



**Disposition of High-Level Waste and Spent Nuclear Fuel: The Continuing Societal and Technical Challenges**

Committee on Disposition of High-Level Radioactive Waste Through Geological Isolation, Board on Radioactive Waste Management, National Research Council

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# **DISPOSITION OF HIGH-LEVEL WASTE AND SPENT NUCLEAR FUEL**

**The Continuing Societal and Technical Challenges**

Committee on Disposition of High-Level Radioactive Waste  
Through Geological Isolation  
Board on Radioactive Waste Management  
Division on Earth and Life Studies  
National Research Council

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“Time is a sort of river of passing events, and strong is its current; no sooner is a thing brought to sight than it is swept by and another takes its place, and this too will be swept away.”

Marcus Aurelius, *Meditations* IV, p. 43 (Morris Hickley Morgan translation; page 142a of Bartlett's *Familiar Quotations*, 14<sup>th</sup> edition). These words were written by a Roman Emperor nearly 2000 years ago. Within a few years after Marcus Aurelius' death the institutions of Roman government crumbled and the Roman Empire descended into anarchy. Two thousand years is a short time compared to the period that high-level radioactive waste and spent nuclear fuel must be isolated. The challenge of assuring their safety and security is to construct an enduring system that can withstand the vicissitudes of nature and societal change.

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This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

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## Preface

The National Research Council of the U.S. National Academies has provided scientific and technical analysis to inform policy decisions related to nuclear waste since the 1950s. In its 1957 report, prepared at the request of the U.S. Atomic Energy Commission, the National Research Council endorsed the concept of geological disposal—placing high-level waste (HLW) in a carefully selected deep underground formation, where it would remain isolated from human beings and the environment long enough for the radioactivity to decay to near natural background levels. The goal was and still is to provide adequate protection of humans and the environment at all future times.

Following this 1957 report and recommendations for geological disposal by other scientific advisory bodies, the United States and many other nations using nuclear technology established programs for managing HLW (including spent nuclear fuel if declared to be waste) through geological isolation. Most of these national programs are far behind their original schedules. No national program has yet been successful in siting a geological repository and emplacing HLW in it.

In 1988, the Board on Radioactive Waste Management (BRWM), the entity within the National Research Council of the U.S. National Academies with responsibility for studies on nuclear waste, convened a study session with experts from the United States and abroad to discuss U.S. policies and programs for managing the nation's HLW. The board's follow-up report, *Rethinking High-Level Radioactive Waste Disposal* (NRC, 1990), provided a broad assessment of the technical and policy challenges

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for developing a repository for the disposal of HLW. The board noted in the report (p. 2):

There is a strong worldwide consensus that the best, safest long-term option for dealing with HLW is geological isolation. . . . Although the scientific community has high confidence that the general strategy of geological isolation is the best one to pursue, the challenges are formidable.

The worldwide consensus of the technical community was documented as well by international bodies. The clearest examples are the collective opinions published by the Nuclear Energy Agency (NEA) of the Organization for Economic Cooperation and Development together with the International Atomic Energy Agency and European Union (NEA, 1991b, 1999d). The views expressed were that geological disposal can be done ethically and safely. It was also recognized that considerable technical work—particularly in the area of site characterization—remained to be done.

In pursuing geological disposal, national programs in several countries have made very significant progress over the past 25 years; however, they have also encountered a number of challenges. These include understanding the nature and rates of geological processes, assessing the potential effects of long-term environmental and climate change, quantitatively assessing repository and waste package performance, and projecting possible long-term human behavior—activities that are needed to assure adequate safety. Those national programs that have made or are in the transition from research to repository development have also confronted a challenge that has both technical and sociological overtones: simply put, some members of the public do not believe that geological isolation can be demonstrated to be a safe, long-term waste disposal solution. They doubt the ability of experts to understand the future behavior of the repository, and therefore to make the right decisions to protect public health. This segment of the public is consequently opposed to ending active control of the waste, even though its continued management may be a burden on future generations. Members of the public and their elected leaders who work or live near proposed HLW repository sites have challenged the integrity and fairness of the site selection process. Such public doubts, objections, and distrust typically come to the fore when a disposal program moves into the task of identifying specific repository sites. The reactions reflect lack of confidence and trust, not only in the geological disposal concept, but also in the organizations and processes involved in HLW management. Siting efforts for new surface storage facilities have also encountered strong local opposition.

In the mid-1990s the BRWM observed that many national programs continue to face these substantial challenges and are actively seeking ways

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to address and overcome them. Believing that an international study would be of value, the BRWM initiated an effort to obtain sponsorship for this study. The scope of the project was self-generated by members of the BRWM, and deliberately broad in order to include new insights arising from an international workshop that was arranged to launch the study.

The objective of this study is to inform and advise policymakers with responsibility for national HLW programs, in the United States and in other nations. This study is also intended for the interested segments of the public, as well as those in the technical and social science communities professionally involved in various issues involving HLW. The products of the study are twofold: a workshop held in 1999 and this report. Both were intended to provide an integrated overview of programmatic histories in many countries, of policy issues, of key scientific and technical aspects, and of observations and insights from social scientists. This report is a selection and synthesis of information presented at the workshop and of information available to the committee from other sources. The findings, conclusions, and recommendations reflect the committee's insights on how to achieve better planning and decision making on HLW. In particular, the study addresses the questions of whether and when to implement disposal of HLW through geological isolation, rather than focusing exclusively on how to implement geological disposal. The committee has addressed the broader challenge of how to assure the ongoing management of HLW needed to achieve safety and security. The study therefore includes consideration of alternatives to geological disposal.

