Because these countries have addressed their interim storage needs, waste managers are able to focus less on meeting aggressive schedules for completing their repositories and more on addressing the technical and political issues they believe are necessary for successful long-term waste disposal. A variety of factors have allowed waste managers in other countries to separate the waste storage and disposal issues. For example, countries that have chosen to reprocess their spent fuel are also able to store their waste—at least temporarily—at the reprocessing plants. Furthermore, the nuclear power programs in other countries are significantly smaller than the U.S. program. Most importantly, however, the countries we visited are able, since they have addressed their waste storage needs, to focus their attention on a repository development schedule that is not constrained by pressure to begin removing waste from power plants or other temporary storage facilities. In stark contrast, DOE's repository development schedule appears to be based predominantly on the earliest possible acceptance and disposal of utilities' waste—rather than on the technical requirements of constructing a repository. What we learned from other countries confirms what we have stated earlier: Resolving the interim storage issue would allow the United States to separate this issue from the repository's development—as other countries have done—and to focus on the steps required to complete the repository.

Agency Comments

This report discusses, but does not evaluate, features of the U.S. nuclear waste management program, drawing primarily from our previous reports on the program. Hence, we did not obtain comments on a draft of the report from DOE. We did provide drafts of the relevant country appendixes to waste management officials in the countries we visited and asked them to review the drafts for accuracy and completeness. These officials generally agreed with the information contained in the appendixes and provided detailed suggestions for any changes they considered necessary. We incorporated these changes, as appropriate, in the report.

We performed our work from June 1992 through March 1994 in accordance with generally accepted government auditing standards. As noted, further information about our scope and methodology appears in appendix IX.

As arranged with your office, unless you publicly announce its contents earlier, we plan no further distribution of this report until 30 days after the date of this letter. At that time, we will send copies to the Secretary of Energy and other interested parties. We will make copies available to others on request.

Please contact me at (202) 512-3841 if you or your staff have any questions. Major contributors to this report are listed in appendix X.

Sincerely yours,

Victor S. Rezendes
Director, Energy and Science Issues

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Abbreviations

AECL	Atomic Energy of Canada Limited
ANDRA	National Radioactive Waste Management Agency (France)
CEA	Atomic Energy Commission (France)
DOE	Department of Energy
GAO	General Accounting Office
NAGRA	National Cooperative for Disposal of Radioactive Waste (Switzerland)
NWPA	Nuclear Waste Policy Act of 1982
SKB	Swedish Nuclear Fuel and Waste Management Company
SKI	Swedish Nuclear Power Inspectorate

Comparison of Waste Programs

Country	Number of reactors	Nuclear-generated electricity in 1992 (approx.)	Earliest repository date	Likely geologic medium	Status	Unique features
Canada	22	15%	2025	Granite	Reviewing concept	Province of Ontario has 20 of Canada's 22 reactors
France	56	73%	2020	Granite or clay	Developing concept	Public opposition significantly slowed program
Germany	21	30%	2008	Salt	Constructing test facility	Opposition from state may affect licensing
Japan	43	27%	2030	Not selected	Searching for site	Government plans to increase use of nuclear power
Sweden	12	43%	2020	Crystalline rock	Searching for site	Waste managers plan to use long-lived copper canister
Switzerland	5	40%	2020	Crystalline rock or clay	Searching for site	Government would prefer to use an international repository
United Kingdom	37	23%	2040	Not selected	Delaying decision	Government plans lower-level waste repository
United States	109	22%	2010	Tuff	Constructing test facility	Federal law designated candidate site

Source: Developed by GAO from data provided primarily by foreign officials. Data are as of June 1993.

The Canadian Waste Program

The Canadians have developed a concept for disposing of highly radioactive waste in a geologic repository but have not yet selected a site or named an organization to build the facility.[8] Officials envision that a repository will be built in a granite formation that stretches over much of central and northern Canada. They have developed a generic repository design, supported by data collected at an underground laboratory, that will be tailored to suit the geology once a site is selected. The Canadians have adequate storage facilities at their nuclear reactors for spent fuel. Therefore, they feel no urgency to dispose of the waste and do not plan to open a repository before 2025.

In 1978, after several years of research, the Canadian government launched its program for disposing of spent fuel. The government originally intended to begin its repository program by searching for a potential repository site, but it changed this approach when initial site investigations met considerable opposition. Selection of a site will not begin until the generic concept is reviewed scientifically and publicly by an independent environmental assessment panel, among others. Nuclear power provides about 15 percent of Canada's electricity—and about 50 percent of the electricity generated in the province of Ontario. Because of its reliance on nuclear power, Ontario is very involved with Canada's waste management efforts and is the province most likely to host the repository.

Background

Since the 1960s, Canada has used commercial nuclear power, most of which is produced in the province of Ontario, where 20 of the country's 22 nuclear reactors are located. Other Canadian provinces rely primarily on hydro power generation to meet their electricity demands and see little need for nuclear power. About 27 million people live in Canada's 3.8 million square miles, creating a population density of about 7 people per square mile.[9] Canada is slightly larger than the United States in territory, but the United States is nearly 10 times larger than Canada in population. With about 10 million people, Ontario is the country's most populous province. Canada is a confederation of 10 provinces and 2 territories that functions under a parliamentary system of government.

[8]The information contained in appendixes II through VIII was provided primarily by officials in the countries we visited. We conducted interviews and obtained documentation when available, but we did not audit each country's waste management program to verify the accuracy and completeness of the information we received.

[9]Demographic data for all country appendixes are from the Funk and Wagnalls 1994 World Almanac and Book of Facts. Figures are rounded.

In Ontario, several related political and economic issues are forcing reconsideration of the province's reliance on nuclear power. According to officials, these factors include (1) a 1990 change in Ontario's political leadership, which led to a moratorium on the construction of new nuclear power plants; (2) recent electricity rate increases, spurred partially by higher-than-planned capital costs at Canada's newest nuclear power plant; (3) a need for refurbishment at some existing plants; and (4) a lower demand for electricity, which is creating a surplus of electricity in Ontario. Officials also said that no new orders for nuclear plants exist and none are expected.

Canada, which has one of the world's richest uranium deposits, does not recycle, or reprocess, its spent fuel; rather, its nuclear reactors use natural uranium in a once-through fuel cycle. Given its abundant supply of uranium, Canada has no plans to reprocess its spent fuel in the future. Canada's reactors are located at five sites, three of which are in Ontario. The reactors are expected to generate about 27,000 metric tons of spent fuel by the year 2000.

Nuclear Waste Policy

Strategy

The Canadians have developed a generic concept for disposing of spent fuel in a deep geologic repository but have not yet selected a site or named an organization to build the facility. Because they have adequate facilities for storing spent fuel at the reactor sites, the Canadians are not anxious to dispose of waste quickly and are planning to take the time necessary to address the technical and political factors involved in designing a disposal program.

According to government officials, the Canadian government began studying waste disposal in the 1970s because the utilities had planned only for waste storage. In 1977, an independent commission reviewed various disposal options and concluded that disposal in a deep geologic repository offered the best potential. The commission reported that the Canadian Shield—a large granite rock deposit stretching across much of Canada—was a stable geologic structure that would be well suited for a repository. After the commission issued its report, the Canadian federal government and the Ontario provincial government announced that they would work together to study waste disposal.

Vigorous opposition to initial site investigations forced Canada to revise its plan for waste disposal. The government initially planned to begin its investigation by establishing research sites at several locations throughout Canada. However, members of the public strongly protested against the site investigations. In response to the opposition, the Canadian and the Ontario governments announced in 1981 that they would first develop a generic repository concept and that the research sites involved would not necessarily become a permanent repository. Only after the concept had been assessed, reviewed, and accepted would a potential site be selected.

According to government officials, Canada's generic approach is possible largely because the geology of the Canadian Shield is homogeneous and is similar to the geology at an underground research laboratory where the Canadians have conducted studies since the 1980s. Studies at this laboratory, which is located in the province of Manitoba, will not use any nuclear waste, and officials do not intend the laboratory to become a repository.

Some in Canada favor long-term, aboveground waste storage over deep geologic disposal. For example, nuclear utility officials noted that storing waste aboveground is less expensive than building and operating a repository—which requires a large capital investment. Environmental groups favor long-term storage because they remain unconvinced of a repository's safety. They believe it would be easier to monitor waste aboveground and more difficult to retrieve waste from underground in the event of an emergency. Government officials recognize the cost argument but believe that long-term, aboveground storage presents an inappropriate burden on future generations. They believe that one of the primary objectives of waste disposal is to avoid burdening future generations, and for this reason they expect that the government will ultimately decide to build an underground repository.