In using the term "disposition," this report follows the usage in the title and text of the 1994 National Academy of Sciences report on excess weapons plutonium (NAS, 1994). "Disposition" denotes active management, either on the surface or in a geological setting underground, whereas "disposal" denotes an end to the need for active management, such as when a geological repository is closed and sealed. The focus of this study is on the alternatives for disposition of HLW, some of which lead to geological disposal.

In early 1999 the necessary funding was pledged and the study was initiated, but in a fashion that is unusual for studies by the U.S. National Academies. More than half of the study committee members reside outside of the United States. An advisory committee was formed that included experts from the national programs sponsoring the study. The study committee met in Washington, D.C., in May 1999, and in consultation with the advisory committee, planned an international workshop to provide an opportunity for experts from many nations and disciplinary backgrounds to exchange views. This workshop was subsequently held at the Irvine, California, facility of the U.S. National Academies on November 4–5, 1999. The workshop was attended by more than 200 people

from 17 countries. A briefing paper *Disposition of High-Level Radioactive Waste through Geological Isolation*, prepared and sent to attendees in advance of the workshop, is available from the Board on Radioactive Waste Management of the National Research Council. The workshop program and the list of attendees are included as [Appendix B](#) and [Appendix C](#), respectively.

Since the workshop, the study committee has used the deliberations at the workshop and other sources of information available to it to prepare this report. The committee met as a group once in Washington D.C., in March 2000, to deliberate on the findings and recommendations in the report and did most of its work in preparing this report through e-mail communications among committee and staff. The committee followed the usual U.S. National Academies' practices in preparing its report. Most notably, report drafts were not circulated outside the committee, and the draft report was subjected to National Research Council review before being approved for release.

The chair and vice-chair express appreciation to the sponsors for their willingness to support an innovative effort of the U.S. National Academies to provide useful advice in a policy area that affects many nations. HLW disposition is a complex endeavor that utilizes information from many disciplines within the physical sciences, engineering, and also, very importantly, the social sciences. It was not easy for a diverse group from many disciplines and many countries to have a productive interchange in a two-day workshop. The chair and vice-chair wish to thank the workshop attendees, and in particular the session organizers, for their contributions, both at the meeting and in subsequent communications to us.

It is even more of a challenge for a committee, made up of 12 members, supported by a small National Research Council staff, to come to agreement on how to turn its collective understanding of the complex and contentious challenges posed by HLW disposition into the consensus reflected in this report. Most U.S. National Research Council committees preparing reports do so through a process including many face-to-face meetings among committee members. Our committee was large and international, which ruled out such a process, so we used e-mail communication instead. We thank our colleagues on the committee for their determined efforts to work together via e-mail, to understand each other's viewpoints, and to resolve a very large number of issues—over long distances and over more than a year following the workshop. We also thank the staff for its outstanding effort in supporting the committee throughout this study. In particular, we thank Kevin Crowley, BRWM Director, whose enthusiasm and energetic support from initial conception six years ago to report production and dissemination has been invaluable to the study; and John Wiley, Study Director, who has carried the heavy burden

of managing the planning and arrangements for the 1999 workshop and the coordination and production of the workshop briefing paper and this report. We also thank the other NRC staff members who contributed to typing, editing, research support, and meeting arrangements: Toni Greenleaf, Laura D. Llanos, Susan B. Mockler, Suzanne Stackhouse, Angela R. Taylor, and Darla Thompson.

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## Executive Summary

There has been, for decades, a worldwide consensus in the nuclear technical community for disposal through geological isolation of high-level waste (HLW), including spent nuclear fuel (SNF).<sup>1</sup> However, none of the national programs established to implement geological disposal has yet succeeded in establishing a geological repository and emplacing HLW in it. The large and growing HLW inventory from civilian and military reactor use over nearly 60 years remains in surface facilities intended only for interim storage. The societal and technical challenges of geological disposal and, more broadly, of ongoing management of HLW have turned out to be substantially greater than anticipated when the United States and other nations established programs for HLW disposal starting some decades ago.

The National Research Council of the U.S. National Academies has carried out technical analyses of HLW for more than 40 years, and its reports often have been cited as supporting geological disposal as the preferred option for the management of HLW. The project that produced this report was initiated by the Board on Radioactive Waste Management (BRWM), the part of the National Research Council responsible for studies on nuclear waste, in response to its observation that many nations, including the United States, were encountering significant difficulties and

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<sup>1</sup> As discussed in [Chapter 1](#), for convenience in terminology the committee uses the term “high-level waste” to include high-level waste from reprocessing nuclear fuels, spent nuclear fuel (SNF) if it is considered to be a waste, and other nuclear materials designated for disposal along with reprocessing waste and SNF.

delays in their plans for geological disposal of HLW. The study committee includes scientists from several nations, as well as a variety of disciplinary backgrounds, and the study has addressed both the societal and the technical aspects of HLW management. In particular, the study addresses the questions of *whether* and *when* to implement disposal of HLW through geological isolation, rather than focusing exclusively on *how* to implement geological disposal. This report is intended to provide elected officials and policymakers, interested parties among the public, and those professionally involved with HLW with an informative overview and with specific insights to aid planning and decision making.

The study committee, with assistance from representatives of the agencies sponsoring the study, organized and held a workshop in November 1999, which was attended by more than 200 experts from 17 countries. The study committee has used the deliberations at the workshop and other sources of information available to it to prepare this report. This Executive Summary provides concise statements of the principal findings, conclusions, and recommendations in the report. [Chapter 1](#) serves as an introduction, and [Chapter 2](#) and [Chapter 3](#) provide expanded but focused discussion of the findings, conclusions, and recommendations. [Chapter 4](#), [Chapter 5](#), [Chapter 6](#), [Chapter 7](#), [Chapter 8](#) through [Chapter 9](#) provide additional information supporting the discussion in [Chapter 2](#) and [Chapter 3](#). Because of the international focus of this study, the recommendations in this report are not specific to any country and are not addressed to any given agency.

## PRINCIPAL FINDINGS AND CONCLUSIONS

The following brief discussion presents the committee's principal findings and conclusions, which are described in detail in [Chapter 2](#).

- **Today's growing inventory of HLW requires attention by national decision makers.** The present situation in the management of radioactive wastes worldwide is one in which—with some important exceptions—safety and security are being achieved by storage, often at or near the facility that produced the waste. Although quantities are minor compared with toxic wastes from other industrial activities, the inventories, particularly of spent fuel, are increasing in many countries beyond the capacity that can be stored in existing facilities. Measures must be taken to deal with this. Moreover, a segment of the public holds concerns and fears that radioactive wastes present an unmanageable threat. The challenge is not just to identify options that are deemed suitable by the technical experts, but also to assure that the decision processes and waste management technologies chosen have broad public support.
- **The feasible options are monitored storage on or near the earth's surface and geological disposition.** Safe and secure surface storage is

technically feasible as long as those responsible for it are willing and able to devote adequate resources and political attention to maintaining and expanding the storage facilities, as has been shown by decades of experience. The major uncertainty is in the confidence that future societies will continue to monitor and maintain such facilities. It is not prudent to pursue only storage, without development of the geological disposal option, unless a society believes it can credibly commit to permanent maintenance of its storage facilities.

- **Geological disposal remains the only long-term solution available.** After four decades of study, geological disposal remains the only scientifically and technically credible long-term solution available to meet the need for safety without reliance on active management. It also offers security benefits because it would place fissile materials out of reach of all but the most sophisticated weapons builders. As in all scientific work, progress in achieving geological disposal has been marked by surprises, new insights, and the recognition that for even the best-characterized sites, there always will be uncertainties about the long-term performance of the repository system. Providing convincing evidence that any repository assures long-term safety is a continuing technical challenge. Nevertheless, a well-designed repository represents, after closure, a passive system containing a succession of robust safety barriers. Our present civilization designs, builds, and lives with technological facilities of much greater complexity and higher hazard potential.
- **Today the biggest challenges to waste disposition are societal.** Difficulties in achieving public support have been seriously underestimated in the past, and opportunities to increase public involvement and to gain public trust have been missed. Most countries have made major changes in their approach to waste disposition to address the recognized societal challenges. Such changes include initiating decision processes that maintain choice and that are open, transparent, and collaborative with independent scientists, critics, and members of the public.
- **Whether, when, and how to move toward geological disposal are societal decisions for each country.** This decision process will be lengthy, and the time can be used to improve both the technical and the societal bases for these decisions.
- **A stepwise process is appropriate for decision making under technical and social uncertainty.** Some—but not all—of today's uncertainties in predicting the future behavior of a repository system can be reduced or eliminated by further research and development. Both fundamental knowledge and ways to deal with uncertainty are advancing, and they will continue to do so during the course of a repository development program. A stepwise decision process can utilize this evolving knowledge to make sound decisions on repository siting (including the geological setting), design, and operation.

- **Successful decision making is open, transparent, and broadly participatory.** National waste disposition programs in democratic countries cannot hope to succeed today without a decision-making process that facilitates choices among competing social goals and ethical considerations. Sufficient time must be devoted to developing this process, including the involvement of broader circles of citizens in examining the choices in an informed way. The challenges of such complex decision making can best be met by flexible and adaptive management. A management system that is flexible, responsive to surprises, capable of midcourse corrections, and effective in its interaction with concerned segments of the public has the greatest possibility of success.
- **International cooperation can help achieve national solutions.** Cooperation especially can help less advantaged nations, for example, those with more limited financial means, small nuclear programs, or unfavorable geology. Cooperation can range from shared research programs to shared storage or disposal facilities offered by a host country to other nations. Sharing technology and facilities will reduce the cost burden for all the cooperating nations and will facilitate the establishment of internationally accepted standards. Progress in adopting a solution in one country serves as a positive example to other countries.

## PRINCIPAL RECOMMENDATIONS

The recommendations from the study are discussed in [Chapter 3](#). The following brief discussion presents the principal recommendations.

1. **National organizations with responsibility for the management of HLW, together with the scientific and engineering communities (including social scientists), should provide the leadership and support for solving the problems posed by HLW.** Because the current situation in many countries does not present an urgent safety hazard and because the issue of radioactive waste management is extremely sensitive politically, there is a temptation to postpone or avoid decisions and actions. Nevertheless, the safety problem is immediate in some countries and will grow elsewhere as more waste is generated and new storage facilities become necessary. Moreover, security concerns will grow as more fissile material arises from dismantling nuclear weapons unless a disposition route for this material is prepared. Accordingly, actions are needed to generate options, understand their implications, and involve the public in the choice of approaches to safe and secure disposition.
2. **National HLW programs should expand their efforts beyond technical project development and implement processes that involve the public in decisions to assure safety and security.** A decision is by definition a choice between at least two alternatives. In a democracy, the

acceptability of controversial decisions at the societal level depends largely on the use of criteria that have been established and understood in advance and on the use of procedures that are seen as fair. Program managers and national leadership should assure that the criteria and procedures used in decisions concerning HLW meet these tests. Choice must always be available. We recommend that radioactive waste management programs develop both the option for adequate storage, to assure that this capability is available for as long as it is needed, and the geological disposal option.