Organization

Since Canada is still researching a repository design and has not selected a site, no organization has been named as responsible for building and operating a repository. However, the nuclear utilities will fund the effort from fees on electricity usage, and the government will contribute to the funding because it also has some waste to dispose of. Government officials said that the government may ultimately allow a utility-owned organization to gain full responsibility for the disposal program, but this decision has not yet been made.

While waste management is considered the responsibility of the utilities that create the waste, the federal government has had a major role in waste disposal research thus far. Officials said the Canadian government became involved with waste disposal because the utilities had planned only for waste storage. Researching the disposal concept is the responsibility of Atomic Energy of Canada Limited (AECL), a corporation owned by the federal government that also developed Canada's nuclear reactors. Ontario Hydro, a provincially owned corporation and the nation's primary nuclear utility, is also very involved with waste management research and provides about half of AECL's funding. The remainder of AECL's funding comes from the federal government. The Atomic Energy Control Board, a federal agency, regulates the nuclear industry and will ultimately license the repository. It is responsible for health, safety, and security matters concerning nuclear energy. According to government officials, the federal Ministry of Energy, Mines, and Resources sets Canadian nuclear policy.

Like other projects that have an environmental impact, the repository concept is being reviewed by an independent environmental assessment panel. Appointed by the Minister of the Environment in 1989, the members of this panel will consider the social aspects of repository development as well as technical and scientific issues. The panel estimates that it will provide its report to the government around 1996. On the basis of the report and other considerations, the government will decide whether and how to proceed with siting and developing the repository.

Funding

If the government decides to proceed with the construction of a repository, the nuclear utilities—primarily Ontario Hydro—will fund the effort from fees collected on electricity use. The price of Ontario Hydro's electricity includes the cost of storing spent fuel and the estimated future costs of eventually transporting and disposing of it. The federal government will probably also contribute to the funding, since it owns some spent fuel. The federal government is currently funding half of AECL's research efforts, while the remainder of the funding comes from Ontario Hydro. According to AECL officials, the government has agreed to fund half of AECL's research through 1997, but funding after this time is contingent upon the government's decisions about waste disposal.

To ensure that many views are heard, officials said that Canada directs proponents of programs to provide funding for "intervenors"—generally public interest groups—to allow their participation during the process. For example, AECL has provided funding to help groups prepare for public hearings on the repository concept. Environmental group officials have criticized the level of funding as insufficient.

Waste Management and Disposal Approach

Key Aspects

AECL has developed a generic design for a repository that would be altered to suit a specific site and has been supported by data obtained from its underground research facility. The repository would be 500 to 1,000 meters deep in the granite of the Canadian Shield. Used fuel would be encased in titanium or copper canisters with a minimum life expectancy of 500 years; the canister material has not yet been selected. Clay would be used to surround the canisters, and a mixture of clay and other geological material would fill the repository openings. Officials said that as the reference design is altered to fit the characteristics of a specific site, it may include a canister with a greater life expectancy, in part to help alleviate public concern. Once sealed, the repository is planned to be a passive system; it would not require monitoring, maintenance, or control. Waste retrieval would be possible—although difficult and expensive—for at least several hundred years while the containers remained substantially intact. Because the province of Ontario has most of Canada's nuclear reactors and nuclear waste, the repository is expected to be sited in Ontario.

Schedule

According to Canadian officials, building a repository is not urgent because Canada's spent fuel can easily be stored in existing facilities at the reactor sites. Also, the officials said they would spend the time necessary to gain as much public acceptance as possible. Under the current tentative schedule, the government plans to decide around 1996 whether and how to proceed with developing a repository. A repository would then be available no earlier than 2025.

Regulatory Approach

In reviewing an application for a repository license, Canadian regulators said they would place the burden for proving the repository's safety on the applicant—most likely the waste producers. Regulatory officials said that they would avoid prescriptive regulation dictating how safety should be ensured to give the license applicant flexibility in designing the repository. Also, too little is currently known about long-term geologic processes to issue detailed performance standards, according to Canadian regulators. Before issuing a license, the regulators will review the argument, known as the safety case, put forth by the operator and act as skeptics to ensure that the operator's plan will meet general safety targets. Officials said this approach encourages innovation by the operator instead of simply meeting regulatory standards and avoids undue emphasis on less important features of the repository design.

The regulatory agency has no decision-making role in the current effort to develop a repository concept; however, it did issue general guidance describing what it would ultimately consider important for proving a repository's safety during the licensing process. The regulators set a broad, quantitative radiation risk goal requiring that the risk of death in affected populations not exceed 1 in 1 million per year during the first 10,000 years. After 10,000 years, the risk must be shown qualitatively—the applicant must provide "reasoned arguments"—that the radiation releases will not suddenly change and acute risks will not be encountered by individuals. Regulatory officials believe that requiring quantitative projections of a repository's safety after 10,000 years is difficult and inappropriate, primarily because of uncertainties about environmental conditions, such as the possibility that an Ice Age may profoundly change climatic and geologic conditions.

Interim Storage

Canadian spent fuel is currently being stored primarily in pools at the five reactor sites. Some fuel is moved from pools into dry storage at the reactor sites. The Canadians plan to store waste for several decades in order to allow the heat and radioactivity to dissipate. Officials said that existing storage facilities at nuclear plants can easily be expanded to accommodate additional wet or dry storage if necessary. From its studies and testing, Ontario Hydro has concluded that spent fuel can be stored safely in dry storage containers for at least 100 years. A study of interim storage in the 1970s concluded that on-site storage was preferable to storage at a centralized facility because, among other things, waste transportation would be avoided, and the infrastructure for operating and monitoring was in place at the reactor sites.

The environmental assessment panel has included long-term, aboveground storage in its scope of study and will examine this in its report. Lower costs and easier monitoring and retrieving capabilities are cited as benefits of extended aboveground storage.

The French Waste Program

France relies heavily on nuclear power to satisfy its demand for electricity and will likely build a deep geologic repository to dispose of its highly radioactive waste. Nuclear power, which is nationalized in France, supplies about 73 percent of France's electricity—the highest percentage in the world. Because nuclear power offers the best available option for energy independence, France plans to continue relying heavily on it. France also reprocesses its spent nuclear fuel to recover and recycle uranium and plutonium in an effort to achieve energy self-sufficiency, and it stores high-level wastes at its reprocessing sites. Yet despite its dependence on and continued acceptance of nuclear energy, France has encountered unexpected opposition to siting a repository. The French had planned to investigate four sites in different geologic media and then select one for an underground laboratory; however, strong public opposition to preliminary site investigations caused the Prime Minister to declare a moratorium on site investigations in 1990.

Late in 1991, the French Parliament passed legislation containing three key provisions on nuclear waste disposal. First, for about 15 years, several concurrent research efforts are to be conducted, including an examination of geologic disposal as well as an exploration of waste storage and reduction methods. Second, the French waste management agency was given greater autonomy from the agency responsible for developing the nuclear industry; and third, a policy of openness with the public was required to help alleviate public concerns about high-level waste disposal. Because the research is to continue until around 2007, the French do not anticipate that a repository will be available until 2020 or later.

Background

According to government officials, 54 of France's 56 reactors were built between 1970 and 1990. France's first commercial nuclear reactor began producing electricity in 1956, but France did not become involved with nuclear energy in earnest until the early 1970s—the time of the energy crisis. At that time, France was importing 75 percent of its energy resources. Because it lacks sufficient quantities of domestic oil, natural gas, and coal, French officials said, the country had no alternative but to use nuclear power to gain energy independence. The French expect to build about one new nuclear power plant per year through 2005. After 2005 the pace may quicken when the oldest reactors have to be replaced; however, French officials do not expect nuclear power to supply more than 75 to 80 percent of France's electricity in the future.

Reprocessing spent nuclear fuel to recover and recycle the uranium and plutonium helps the French attain the energy independence they desire. Two reprocessing installations reprocess French spent nuclear fuel. According to French officials, roughly two-thirds of France's reprocessing work is domestic; the remaining third is for foreign customers who are returned high-level waste upon the completion of reprocessing. Reprocessing spent fuel reduces the volume of highly radioactive waste but creates additional amounts of lower-level waste. The French estimate that by the year 2000 they will have accumulated approximately 2,000 cubic meters of high-level waste and 88,000 cubic meters of lower-level reprocessing waste for disposal.