- 3. For both scientific and societal reasons, national programs should proceed in a phased or stepwise manner, supported by dialogue and analysis.** Each national program should perform a study of realistic alternatives, including a description of the current safety and security afforded by the status quo storage configuration over long time periods, perhaps decades to centuries. This description will provide a baseline for evaluation of alternatives, as well as steps toward geological disposal. Decision makers, particularly those in national programs, should recognize the public's reluctance to accept irreversible actions and emphasize monitoring and retrievability. Demonstrated reversibility of actions in general, and retrievability of wastes in particular, are highly desirable because of public reluctance to accept irreversible actions.
- 4. National programs should increase international cooperation by sharing information, coordinating policies, supporting international organizations, developing a consensus on international standards, and seeking other ways to assure that all countries achieve safe disposition of their radioactive waste.** Global cooperation on HLW can bring benefits to all. International cooperation at the technical level is already intensive; coordination at the strategic and political levels should intensify. Some countries may agree to share waste treatment, storage, or disposal facilities. Laws, regulations, or ethical assertions that would prevent the transfer of HLW between willing and competent partner countries could preclude sound options to enhance safety, security, and economics.
- 5. National programs should take an integrated, comprehensive, and risk-based systems view to assure safety and security for storage facilities and repositories, both in the implementation of the waste management program and in its regulatory oversight.** Cross-disciplinary experience and comprehensive analysis of the possibilities for HLW containment failure should be used to assure the safety and security of the HLW management system at all times, including during handling, interim storage, and transportation, as well as for long-term storage and geological disposal. Whether to proceed with implementation of geological disposal will depend in large measure on regulatory decisions. A phased approach to regulation of a geological repository, as expounded

10 years ago in the BRWM's report *Rethinking High-Level Radioactive Waste Disposal* (NRC, 1990), remains sound advice.

Safety and security assessment experts must communicate their belief that their calculated results, although imperfect, provide sufficiently reliable input for decision makers. As long as one can be accurate in assuring that the levels of radioactivity release are low, precise estimates are not needed. Even with some orders of magnitude of residual uncertainty, the calculated release may be clearly within defined safety goals or limits. All parties involved in the decision-making process should have a consistent and accurate perception of what model-based analysis can and cannot do, so that they do not make erroneous decisions based on incorrect or biased expectations.

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# 1

## Disposition of High-Level Waste and Spent Nuclear Fuel: An Overview of the Societal and Technical Challenges

The development and use of nuclear technology, which began in the early 1940s, has produced a substantial inventory of radioactive waste—material with no current or currently known future use. The most radioactive fraction of this waste must be isolated from humans and the environment, because it produces hazardous levels of ionizing radiation that may persist for a long period of time and because some components of this waste can be used to make nuclear weapons. [Sidebar 1.1](#) describes the types and origins of this waste. For convenience, all such waste materials are referred to collectively as high-level waste (HLW) in this report, with the more precise terms used only as necessary to avoid ambiguity.

### **SIDEBAR 1.1: WHAT IS HIGH-LEVEL WASTE AND WHERE DOES IT COME FROM?**

High-level waste, spent nuclear fuel, highly enriched uranium, and plutonium are the radioactive materials of concern in this report. Because all are related to nuclear processes, they have some similarities but also have significant differences: how they are produced, what is in them, and what hazards—for safety and security—they represent. The key characteristics of relevance when considering disposition alternatives are the intensity of the radiation emitted, the rate at which the intensity decreases, and the ease with which the material can be misused in nuclear weapons. The most relevant characteristic that these materials have in common is that all represent a hazard for very long times into the future, unless measures are taken to isolate them from the human environment.

After uranium is made into fuel for a nuclear reactor, it is used to produce energy. In the process, some of the uranium fissions—splits—producing energy



and fission products. Another portion of the uranium is transformed into plutonium, some of which also fissions. When the fuel is removed from the reactor it is labeled spent nuclear fuel (SNF). This SNF is highly radioactive from the decay of the fission products, is still generating heat, and contains some plutonium as well as unconsumed uranium. In the United States, the Department of Energy maintains the label SNF for this spent fuel and does not formally classify it as high-level waste. The U.S. Nuclear Regulatory Commission does classify spent nuclear fuel as HLW. Most countries do not count SNF as high-level waste. The distinction is maintained because of the uranium and plutonium in SNF, which can be used for further energy production or, as discussed later, for nuclear weapons. The HLW, when SNF is not included, does not contain very much plutonium or uranium and is therefore not a proliferation concern, and is in that sense not a security threat.

To extract plutonium and uranium from SNF, chemical or electrometallurgical processes are used to separate the fission products with high levels of radiation and heat generation, leaving the plutonium and uranium with little radioactivity or heat generation. The fission product waste stream is labeled HLW in all countries. This material represents a health hazard because of the radiation, as well as the toxic properties of some of the materials.