France is nearly 221,000 square miles large—roughly twice the size of Colorado—and has a population of about 57 million, or 259 people per square mile—about 16 times Colorado's population. France is a republic, consisting of 22 administrative regions, which are subdivided into 95 departments. The republic includes an executive branch with a president, prime minister, and cabinet; a legislative branch with a bicameral parliament; and a judicial branch consisting of a constitutional court. The energy industries, including the nuclear energy industry, are owned and controlled by the French government.

Nuclear Waste Policy

Strategy

Though likely to construct a deep geologic repository to dispose of highly radioactive waste, France recently slowed its program in response to strong public opposition. In 1987, the French began initial investigations for an underground laboratory at four candidate sites but met significant opposition at three of the sites. According to French officials, the opposition came not only from local citizens living near the sites but also from other French communities and international environmental groups. Officials speculated that the government may have been overconfident after gaining public acceptance for a low-level waste disposal facility. As a result, the government did not fully address the concerns of the affected public, many of whom believed the facility was being forced on them with no advantages or compensation.

Concerned about this unexpected, vigorous opposition, the Prime Minister intervened in 1990 and imposed a moratorium on investigations for a geologic repository for highly radioactive waste. Ultimately, according to officials, the opposition led the Parliament to enact legislation in 1991 signaling the government's willingness to take additional time to thoroughly investigate waste disposal and to gain acceptance from the French public. Although the legislation requires research into various waste management methods, French officials said the results of this research are not expected to preclude the need for a geologic repository.

Although the central government generally establishes French nuclear policy, the Parliament assumed a more active role in waste management issues when it enacted the 1991 legislation. This legislation had three key provisions, according to French officials. First, several concurrent research efforts are to be conducted until around 2007. Researchers are to examine options for retrievable or nonretrievable disposal in deep geologic formations by constructing underground laboratories. Also, researchers are to explore methods to lower the volumes and radioactivity of highly radioactive waste through separation and transmutation[10] and to study methods for long-term waste storage on the surface. Second, the legislation reorganized the French waste management program, making the waste management agency independent of the Atomic Energy Commission. Finally, the legislation dictated a policy of openness with the public to help alleviate public concerns about high-level waste disposal.

The measures dealing with openness in the legislation require that information be available to potentially affected populations. For example, the newly created National Review Board will report annually to the Parliament on the progress of the research dictated by the legislation, and the report will be made public. According to officials, France also plans to employ a prominent person, probably from the Parliament, to open a dialogue with populations in the areas where a deep geologic repository may be located. After the research required by this legislation has been completed, the Parliament appears to plan to play a central role in final decisions about waste management.

Organization

The French government is responsible for waste management policy, regulations, and control, as well as for authorizing and licensing waste disposal sites. The waste producers—primarily the French national electric utility, Electricité de France—are to perform all necessary operations to produce a waste form suitable for disposal and to pay for

[10]Through separation and transmutation, long-lived radioactive elements are changed into shorter-lived elements.

disposal efforts. Because its energy industries are nationalized, France exercises strong central control over its energy agencies and companies.

The National Radioactive Waste Management Agency (ANDRA) is responsible for designing, siting, constructing, and operating long-term disposal facilities, as well as for undertaking all necessary studies to this end. Created in 1979, ANDRA is a government agency and was separated under the 1991 legislation from its parent organization, the Atomic Energy Commission (CEA), to give ANDRA increased independence and stature within the French government. French officials supported this move and believed it would help alleviate public concerns about the potential conflict of interest between ANDRA and the Commission, which is viewed as a promoter of nuclear energy. Another major organization involved with nuclear wastes is Cogema. Established in 1976 as an industrial firm wholly owned by CEA, Cogema is a government corporation that operates reprocessing and high-level waste storage facilities at Marcoule and La Hague.

Other agencies are involved with regulating nuclear installations. Within the Ministry of Industry and International Trade, the Nuclear Installations Safety Directorate has issued general safety guidance and objectives for the repository. The Institute for Nuclear Protection and Safety, part of the CEA, provides technical support. The Central Service for Protection against Ionizing Radiation, under the Secretary of Health, among other things, monitors radioactivity in the environment and has the right to veto any construction or operating license for nuclear facilities. Licensing nuclear installations, including waste disposal sites, involves all major departments concerned. Licenses are generally signed by the Prime Minister.

Funding

ANDRA is generally financed by waste producers, mainly the utility, CEA, and Cogema. Costs for managing highly radioactive wastes up to the point of disposal are the responsibility of the waste generator. Then, ANDRA charges the costs of developing a geologic disposal system to the prospective generators according to the space they have reserved for disposing of waste. CEA also conducts and funds some waste research efforts.

Waste Management and Disposal Approach

Key Aspects

France has not yet chosen a repository design for its highly radioactive wastes. Although firm specifications and criteria are yet to be established, a complementary multiple-barrier system is generally envisioned for the repository. This system would include a canister containing the waste, a backfill material surrounding the canister and filling the repository tunnels, and the geology, which would serve as the final barrier to the release of radiation. The system's actual design will depend on the chosen geology and site-specific information. ANDRA officials believe that a long-lived waste canister might help gain public acceptance; however such a canister might be more than is technically necessary to demonstrate the repository's safety. Researchers are also considering placing a surrounding wrap, known as an overpack, on the waste canisters to help make them retrievable.

Originally, the French were considering four types of geology—clay, granite, schist, and salt—for siting a repository. Now they are primarily considering granite and clay. As required under the 1991 legislation, ANDRA plans to conduct studies at underground laboratories. The French plan to select two sites with the assistance of a negotiator, who will work with the local populations to try to ensure public support.

Schedule

Before the 1990 moratorium on geological site investigations, France planned to have an underground research laboratory in the 1990s and a repository operating in 2010, assuming favorable results from the laboratory investigations. The moratorium and subsequent legislation requiring 15 years of research into alternatives have substantially slowed the program. ANDRA officials believe that it will be at least 2020 before a French repository is available. They are not in a hurry to develop a repository and want to minimize the French public's concerns. Because France has adequate capacity for storing its wastes, developing a repository is not urgent. However, officials do not want to delay the repository's development too long because costs are likely to mount with time and the officials are reluctant to put off the responsibility for other generations to address.

Regulatory Approach

In June 1991, the French regulators established the Basic Safety Rule defining the objectives to be adopted in the design and construction of a geologic repository. The basic objective is that the repository ensure human and environmental protection in the long and short term. Radiation exposure to individuals must be limited to .25 millisievert[11] per year for extended exposure associated with certain or probable events. This limit must be demonstrated through modeling for the first 10,000 years that the repository is to be in operation. Quantitative predictions of repository releases after 10,000 years are more difficult because the geologic barrier may be less stable; thus, the rule also allows qualitative predictions of releases after that time.

French officials said they avoid prescriptive, detailed regulations dictating how general safety goals should be met. They believe this approach gives the applicant for a license the flexibility to meet the general safety goal and focuses the responsibility on the applicant for designing a safe system. ANDRA is responsible for setting the specifications for the system of barriers—the waste packages themselves and the site-engineered barriers—and for ensuring that the safety standards established by the regulators are correctly observed. Safety regulators have given ANDRA several scenarios that it must address in developing its safety arguments before proceeding with the repository's development.

Interim Storage

Most of France's spent fuel is stored first at reactor sites in pools for about a year and then in facilities located at the reprocessing plants until it is reprocessed. Spent fuel is transported to the reprocessing plants in specially designed casks. Transport is primarily by rail within France and continental Europe; trucks are used for short hauls, and ships transport spent fuel from countries outside the continent, such as Japan. The resultant high-level waste from reprocessing is immobilized in glass and will be stored for 30 years or more in vaults at the reprocessing facilities.

According to government officials, lack of storage is not an issue in France. Volumes of high-level waste are not large and can easily be stored in existing facilities at reprocessing plants until a repository is developed. If necessary, officials said, additional storage facilities could easily be built at the La Hague reprocessing plant and at reactor sites.

[11]A millisievert is a measure of radiation energy absorbed.

The German Waste Program

Germany is testing the suitability of a salt formation near the town of Gorleben as a deep geologic repository for high-level waste. If the site proves satisfactory, Germany plans to begin depositing high-level waste for final disposal in 2008. However, Germany has faced considerable opposition to its nuclear power and waste facilities. When the Gorleben site was selected in the 1970s, the Lower Saxony state government—which will license the repository—welcomed the facility. Since then, however, the state government has changed and is now opposed to nuclear power. Government officials expect that, if still in power at the time of licensing, the current state government will deny the repository's license or prolong the licensing procedure indefinitely. A recent report indicates that, partly because of opposition, Germany may be reconsidering the Gorleben project in favor of long-term storage and the exploration of other potential repository sites.

Under German law, nuclear power plant operators must demonstrate plans for waste management 6 years into the future before nuclear plants are allowed to continue operating. The German utilities have responded by sending their spent fuel abroad for reprocessing. In the future, however, the utilities may choose to store their spent fuel for a period of time before disposing of it in a repository.

Background

During 1992, nuclear power provided about 30 percent of Germany's electricity. The country's 21 nuclear reactors are located at 18 sites and are expected to generate 3,300 cubic meters of high-level waste by the year 2000. According to government officials, Germany's use of nuclear power, begun in the 1950s, is not expected to increase in the near future, mainly because of the utilities' concerns over high costs and public opposition. The officials also said that if nuclear power is to continue in Germany, new plants must be constructed, starting in the late 1990s, to replace the plants that are aging. However, no new plants are currently planned or under construction. Germany has few natural resources except for coal and relies on imports for oil.

The German utilities have contracted with British and French firms for reprocessing services. However, the utilities may choose to store their spent fuel rather than reprocess it in the future. Government officials said that utilities now favor disposing of spent fuel over reprocessing because disposal is currently less expensive. German environmental groups also oppose reprocessing because it creates additional volumes of lower-level waste.

About 80 million people live in Germany's 138,000 square miles, or about 583 people per square mile. Germany is slightly larger than New Mexico in territory and significantly larger in population—New Mexico contains 1.6 million people. Germany is made up of 16 laender, or states, and is a federal republic.

Nuclear Waste Policy

Strategy

The Germans are studying the suitability of a salt formation near the town of Gorleben as a deep geologic waste repository. If the site proves acceptable, they plan to construct a repository and begin accepting waste at the facility in 2008. The Germans have a long history of experience with salt mining and have also conducted various studies of salt in an underground laboratory since the 1960s. Given the nation's experience and the abundance of salt deposits in Germany, the German government decided in the 1970s to move forward with the development of a salt repository, according to officials. Two other repositories—one under construction and one already built—will be used for storing lower levels of waste. Once these facilities are full, all types of nuclear waste will be stored at Gorleben. Officials said that the German government favors moving waste into deep geologic repositories as soon as technically possible because it considers repositories the safest place for waste disposal.

Germany has faced considerable opposition to its nuclear power and waste facilities. According to officials, when the Gorleben site was proposed in the 1970s, the Lower Saxony state government welcomed the facility and the economic benefits it would bring. Since then, however, the Lower Saxony government has changed, and it now opposes nuclear power. Lower Saxony will be responsible for licensing the repository and, if the ruling government remains in power, is expected to deny the license or prolong the licensing procedure indefinitely. A nuclear trade journal recently reported that Germany may abandon the Gorleben project, partly because of opposition. The article suggested that Germany may opt to store its spent fuel while exploring alternative repository sites.

The German government also encountered substantial public demonstrations—involving thousands of protesters, according to government officials—when the Gorleben project began in the late 1970s and early 1980s. Officials said that more recent demonstrations have focused on interim storage facilities and lower-level waste repositories. The public also opposed the construction of a reprocessing facility by German utilities. The utilities ultimately abandoned the unused reprocessing facility largely because of the high costs of meeting Germany's strict safety standards, which were enacted in part to alleviate public concerns. To help gain public acceptance, the government has incorporated public hearings into the licensing process, established a visitors' center at Gorleben, and published information on its activities in the nuclear area.

German nuclear policy is implemented at both the federal and state levels. German law requires nuclear power plant operators to demonstrate plans for waste management (e.g., reprocessing, interim storage) 6 years into the future before nuclear plants are allowed to continue operating.

Organization

Government officials said that Germany's Atomic Energy Act made the federal government responsible for radioactive waste disposal because of the potential long-term danger involved. In fulfilling its responsibility, the federal government founded the Federal Office for Radiation Protection and contracted with a private company to construct and operate the potential repository at Gorleben. This Office is under the jurisdiction of the Federal Ministry for the Environment, Nature Protection, and Reactor Safety. The Federal Ministry for Research and Technology is also involved with research in nuclear waste storage and disposal.

Although the federal government is ultimately responsible for waste disposal, the state governments serve as the licensing authorities for all nuclear waste repositories. For the Gorleben repository, the state of Lower Saxony is the licensing authority and can deny the license on technical grounds. However, the federal government has the authority to overrule a state's licensing decision if it deems such action appropriate. Officials said that the federal government may, for example, direct a state to license a nuclear facility if the state's objections are political rather than technical. According to an official, the federal government recently used this power to force Lower Saxony to proceed with the licensing process of a lower-level waste repository.

German utilities are responsible for the management of spent fuel and waste through reprocessing, treatment, and on-site storage. Officials said that the utilities are owned by a mixture of private interests and state and local governments.

Funding

The nuclear utilities are funding the construction of the facility at Gorleben, but the German federal government has funded some waste disposal research. Nuclear power producers pay current costs by reimbursing the government for its efforts, and they accumulate reserves to cover future waste disposal costs.

Waste Management and Disposal Approach

Key Aspects

The Germans have used their long experience with salt formations to develop a repository concept. Under the current program, the geology at Gorleben—a salt dome—will be the primary barrier against the release of radiation. Over time, the salt will move, thus encapsulating and containing the waste. The planned steel and cast-iron canisters will therefore provide little long-term containment but will merely contain the waste until the salt moves around them. The repository concept accommodates both reprocessed high-level waste and used fuel. The Germans do not plan to recover the waste once it has been disposed of, so they have not incorporated postclosure retrievability into their design.

The Germans said they plan to store highly radioactive waste 30 to 40 years before disposing of it in a repository. According to German government officials, storing the waste allows it to cool and will enable the Germans to maintain a temperature in the repository under 200 degrees Centigrade; temperatures above this level could adversely affect the salt. For example, high temperatures could cause the salt dome to shift and rise excessively, causing dangerous fractures.

Schedule

Site investigations for the test facility at Gorleben began in 1979. Drilling began in the 1980s but was interrupted for 20 months during 1987 and 1988 when a shaft collapsed. German officials said they expect to conduct testing until the late 1990s. If the tests are positive, the Germans said they hope to open Gorleben in 2008 for accepting high-level waste. A recent report, however, indicated that because the German utilities plan to expand their interim storage capacity for spent fuel, a repository would not be required until after 2035.

Regulatory Approach

The Minister for the Environment of Lower Saxony will decide whether to license the Gorleben facility after reviewing the repository plans and conducting public hearings. According to officials, the repository will be allowed to cause a radiation dose of no more than 0.3 millisieverts at the land surface. The German regulators are developing fairly detailed safety requirements that the repository will be required to meet. A regulatory official said these requirements are necessary to help ensure the repository's safety over long time periods.

The repository's safety must be demonstrated by a site-specific safety assessment. After the repository's closure, possible exposure to radiation from disposed waste must be kept within the range of natural radiation dose rates for a period of about 10,000 years. However, the safety assessment must provide assurances that the quality of the entire repository system will be maintained for a longer period.

Interim Storage

Interim storage of spent fuel and waste from reprocessing is the responsibility of the utilities. Spent fuel is currently being stored in pools at 18 reactor sites throughout Germany or in interim dry storage facilities or at reprocessing facilities in France and the United Kingdom. The highly radioactive waste remaining after reprocessing is scheduled to be returned to Germany beginning in 1994. The Germans plan to cool their waste by storing it for 30 to 40 years before disposing of it to help avoid elevating the temperature in the repository and perhaps damaging the salt formation. Spent fuel and reprocessed waste are transported between Germany and the reprocessing facilities by train, truck, and ship.

The German utilities have constructed two interim dry storage facilities (in Gorleben and Ahaus) for spent fuel and reprocessed waste returned from abroad. According to a recent report, the utilities plan to expand their interim storage capacity for spent fuel. Near the Gorleben storage site, the utilities are also building a test facility for preparing, or conditioning, spent fuel for interim storage and final disposal. After conditioning, the spent fuel can be shipped and stored in an interim facility and then disposed of in a repository.

According to German officials, German environmental groups have protested the plans for using interim storage facilities for spent fuel. One environmental group advocates storage at the reactors because it believes this is less dangerous than central storage and reduces the number of nuclear facilities needed. Also, the group believes that once reactor storage capacities are full, the plants will be forced to cease production.