Security issues relate primarily to the ability to make nuclear weapons. Such weapons use highly enriched uranium (HEU), which is enriched in uranium-235, and plutonium. Manufacture of most nuclear fuel does not produce HEU, although some special fuel does use more HEU than other nuclear fuels.

Plutonium comes from reactor operations. What is called "Weapons-grade" plutonium is manufactured by running a reactor in a very short cycle, extracting the fuel, processing the fuel, and extracting the plutonium. If the reactor is run in a normal energy-producing cycle, the resulting plutonium has a lower concentration of the most attractive isotope, plutonium-239, and higher concentrations of other isotopes, which make handling the material more difficult and make it less attractive for bomb manufacture.

As the United States and Russia (and countries of the former Soviet Union) moved forward in arms control treaty negotiations, each country dismantled large numbers of nuclear weapons, resulting in an increasing amount of HEU and weapons-grade plutonium being stored. "As a result [of these treaties], 50 or more metric tons of plutonium on each side are expected to become surplus to military needs, along with hundreds of tons of highly enriched uranium. . . . The existence of this surplus material constitutes a clear and present danger to national and international security" (NAS, 1994, p. 1). Some have argued that reactor SNF is not a serious security threat because reactor-grade plutonium differs from weapons-grade plutonium. However, "[p]lutonium customarily used in nuclear weapons (weapons-grade plutonium) and plutonium separated from spent reactor fuel (reactor-grade plutonium) have different isotopic compositions. Plutonium of virtually any isotopic composition, however, can be used to make nuclear weapons. . . . Thus, the difference in proliferation risk posed by separated weapons-grade plutonium and separated reactor-grade plutonium is small in comparison to the difference between separated plutonium of any grade and unseparated material in spent fuel" (NAS, 1994, p. 4). Another argument is that only separated plutonium is of concern, not SNF, but "[s]pent fuel poses proliferation risks that are initially far lower, but increase with time as the intense radioactivity that provides the most important barrier to recovery of this material decays" (NAS, 1994, p. 205).

“Because plutonium in spent fuel or glass logs incorporating high-level wastes still entails a risk of weapons use, and because the barrier to such use diminishes with time as the radioactivity decays, consideration of further steps to reduce the long-term proliferation risks of such materials is required, regardless of what option is chosen for disposition of weapons plutonium” (NAS, 1994, p.2).

The National Research Council's (NRC's) report, *The Disposal of Radioactive Waste on Land* (NRC, 1957; see [Sidebar 1.2](#)), which was written at the request of the U.S. Atomic Energy Commission, marked the beginning of a decades-long process, still under way, in which governments in the United States and elsewhere have sought to identify disposal sites for HLW, including the effort that is now under way at Yucca Mountain, Nevada. Repository research and siting efforts are under way in many other countries as well, most notably, Belgium, China, Finland, France, Germany, Japan, Russia, Sweden, and Switzerland. Additionally, Canada, Italy, Mexico, the Netherlands, Taiwan, South Korea, Spain, and the United Kingdom have storage programs for their HLW. Moreover, HLW in need of safe management is also located in nations that are part of the former Soviet Union, in countries having Soviet-designed nuclear power reactors, and in other countries. [Figure 1.1](#) illustrates the general concept of a geological repository.

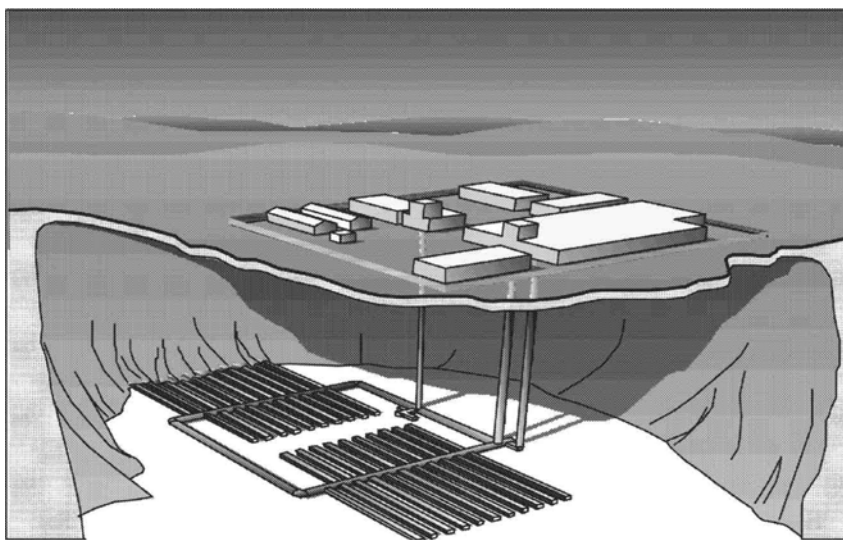


Figure 1-1 Deep geological repository concept.