The Japanese Waste Program

The Japanese plan to build a deep geologic repository for high-level waste and are in the second of four stages begun in 1976 and designed to accomplish this goal. During this stage, the Japanese plan to select potential candidate sites for the repository. Next, they plan to build demonstration facilities at one or more sites before entering the final stage of constructing and operating the repository. However, an organization has not yet been named as responsible for the repository's construction and operation. Officials said that because they plan to store their waste for 30 to 50 years to allow it to cool before disposal, they sense no immediate urgency to dispose of it and do not anticipate the need for a repository until 2030 or later.

Nuclear power offers Japan, a country with limited indigenous energy sources, relative energy independence. According to government officials, approximately 80 percent of Japan's energy resources are imported. By recycling, or reprocessing, its used nuclear fuel, Japan is able to reduce its dependence on imported energy sources. Thus, the Japanese view spent fuel as an energy resource rather than as waste, and they plan to construct a domestic facility to reprocess it. They also plan to nearly double the number of nuclear power plants by the year 2010.

Background

Japan plans to increase its reliance on nuclear power over the next few decades in a continuing attempt to improve the country's energy independence. Japan began its nuclear power program in the mid-1950s and relies on nuclear power for about 27 percent of its electricity. By the year 2000, Japan expects nuclear power plants to produce about 35 percent of its total electricity; by 2010, it expects nuclear power to produce 43 percent of the country's total electricity. To meet these targets, officials said Japan will need to build about 40 nuclear plants in addition to the 43 that are currently operating.

As part of their move toward energy independence, the Japanese plan to build a facility for reprocessing spent fuel from their nuclear power plants so that the recovered uranium and plutonium can be used as fresh reactor fuel. According to officials, the reprocessing facility is scheduled to begin operating by the year 2000. The Japanese have built a small reprocessing plant that will be used primarily for research and development once the larger plant is opened. Until the larger reprocessing facility is completed, most Japanese spent fuel is being shipped to France and Britain for reprocessing in these countries.

Japan is roughly 146,000 square miles large and has a population of nearly 125 million people, or 830 people per square mile. The country is slightly smaller than California but has a population about four times as large. Japan is divided into 47 prefectures and functions under a parliamentary democracy.

Nuclear Waste Policy

Strategy

The Japanese reprocess their spent fuel and plan to store the resultant high-level waste for 30 to 50 years before ultimately disposing of it in a deep geologic repository. Because they plan to store their waste for a long term, the Japanese said they feel no urgency about developing a repository and have established a four-phase plan for waste disposal. During the first stage, from 1976 to 1984, they studied potentially feasible geologic formations and concluded that any type of formation would be reasonably possible for a deep repository. Now in the second stage, begun in 1985, they are selecting possible candidate sites. Once they have selected one or more sites, they will demonstrate safety at the site(s) during the third stage, and during the fourth stage, they will build and operate a repository. The Japanese are also studying partitioning and transmutation, which would change long-lived, highly radioactive waste into shorter-lived elements. However, these remaining elements would still be dangerous and would require disposal.

Japan has met some opposition to its nuclear facilities and policies. In 1993, the return of Japanese plutonium from a reprocessing facility in France received international attention from those concerned with, among other things, the safety of transporting highly radioactive elements over the sea. According to officials, the Japanese government and nuclear utilities attempt to avoid confrontation with affected local communities by providing them with subsidies for infrastructure improvements and public works projects. Japanese officials said that, if necessary, they would spend 10 to 15 years working to gain public support before moving ahead with the licensing process for a nuclear facility.

Organization

The Japanese central government is primarily responsible for high-level waste research. The disposal of high-level waste is addressed under the auspices of the government's Science and Technology Agency. Research and development is being led by a quasi-governmental organization, the Power Reactor and Nuclear Fuel Development Corporation of Japan. Other organizations, such as the Japanese Atomic Energy Institute and the Geological Survey of Japan, are also involved in research. Japan's nuclear policy is generally formulated by the Atomic Energy Commission and the Nuclear Safety Commission, two bodies that advise the Prime Minister.

The organization for implementing waste disposal has not yet been named. This organization will be responsible for selecting the site and constructing the repository. Officials said that some questions remain as to exactly what the roles and responsibilities of government and industry will be within this organization. Japanese officials believe the privately owned utilities may be involved in constructing and operating the repository as well as in funding it.

Other government agencies, such as the Ministry of International Trade and Industry, implement Japan's nuclear policies. Underground waste disposal facilities would be licensed by the Office of the Prime Minister following a review of an operating and safety plan by the Director-General of the Science and Technology Agency.

Funding

The Japanese government funds nuclear research and development, but the utilities will fund the waste's storage and ultimate disposal.

Waste Management and Disposal Approach

Key Aspects

The Japanese have not decided on the specific details of their repository's design, but they envision using a multibarrier approach. Partly because of difficult geologic conditions, the Japanese are studying the use of long-lived engineered barriers in their repository design, such as a thick canister overpack (surrounding wrap) and a clay backfill.

The Japanese are developing a generic repository design that could be located in a variety of geologic formations throughout Japan. In siting the repository, the Japanese plan to emphasize finding a site that is acceptable to the public as well as technically suitable. They also plan to construct a demonstration facility at the site, which they hope will help assure the public of the repository's safety.

Schedule

Because the Japanese plan to store their waste for 30 to 50 years before disposal, officials said they sense no immediate urgency to dispose of the waste. According to government officials, their tentative milestones are to select a potential repository site by the year 2000, construct a demonstration facility at the selected site, and then build a repository by 2030 or 2040.

Regulatory Approach

The Japanese have not yet developed safety standards for disposing of high-level waste. Japanese researchers believe that the absence of specific regulation is appropriate for the research phase of a repository program because it allows the flexibility needed to find the optimal solutions for waste disposal problems. In the meantime, Japan's research program is proceeding in accordance with Japanese environmental standards for releases of radioactive materials and the general standards for repository performance from international nuclear energy organizations.

Interim Storage

After initial storage in pools at the reactors, most Japanese spent fuel is shipped abroad for reprocessing. Japan's nuclear plants are located at coastal sites, so most spent fuel and high-level waste are transported by ship. The Japanese plan to open an interim storage facility near the future reprocessing plant, which will store reprocessed waste returned from France and the United Kingdom. The storage facility is scheduled to open in 1995 and can be expanded, if necessary. The Japanese plan to store the waste for 30 to 50 years before disposing of it in order to reduce its heat and radioactivity.

The Swedish Waste Program

Sweden plans to construct a deep geologic repository to dispose of highly radioactive waste but has not yet selected a site for the facility. The Swedish nuclear waste program has been framed to a large extent by two requirements: (1) that nuclear utilities demonstrate a safe disposal plan before new reactors be licensed and (2) that nuclear power be phased out by 2010. In view of these requirements, Sweden has developed a disposal concept and anticipates a relatively small, finite amount of waste. A little larger than California, Sweden has 12 nuclear power reactors at four sites on its seacoast, which provide roughly half of the country's electricity. Because Sweden relies so heavily on nuclear power and has limited energy options, many question whether it will be able to develop alternative energy sources by 2010.

The Swedish nuclear utilities—under a combination of private and government ownership—are responsible for all aspects of managing nuclear waste, including storing and transporting the waste, developing safe disposal options, and funding and setting time frames for the disposal program. In fulfilling their responsibilities, the utilities developed the concept of a long-lived waste container to be placed deep in the crystalline rock found in much of Sweden. The container is expected not only to resist corrosion in Sweden's geology for 1 million years but also to help gain public acceptance for the repository. Wastes are stored temporarily at the reactors, then transported by ship to a central underground storage facility opened in 1985 near one of the four nuclear plant sites. The wastes are to be cooled there for 30 to 40 years and then, in an on-site facility to be operational around 2006, prepared for disposal in a repository. Given a nonbinding target date of 2020 for an operational underground repository, Sweden is currently searching for a potential repository site.

Background

Sweden's population depends on nuclear power for a large percentage of its electricity. About 8.6 million people live in Sweden's roughly 170,000 square miles, or about 49 people per square mile. Sweden has slightly more territory than California but roughly one-quarter as many people. During 1992, 12 nuclear power reactors located at four sites along Sweden's seacoast generated about 43 percent of the country's electricity; officials said that this figure generally averages 50 percent. The reactors are expected to generate about 5,600 metric tons of spent nuclear fuel by the year 2000 and about 7,800 metric tons by 2010, when nuclear power is scheduled to be phased out. Sweden's first commercial reactor began operating in 1972, and the last one began operating in 1985. Under a constitutional monarchy, Sweden has a monarch, a prime minister, and a unicameral (one-chamber) parliament. The country is divided into 24 provinces.

Public opposition to nuclear power has played a significant part in shaping Sweden's nuclear waste policy. The 1979 accident at the Three Mile Island nuclear plant in the United States prompted a national referendum in Sweden in 1980 that put the issue of continuing to rely on nuclear power to a direct popular vote. On the basis of the referendum's results, Parliament decided to phase out nuclear power by 2010. This planned phaseout signals the end of Swedish nuclear power and gives Sweden, unlike countries with continuing nuclear programs, a finite amount of waste to dispose of.

Despite the phaseout policy, many believe that nuclear power will continue beyond 2010 because Sweden relies on nuclear power for nearly half of its electricity and at present has few alternatives. Sweden uses mainly hydro power to satisfy its remaining demand for electricity but has limits on water resources and faces strict carbon dioxide emission standards. Officials said that debate currently centers on whether existing nuclear plants should be allowed to operate until the end of their useful lives. No new nuclear plants are planned, however, and many Swedish officials told us they believe that nuclear power will eventually end in Sweden, although perhaps later than 2010.

According to officials, Sweden initially intended to reprocess its spent fuel but revised its plans because of concerns about plutonium proliferation and the costs associated with reprocessing. Previously, Sweden had contracted for reprocessing services with both the United Kingdom and France and had shipped some of its spent fuel to these countries. Agreements have been reached so that the waste produced by reprocessing this spent fuel will not be returned to Sweden; therefore, Sweden will not have to handle and dispose of both spent fuel and reprocessed waste.

Nuclear Waste Policy

Strategy

Sweden plans to dispose of its spent fuel in a deep geologic repository and is searching for a suitable repository site. Swedish nuclear waste policy is based on the premise that the utilities that create the waste are responsible for managing and disposing of it safely. In 1977, the government required nuclear utilities to demonstrate a safe method for disposing of spent fuel before it would license new nuclear plants for operation. To satisfy this law, the utilities developed a concept for disposing of spent fuel that involves burying the waste in long-lived containers deep in the Swedish crystalline rock.

Sweden decided to develop a generic repository concept before selecting a candidate site. Because the geology throughout the country is similar, officials believe that the repository could be located almost anywhere. This repository concept is also based on extensive research conducted by Sweden and other countries at a Swedish underground laboratory sponsored for about 10 years by the Nuclear Energy Agency. A second underground laboratory will be used for further investigations.

Organization

Sweden's four utilities are owned by a mixture of government and private interests. Some reactors are owned by the central government, while others are owned by private companies, in which several Swedish cities or the central government are large shareholders. Swedish utilities bear the costs and responsibility for the safely handling and disposing of radioactive waste from nuclear power operations. The 1977 Stipulation Act tied the operation of new plants to the demonstration of safe waste disposal methods. To address these responsibilities, the four Swedish nuclear utilities formed the Swedish Nuclear Fuel and Waste Management Company (SKB), which plans, builds and operates nuclear waste facilities. SKB submits its research plans to the government for review every 3 years to ensure that the research is appropriate to meet the goal of developing a safe repository.

The Swedish Nuclear Power Inspectorate (SKI), which reports to the Ministry of the Environment and Natural Resources, regulates the nuclear industry. The Swedish Radiation Protection Institute, which also reports to the Ministry of the Environment and Natural Resources, sets radiation dose limits. The Swedish Parliament sets general nuclear policy.

Funding

SKB's efforts are funded through a levy on electricity, and funds are currently accumulating in a government-administered waste management fund. SKI collects funds from the utilities at a set rate per kilowatt hour of nuclear electricity produced. The fund is to cover all costs for managing spent fuel off the plant premises and for decommissioning the plants. SKB is reimbursed from the fund by SKI, which reviews and authorizes SKB's request before recommending that the government provide the funds.

Waste Management and Disposal Approach

Key Aspects

Sweden has developed a repository concept that will be refined once a site is selected and site investigations occur. Containment in long-lived canisters and disposal in crystalline rock was selected as the best way to show how and where the waste could safely be disposed of.

Sweden plans to use a "robust" copper and steel canister to contain and isolate the waste for over 1 million years, thus emphasizing the engineered barrier in its multibarrier approach to its repository. SKB believes a strong engineered barrier is critical to demonstrating safety and gaining public support. Sweden's repository will become saturated with water after closure. Sweden chose a copper canister because it will resist corrosion in the expected chemical conditions. These canisters—about 5,500 of them—will be placed approximately 500 meters deep in the crystalline bedrock common to many areas of the country. Each canister will be surrounded by hard-packed bentonite clay, and the repository will be sealed by backfilling tunnels and shafts with a mixture of bentonite and sand. The groundwater is expected to cause the clay to swell and fill up the space between the canisters and the rock. The rock will serve to contain waste only if the container fails. Once sealed, the repository is not expected to require monitoring. The canisters could be retrieved in the future, although with some difficulty.

In selecting a site, SKB will try to find a location where a facility will be acceptable to the local population. Local areas have strong veto powers over nuclear facilities in Sweden, and SKB officials said they wish to avoid resistance and a veto. To locate a willing host for the repository, SKB has canvassed all local areas in the country to seek volunteers. If a volunteer cannot be found, some have speculated, the repository may be built near an existing nuclear facility where the public already accept nuclear facilities. Similarly, SKB has built its lower-level nuclear waste facility and interim storage facility near existing nuclear power plants.

SKB officials believe that demonstrating the success of the repository design in a planned demonstration facility will be important to gaining public acceptance. Once a site is chosen, SKB plans to build a facility to demonstrate the safety of disposal methods. Scheduled to begin around 2008, the demonstration facility will contain approximately 5 to 10 percent of the country's wastes. If this effort is deemed successful, the repository will then open for full-scale waste disposal operations.

Schedule

The repository milestones established by SKB are considered flexible. SKB officials said that because Sweden has adequate storage capacity, no technical urgency exists to dispose of the waste. The program's tentative milestones include the following:

- Select a potential site and begin characterizing it (1997).
- Begin emplacing waste samples in the laboratory (2008).
- Begin constructing a repository (2010).
- Begin operating a repository (2020).

Regulatory Approach

Although SKB is responsible for demonstrating the safety of the repository, the repository must meet general safety goals established by the government. According to SKB, the repository must (1) prevent doses exceeding 0.1 millisievert per year now and in the future, irrespective of national boundaries, and (2) limit the resultant risk of death to affected groups from unusual events or accidents to less than the risk posed by a dose of 0.1 millisievert per year. Swedish officials said that too little is known about how events such as another Ice Age would affect the repository to allow quantitative predictions after 10,000 years, so beyond this time period, qualitative safety arguments may be used.

Swedish regulators said they do not intend to dictate how SKB should meet the safety goals. They believe it is appropriate to allow the utilities—which are ultimately responsible for nuclear safety under Swedish law—the flexibility to meet technical challenges as they occur. SKB develops and carries out the research and development program, which is submitted every third year to SKI. SKI reviews the program to see that it fulfills legislative requirements and moves toward the established safety goals; then SKI forwards the program to the government for approval.

Interim Storage

Highly radioactive spent fuel is initially stored in pools at reactor sites for 1 to 5 years and then shipped to Sweden's central interim storage facility located adjacent to an existing nuclear plant. A government-appointed parliamentary committee proposed interim storage in the mid-1970s to allow time to resolve final waste management plans. Because temporary storage facilities at the nuclear reactors were going to be full by the mid-1980s, SKB built a central storage facility adjacent to the nuclear power plant at Oskarshamn. Opened in 1985, the underground facility will store all of Sweden's spent fuel in pools of water for 30 to 40 years—allowing the waste to cool before it is placed in a repository. Sweden studied storage times ranging from 10 to 100 years and discovered little technical difference; officials said the repository's design could be adjusted to accommodate the various temperatures. Cooling the waste, however, does make the repository design simpler and repository volume smaller. Used fuel is transported from the coastal reactor sites to the storage facility in a specially designed ship.

The storage facility holds spent fuel underground in pools of water. Studies estimated that underground storage would cost approximately the same as aboveground storage. Sweden chose wet (pool) storage because it was the best technology available. However, Swedish officials said that, had the decision been made in the 1990s, they might have built a dry storage facility because such facilities are generally less expensive. The interim storage facility will be expanded to allow the entire Swedish inventory of spent fuel to be stored in one location after nuclear power plants are shut down. At the storage facility site, Sweden also plans to build a plant for encapsulating spent fuel in the copper and steel canisters in preparation for disposal in the repository. It expects the encapsulation facility to be operational in 2006, at the earliest.