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Many national programs are seeking improved methods for addressing the safe and responsible management of HLW. Some countries have begun a phased approach to repository development, while others have suspended their programs until some later date when, it is hoped, advancements in knowledge will allow more informed decisions to be made. In the United States, for example, the U.S. Department of Energy is considering a plan for a HLW repository at Yucca Mountain that would be designed for ultimate closure (disposal) but would provide the capability to delay for centuries, or even indefinitely, the date of actual closure (see [Sidebar 1.3](#)). The final decision on closure would therefore be made by a future generation. In Canada, a federally appointed panel has recommended that the government postpone the search for a repository site until broad public acceptance of the geological isolation approach has been achieved. In Germany, there has been intense public opposition to moving spent fuel to an interim storage facility at Gorleben, the site of the German candidate repository, and the decision on whether to proceed with development of a repository at Gorleben has been delayed. In the United Kingdom, a House of Lords committee conducted a full-scale inquiry into the management and disposal of radioactive wastes after a government decision to cancel a proposed underground research laboratory project at Sellafield. Spain has halted its siting program, and in Hol

### **SIDEBAR 1.2: THE CHANGING CONTEXT OF GEOLOGICAL DISPOSAL**

Many changes have occurred in practices and policies for waste disposal since publication of *The Disposal of Radioactive Waste on Land* (NRC, 1957). Particularly important is the composition of the accumulating inventory of HLW. In the 1950s and 1960s, it was widely assumed that essentially all spent nuclear fuel (SNF) would be reprocessed to recover uranium and plutonium. Today, the United States and some other nations have established national policies not to reprocess SNF, but rather to dispose of it directly. England and France have built and still operate reprocessing facilities; Japan has a reprocessing facility under development and has also sent its SNF to England and France for reprocessing; and Russia currently is reprocessing some of its SNF. Germany, Belgium, Switzerland, and the Netherlands have reprocessing contracts with France and the United Kingdom. Some plutonium produced from reprocessing facilities is recycled in lightwater reactors, and the remainder is stockpiled. It has greatly diminished value as a reactor fuel because there are plentiful supplies of uranium on world markets and because the technology of fast breeder reactors, which need plutonium as fuel, has not been developed to reach economical feasibility. Plutonium is also viewed as highly dangerous because it can be used to fabricate nuclear explosives (see [Sidebar 1.1](#)). The United States and Russia now have sizable inventories of plutonium from dismantling nuclear weapons that both nations have declared to be surplus (NAS, 1994). This surplus plutonium may be burned in current nuclear reactors, or it may be designated as waste.

land all work on specific disposal projects has been formally suspended for 100 years. [Chapter 4](#) of this report provides a summary of the status of national HLW programs.

In the midst of this general picture of forced or planned delays in repository programs, there are some more positive examples. In the United States, the Waste Isolation Pilot Plant (WIPP) has gone into operation as the first geological repository designed for disposal of transuranic waste (see [Sidebar 4.1](#)).<sup>1</sup> A community in Finland has agreed to host a HLW repository, and application has been made for a siting permit. The low- and intermediate-level waste programs in Sweden and Finland have been successful, and the Swedish HLW program is advancing, although more slowly than originally planned.

Repository programs have not moved ahead as they were expected to by the technical community and by the political leadership that has sought advice from the technical community on management of HLW. In many countries, *when*—and even *if*—the country will move ahead toward geological disposal are now open questions (NEA, 1999a).

## QUESTIONS TO BE ADDRESSED IN THIS REPORT

The committee used the following seven questions to frame the discussions at its November 1999 workshop ( [Appendix B](#) ) and to frame the deliberations that led to this report:

1. How can safety be assured for HLW?
2. How can safety and security against human actions be assured for HLW?
3. What are the inherent limits to assuring safety and security by geological repositories or by surface storage?
4. Why has there not been more progress toward geological disposal?
5. Are there available alternatives to geological disposition or surface storage?
6. Do national programs have to choose now between geological repositories and surface storage?
7. Are new initiatives needed in international cooperation?

These issues are discussed briefly below to set the context for the more detailed discussions that appear in subsequent chapters of this report.

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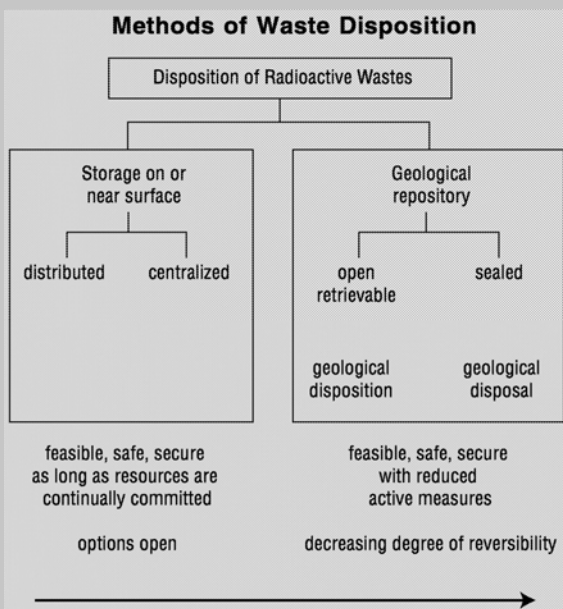
<sup>1</sup> The U.S. government defines transuranic waste as waste that is not HLW but contains alpha-emitting isotopes that have atomic numbers greater than 92 and half-lives greater than 20 years in concentrations that exceed 100 nanocuries per gram. This waste is comprised primarily of materials contaminated with plutonium and other actinides from weapons production activities. Transuranic waste is considered to be a component of long-lived intermediate-level waste or “alpha-bearing” waste in other countries.

### SIDEBAR 1.3: WHAT IS THE DIFFERENCE BETWEEN DISPOSAL AND DISPOSITION?

The committee uses the terms *disposition* and *disposal* in very precise ways in this report, as illustrated by the figure below. The term *disposition* is used to describe the active management of radioactive waste, either in distributed or centralized storage facilities located at or near the earth's surface, or in yet unsealed underground geological repositories designed for permanent isolation of waste. The term *disposal* denotes an end to the need for reliance on active management for assuring safety and security of the waste.