The Swiss Waste Program

Switzerland is studying crystalline rock and clay formations to determine the feasibility of using them as a geologic repository for highly radioactive wastes. If possible, Switzerland would prefer to dispose of its relatively low volume of waste abroad in an international repository, primarily because this alternative would be more economical than building a domestic facility. However, Switzerland recognizes that an international repository is highly unlikely under the current political environment, so it is planning to build its own repository. If Switzerland moves ahead with a repository, the waste management organization plans to propose a site by the year 2000, construct an underground laboratory on the site, and open a repository sometime after 2020.

The Swiss government stipulated in 1978 that existing nuclear plants could not continue operating beyond 1985, nor could the future development of nuclear energy occur until the permanent safe disposal of waste could be demonstrated. In response, the Swiss waste management organization developed a general concept to demonstrate safe disposal. This concept was deemed technically feasible in 1988; however, the government required the waste management organization to demonstrate the existence of a suitable site. According to an official, the government ruled that because waste disposal had been shown to be feasible in principle, reactors could continue operating. Because of public opposition, though, nuclear power faces an uncertain future in Switzerland.

Background

Nuclear power provides nearly half of Switzerland's electricity—about 40 percent during 1992. Despite Switzerland's reliance on nuclear power, a 1990 national referendum imposed a 10-year moratorium on the construction of new nuclear power plants, so no new nuclear power plants can be built until the year 2000. Another initiative requiring the soonest possible phaseout of nuclear power was rejected by 53 percent of the voters. Switzerland imports nearly 85 percent of its energy and has no domestic oil resources.

The first Swiss commercial nuclear reactor was commissioned in 1969. The existing five reactors, located at four sites, are expected to generate 200 cubic meters of high-level waste by 2000. Switzerland is nearly 16,000 square miles large, roughly half the size of South Carolina, but it has nearly twice the population—about 6.8 million people, or 428 people per square mile. Switzerland is a federation of 26 cantons (states) that function as a federal republic.

The Swiss have traditionally reprocessed their spent nuclear fuel but are now reconsidering this policy. The Swiss have contracted with British and French firms to reprocess their spent fuel. According to a Swiss official, under early reprocessing contracts, the British and French firms were to retain the high-level waste from Swiss spent fuel. During the late 1970s, this arrangement changed, and reprocessed wastes are now scheduled to be returned to Switzerland beginning in the mid-1990s. The Swiss may discontinue the use of reprocessing. This decision has not yet been made, but officials cited economic reasons for reconsidering their position on reprocessing. In addition to the current availability of inexpensive uranium, utilities have concluded that it is cheaper to store spent fuel than to reprocess it. Used fuel is transported between Switzerland and the reprocessing facilities by train, truck, and ship.

Nuclear Waste Policy

Strategy

The Swiss plan to dispose of high-level waste in a deep geologic repository and are attempting to locate a potential repository site. In 1978, the government required the utilities to demonstrate safe waste disposal as a condition for continuing the operation of existing nuclear plants beyond 1985 and developing nuclear energy in the future. The utilities responded with a concept for waste disposal that was deemed technically feasible in 1988; however, the government was unconvinced that an adequate site existed and could be found in Switzerland. According to Swiss officials, the government concluded that safe waste disposal had been demonstrated, so the reactors could continue operating.

The utilities have investigated crystalline rock and clay formations for their suitability as a repository. The Swiss have also conducted research at an underground granite laboratory, which opened in the early 1980s. This facility is used exclusively for research and will not be used as a final repository. According to an official, the Swiss intend to focus on one or two specific sites during the 1990s, and they plan to propose a single site for a potential repository by the year 2000. The Swiss expect to construct an underground laboratory at the proposed site before building a full-scale repository.

Although the Swiss are pursuing the development of a domestic repository, they would prefer to dispose of their waste abroad in an international repository. With only five reactors and a relatively small volume of high-level waste to dispose of, the Swiss believe that paying another country to dispose of their waste might be more economical than building a domestic facility. Recognizing, however, that the current political environment makes the possibility of an international repository highly unlikely, the Swiss are moving forward with their domestic program.

Considerable public opposition exists to Switzerland's geologic investigations. The best geologic structures are in a relatively small area in the north near the German border, and Switzerland has met strong opposition from groups in Germany and Austria. According to Swiss officials, opponents tend to exhaust all legal means at their disposal to prevent site investigations; in some cases, these challenges have significantly slowed investigations. The Swiss have also encountered substantial public opposition to their efforts to investigate sites for a lower-level waste repository.

Swiss waste management organizations have the authority to negotiate a direct payment to affected local areas that host a waste facility. According to Swiss officials, such an agreement already exists for a planned interim storage facility; the affected governments will receive a direct annual payment in compensation for allowing a nuclear facility to be operated nearby. A similar arrangement will likely be used for other waste facilities, according to a Swiss official.

Organization

In 1972, the Swiss waste producers—the four nuclear utilities—joined with the federal government to form the National Cooperative for the Disposal of Radioactive Waste (NAGRA) to provide for permanent waste disposal. According to officials, Swiss law designates nuclear waste producers—primarily the electricity utilities—as responsible for safe and permanent waste storage and disposal. The nuclear utilities formed another company in 1990 to plan and construct an interim storage facility to hold nuclear waste until a geologic repository is available.

The Swiss federal government grants licenses for nuclear facilities, but before licenses for constructing and operating nuclear facilities can be granted, the Parliament must approve a general license for the facility. The primary regulatory agency is the Federal Nuclear Safety Inspectorate, which advises the federal government on licensing matters. The Swiss federal government sets general nuclear policy.

Funding

The costs of waste management are generally borne by the waste-producing utilities; no organization exists for collecting and redistributing funds. The federal government provides a minor contribution for the management of its waste arising from medicine, industry, and research.

Waste Management and Disposal Approach

Key Aspects

According to NAGRA, Switzerland's general repository concept includes deep emplacement (400 to 1000 meters deep) underground, most likely into crystalline rock or clay; the geology and other site-specific factors will determine the details of the design. The artificial barriers will include a thick stainless steel canister and a bentonite clay backfill that will surround the canisters in the shafts. In performance models, Swiss researchers predict that the canister will provide complete containment for the first 1,000 years after emplacement. Swiss researchers, however, believe that the canister will exceed this expectation and remain intact for 100,000 years or more. No special monitoring is planned for long-term safety once the repository has been sealed, nor do the Swiss expect to make any special provisions for waste retrieval. After selecting a potential repository site, the Swiss plan to construct an underground laboratory before building a repository.

Schedule

The Swiss plan to propose a repository site by the year 2000 and open a repository no earlier than 2020. The federal government has not imposed any time constraints for disposing of high-level waste.

Regulatory Approach

Swiss regulators said they will place the burden of proof for demonstrating safety on the applicant during the licensing procedure. The regulatory agency has set a radiation dose limit (0.1 millisievert per year), but the applicant is responsible for designing a system that will meet this goal. During the formal review, the regulators will act as skeptics, reviewing the applicant's safety case for potential flaws in methodology. After the regulators are satisfied with the safety case, they will send the application forward to the federal Department of Transport, Communication and

Energy. After evaluating the application and obtaining comments from the public, the Department will forward the application to the central government, which will grant the license, with Parliament's approval.

Interim Storage

Spent fuel is generally stored in pools at the reactors before being sent by truck, train, or ship to the United Kingdom or France for reprocessing. To store the high-level waste returned from abroad, the Swiss utilities are planning to build a centralized interim dry storage facility. The facility can also store spent fuel, should the utilities decide against reprocessing. If necessary, this facility will also be able to store lower-level radioactive waste.

The utilities formed a company in 1990 to build and operate the storage facility. The government will license the facility, which is expected to be operational in the late 1990s. It will be located adjacent to a research institute that treats and stores radioactive waste from medical applications, industry, and research. The utilities chose centralized storage because they believe it simplifies administrative and control procedures, confines facilities to one site, reduces transportation efforts, and lowers costs. Highly radioactive waste will be dry-stored for approximately 40 years to allow it to cool.

The interim storage facility is meeting considerable public opposition—over 20,000 formal objections have been raised thus far during the licensing process. Opposition groups are concerned about a variety of issues, such as the extent to which the facility is protected against disasters (e.g., an airline crash) and the large concentration of nuclear facilities in one area. This opposition may delay the development of the storage facility.

The British Waste Program

The United Kingdom is deferring decisions on the final disposal of highly radioactive waste for at least 50 years. Government officials believe that the United Kingdom will eventually dispose of the waste in a geologic repository, but the government will make its decision to do so at a later time. In the interim, the British will reprocess most spent fuel and store the resultant high-level waste. The United Kingdom has a relatively low volume of highly radioactive waste, which can easily be stored. The British believe storage offers the technical advantages of allowing the radioactivity to decay and the waste to cool.

Considered more pressing than the need for a high-level waste disposal facility is the need for a repository for lower-level radioactive waste. The United Kingdom reprocesses its spent fuel domestically, and while this process reduces the volume of high-level waste, it creates a significant amount of lower-level radioactive waste. A potential site for a lower-level waste repository is under investigation. Current plans are to commission this repository by about 2007.

Background

During 1992, 37 nuclear reactors provided the United Kingdom with 23 percent of its electricity. Government officials expect that the United Kingdom will maintain the current level of reliance on nuclear power for the foreseeable future. The country commissioned its first commercial nuclear reactor in 1956, and its reactors are expected to generate 1,280 cubic meters of high-level waste by the year 2000. Officials said that recent attempts to privatize the government-owned nuclear utilities were unsuccessful, at least in part because the costs of decommissioning aging reactors were uncertain. The United Kingdom's domestic energy sources include coal, oil, and natural gas.

Most spent fuel is reprocessed in Britain because it is considered a resource that can be recycled to use recovered uranium and plutonium. The government owns British Nuclear Fuels, a corporation that provides commercial fuel cycle services, including spent fuel reprocessing for domestic and foreign customers. However, the economics of reprocessing have recently been questioned. One of the country's nuclear utilities, Scottish Nuclear, plans to store its used fuel up to 100 years instead of immediately reprocessing it. According to officials, Scottish Nuclear finds storing its used fuel less expensive than reprocessing it.

The United Kingdom comprises roughly 94,000 square miles and has a population of nearly 58 million, or about 613 people per square mile.

Nearly the size of Oregon, it has almost 20 times as many people. The United Kingdom, which consists of England, Wales, Scotland, and Northern Ireland, functions under a constitutional monarchy. The Parliament is the legislative governing body for the United Kingdom, and it consists of two houses—the House of Lords and the House of Commons.

Nuclear Waste Policy

Strategy

The British government is deferring decisions on the final disposal of highly radioactive waste for at least 50 years. Officials said that because they have a relatively small volume of waste and adequate storage facilities, they do not consider high-level waste disposal an urgent need. In addition, storing the waste for 50 years or more allows the radioactivity to decrease substantially. Government officials also said that Britain will probably eventually dispose high-level waste in a repository, but the decision to do so will be made at a later time.

Some have questioned the government's deferral of decisions about the disposal of highly radioactive waste. Certain observers claim that the government is reluctant to move ahead with waste disposal because of public opposition. During the late 1970s, the United Kingdom encountered public protests against a research drilling program for high-level waste disposal, which ultimately led to the program's cancellation. Government officials, however, cite the technical advantages of storing waste as the primary motivation for the delay.

The British are currently concerned with disposing of the lower-level waste—especially that known as intermediate-level waste—generated during reprocessing, which they consider a more pressing need. Recent attention has focused on efforts to investigate and ultimately build a repository for this waste at a site near the reprocessing facilities. The British plan to commission this repository by about 2007. Most intermediate-level waste is currently stored at the reprocessing facility, and most low-level waste is disposed of in a shallow-burial facility. Officials said that although storing high-level waste allows the radioactivity to decay substantially, no such advantage accrues from delaying the disposal of low- and intermediate-level waste.

Organization

No organization has yet been given responsibility for disposing of highly radioactive wastes, although waste producers—primarily the nuclear utilities—are considered responsible for the waste they create. To manage low- and intermediate-level waste disposal, the nuclear industry formed the United Kingdom Nirex Limited. The shares in the company are owned by the nuclear utilities and other nuclear organizations; the Department of Trade and Industry also holds a special share.

The Radioactive Waste Management Advisory Committee advises the government on policy issues and consists of experts from a variety of disciplines, including the nuclear industry, academia, medical and research institutions, and the environmental field. In England and Wales, the regulatory authority is Her Majesty's Inspector of Pollution together with, in the case of licensed nuclear sites, the Ministry of Agriculture, Fisheries and Food in England and the Secretary of State for Wales in Wales. Scotland and Northern Ireland have similar regulatory organizations. British policies on radioactive waste management are set by the Department of Environment.

Funding

The waste producers are to pay the costs of waste storage and disposal in the United Kingdom. The nuclear utilities charge their customers at a rate that includes the expected costs of treating, storing, and disposing of radioactive waste.

Waste Management and Disposal Approach

Key Aspects

Since the United Kingdom has not yet decided to build a repository for high-level waste, it has not developed a repository design. However, a repository design is being developed for the low- and intermediate-level waste; this repository will likely include a multiple-barrier design that includes a waste container and cement backfill.

Schedule

The government plans to decide whether and how to proceed with high-level waste disposal around the year 2040. Government officials said that because the United Kingdom has a relatively low volume of high-level waste that can easily be stored, they do not feel pressured to dispose of the waste.

Regulatory Approach

Government officials indicated that if the government decided to build a repository for high-level waste, they would take a regulatory approach similar to that followed for other nuclear facilities. That is, the regulators would place the burden for designing an acceptably safe nuclear facility on the applicant in the licensing process. To obtain a license, the applicant would be required to demonstrate to the regulatory authorities that doses and associated risks to the public would be within regulatory limits and as low as reasonably achievable. The limits are set by the government on the advice of the United Kingdom National Radiological Board. For low- and intermediate-level facilities, the dose must result in a corresponding risk to affected individuals of not greater than 1 cancer death per 1 million people in any year.

Government officials said that specific limits pertaining to highly radioactive waste disposal have not been set but are expected to be consistent with existing limits for other types of nuclear facilities. The officials said that they prefer general safety guidelines, which give the responsible operator flexibility to meet the broadly stated safety goals, rather than prescriptive regulations. The officials also told us that the government prefers to place on the operator the onus of demonstrating that a nuclear facility will be safe. The regulator acts as a skeptic who must be convinced that the facility will be safe.

Interim Storage

Spent fuel is generally stored in pools at the reactors until it is sent by truck and train to the reprocessing facilities. After reprocessing, the remaining highly radioactive waste is stored at the reprocessing facility; plutonium separated during reprocessing is also stored at the reprocessing facility. To allow heat and radiation levels to decline and to allow time for evaluating disposal options, the waste will be stored for at least 50 years before being disposed of. Officials said storage capacity at the reprocessing facility could easily hold, or be expanded to hold, the high-level waste produced from reprocessing operations during the next 50 years.

Some spent fuel may be stored longer at the reactors in dry storage. According to British officials, one of the country's utilities, Scottish Nuclear, finds that storing spent fuel is less expensive than reprocessing it.

The utility plans to construct a dry storage facility to hold spent fuel for up to 100 years. Some environmental groups in the United Kingdom consider aboveground storage to be the "least-worst" option for managing high-level waste. They believe that additional study of various disposal options is needed before a method is selected.

Objectives, Scope, and Methodology

Senator Bryan requested that we compare and contrast the approaches taken by major nuclear countries for civilian high-level waste management with the approach taken by the United States. To satisfy our objectives, we visited seven major nuclear countries: Canada, France, Germany, Japan, Sweden, Switzerland and the United Kingdom. Experts recommended that we visit these countries because they are major nuclear powers and have relied on nuclear energy to generate a significant percentage of their electricity for several decades. More importantly, each country has a unique approach toward waste storage and disposal. We did not include countries from the former Soviet Union or Eastern Europe in our review. Officials at international nuclear agencies suggested that, at this time, the United States would be in a better position to offer assistance to these nations than to learn from them.

In each country, we interviewed cognizant waste management officials, such as representatives from the central government, and from waste management and regulatory agencies. Where possible, we also met with officials from the affected local governments, nuclear industry, and environmental groups. We supplemented our interviews with documentation when available, but we did not audit each country's waste management program to verify the accuracy and completeness of the information we received. We also provided a summary of information to officials from each country and asked that it be reviewed for accuracy and completeness. We relied primarily on GAO's previous reviews of DOE's nuclear waste storage and disposal programs for information on U.S. waste management. Finally, we met with officials at the International Atomic Energy Agency, the Nuclear Energy Agency, and the Commission for the European Communities. We performed our work from June 1992 through March 1994 in accordance with generally accepted government auditing standards.

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