The figure below illustrates some of the attributes of facilities designed for disposition or disposal of radioactive waste. Facilities designed for disposition require an ongoing vigilance and commitment of resources by society to isolate the waste. Because these facilities are designed to allow for retrieval of the waste, society is able to keep its options open in terms of how waste could be managed in the future. Properly designed disposal facilities, on the other hand, provide safety and security without active management, thus freeing society from future resource commitments, although society would probably maintain vigilance through activities such as long-term monitoring. Disposal facilities are also characterized by a decreasing degree of reversibility. Although a closed and sealed disposal facility could, in principle, be opened and the waste retrieved, such actions could be costly and would require care to avoid exposing workers to high doses of radiation.

The bottom arrow on the figure illustrates one of the important conclusions of this report: namely, the committee's expectation that, with time, most national programs will move from a reliance on disposition to disposal. As discussed elsewhere in this report, however, the time scale for this transition may be decades to centuries.



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## How Can Safety Be Assured for HLW?

Safe management of HLW requires the containment of radioactive materials so that they do not impact adversely on human or environmental health. Safety has been a paramount criterion since the initial studies on HLW management. The summary of the 1957 NRC report states, “Unlike the disposal of any other type of waste, the hazard related to radioactive waste is so great that no element of doubt should be allowed to exist regarding safety” (NRC, 1957, p. 3).<sup>2</sup> Assuring that any releases of radioactivity from a repository will fall within acceptable limits has continued to be a major focus of discussion in the planning of geological repositories in the United States and in other countries.

The problem of assuring safety was considered initially by many of those involved in development of geological repositories to be closely linked to the selection of rock type. The 1957 NRC report found salt deposits to be promising, but did not recommend salt deposits without qualification. For disposal of liquid waste as contemplated at that time, the report noted problems with salt such as the structural weakness of salt cavities, and recommended a research program for further investigation. The report noted as the “second most promising method” the formation of “a silicate brick or slag which would hold all elements of the waste in virtually insoluble blocks” (NRC, 1957, p. 5). Thus, the 1957 report considered, as an alternative or supplement to finding a favorable geological setting, the development of an *engineered barrier* that would prevent radioactive materials from migrating into the geological environment from the original containment structure.

More than four decades later, many national programs have carried out extensive investigations of a variety of rock types and geological settings as candidates for geological repositories.<sup>3</sup> Much is known about the potential performance of candidate geological settings and engineered barriers, but the situation is now widely recognized to be more complex than originally expected. An important approach developed to reduce the impact of this complexity and of the resulting uncertainties is to employ multiple barrier systems, with engineered and geological barriers working together to give a robust overall safety system. A robust approach to

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<sup>2</sup> This quote has been included as evidence that the authors of the 1957 NRC report regarded assurance of safety as a paramount goal. The current committee also regards assurance of safety as a paramount goal, but it believes that the criterion “no element of doubt should be allowed to exist” is potentially misleading, given the complexities and inherent uncertainties in predicting events that could lead to the release of radioactivity. See the discussion later in this chapter, “What Are the Inherent Limits to Assuring Safety and Security by Geological Repositories or by Surface Storage?”

<sup>3</sup> Deep seabed disposal also has been proposed as providing isolation. This is discussed in [Chapter 7](#).

dealing with uncertainties is particularly necessary because of the long time scales to be considered. The radioactivity of most fission products lasts less than a thousand years, but radioactive decay for actinides such as plutonium and neptunium takes place over a much longer time, up to millions of years. Four decades of experience show that surface storage facilities can provide secure containment, as long as the storage facilities are maintained and managed adequately to assure containment integrity. Maintenance and control of storage facilities by responsible institutions for periods up to a few centuries is considered reasonable (IAEA, 1999). There are no technical reasons why such facilities could not be rebuilt periodically, provided adequate resources are allocated for this purpose, technical expertise is maintained, and the inventories remain of a manageable size.

Technical means to evaluate and demonstrate safety are discussed in [Chapter 6](#) of this report.

### **How Can Safety and Security Against Human Actions Be Assured for HLW?**

Human intrusion into a repository and the consequent release of radioactivity could happen inadvertently. It must be expected that humans will continue to drill into and mine the earth to search for and recover a variety of materials that a future society may find valuable. It is difficult to anticipate how effective warning signs or other measures might be in alerting future miners and drillers that they could encounter HLW at a repository site established centuries or millennia before their time or whether such warnings would be necessary. Inadvertent human intrusion into a repository usually has been considered only as a safety issue.

In 1995, the Nuclear Energy Agency (NEA) published a recommendation that *deliberate* intrusion should not be covered in repository safety analysis (NEA, 1995b). Most of the repositories being contemplated for current national programs could be opened by a future generation using today's mining technology—for example, for future utilization of uranium and plutonium as an energy resource. The most serious threat from deliberate intrusion may be the recovery of materials to make nuclear weapons. In this case, the visibility of such intrusion may be important.

The committee uses the term “security” as a parallel term to safety to highlight the problem of human actions that could compromise safe HLW management in a different way, namely by the retrieval of fissionable components of HLW such as plutonium with the intent of making nuclear weapons, or by the dispersal of highly radioactive materials over populated areas as an act of terrorism. The risk of human intrusion, including both inadvertent intrusion and deliberate intrusion, is a concern for both waste storage and underground disposal.

These issues also are discussed in [Chapter 6](#) and [Chapter 7](#).

### **What Are the Inherent Limits to Assuring Safety and Security by Geological Repositories or by Surface Storage?**

During the 1990s, experience in many national programs that investigated geological disposal demonstrated the need for flexibility and for accommodating the inherent limitations in the information that scientific investigation can provide about the geological setting and the durability of engineered barriers. These important limitations in scientific understanding comprise “scientific uncertainty,” which can be reduced but not entirely eliminated by further research. This term will be used frequently throughout the report, with the committee’s recognition that the relative importance of different uncertainties lies in their potential consequences. All are not equally important. A robust safety system with built-in redundancy can reduce the consequences of uncertainties in the performance of individual components.

Current scientific and technical knowledge might be interpreted as leading to pessimism that “every element of doubt” (the phrase used in the 1957 NRC report) regarding the safety of HLW can be eliminated. However, extensive analysis of uncertainties may allow the overall doubts to be resolved. The British philosopher Francis Bacon wrote in 1605:

If a man will begin with certainties, he shall end in doubts; but if he will be content to begin with doubts he shall end in certainties.

Today, it is understood within the waste management community that the design and assurance of the safety of geological repositories must be a carefully considered exercise in making decisions in the face of scientific uncertainty. For long-term surface storage, the uncertainties are of a different character: they involve uncertainties as to whether the needed commitment of the necessary resources and vigilance will be maintained by society in the distant future.

[Chapter 6](#) introduces concepts from risk analysis and decision making in the face of uncertainty (see [Sidebar 1.4](#)). Characterizing uncertainties is also discussed in [Chapter 6](#) and [Chapter 8](#).

### **Why Has There Not Been More Progress Toward Geological Disposal?**

The technical challenges in designing and constructing a geological repository for HLW and assuring its safety have proved to be larger than many experts originally expected. Surface storage is much easier to construct than a geological repository, but ongoing maintenance is required. In addition, there are a number of important societal issues. In particular, radioactive waste is feared by many members of the general public, and



there is a distrust of experts and organizations that manage this waste. Often, national programs have regarded management of HLW as a purely technical problem, rather than both a technical and a societal problem (see [Sidebar 1.5](#)). As a result, the institutional and decisional processes often have been poorly equipped to deal with the societal challenges encountered. Meeting the societal challenges involves achieving better understanding of the answers to questions such as the following:

1. What explains the public concerns about the management of HLW?
2. How have such concerns been addressed in national waste management programs and with what results?
3. What lessons have been learned, and what new approaches are emerging, to gain increased public support and confidence in the making and implementation of decisions concerning the storage and disposal of HLW?

#### SIDEBAR 1.4: RISK AND SAFETY

Many areas of science and public policy are concerned with assuring public health and safety. Modern methods for analysis of safety involve assessing both the likelihood and the severity of situations involving harm: to humans, to property, or to aspects of the environment. Such analysis is often described as “risk analysis.” in this context, “risk” is defined as a description of possible harm, in terms of both the probability of occurrence and the severity of the consequences. In some public health and safety contexts, the probability of occurrence can be obtained from available statistical information. However, in many contexts, such statistical information is not available. Judgments about probability of occurrence must be based on other types of information, such as extrapolation from observed data or predictive use of scientific models. For example, the risk of developing cancer as a result of exposure to low doses of ionizing radiation (from radioactive waste or from other sources) cannot be observed directly from epidemiological data, but rather is estimated from data on increased cancer incidence following exposure to higher doses of ionizing radiation. (For details, see the series of NRC reports “Biological Effects of Ionizing Radiation” [BEIR].) Broader discussions of risk and the use of risk analysis can be found in recent NRC reports such as *Understanding Risk: Informing Decisions in a Democratic Society* (NRC, 1996a), *Science and Judgment in Risk Assessment* (NRC, 1994b), and *Improving Risk Communication* (NRC, 1989b). An historical overview of the development of the concept of risk is found in Bernstein (1996). A good modern overview on risk and uncertainty is found in Morgan and Henrion (1990).

The status of national programs is summarized in [Chapter 4](#). [Chapter 5](#) discusses public perceptions and attitudes toward radioactive waste, particularly HLW. [Chapter 5](#) and [Chapter 8](#) also address how public participation and public confidence might be enhanced through broader, more transparent processes for decision making and for implementation of decisions on management of HLW.

### **SIDEBAR 1.5: WHO ARE THE PUBLIC AND THE TECHNICAL COMMUNITY?**

HLW is an example of a public policy issue in which there is a widespread perception of a division between the public and technologists. On one side appear to be the technical and scientific experts in the technologies and processes involved with HLW. These experts include not only physical scientists, but also engineers and managers, workers in the nuclear industry, social scientists, and policymakers who have engaged themselves in radioactive waste issues. Members of the public, on the other side, may lack specialized training or experience, but nevertheless many have genuine interest—and sometimes concerns or fears—about radioactive waste.

In developing this report, the committee recognized that both groups are heterogeneous in their knowledge and in their feelings, perceptions, and judgments about HLW. The word “community” should not be taken to imply consensus. Also, by its choice of terminology, the committee does not wish to imply that any interested parties are, or should be, excluded as participants in the public policy process. In this sense, all persons are members of the public, all should be enabled to engage in discussion and debate, and all can help in implementing recommendations to address the challenges posed by HLW. A continuing theme in the 1999 workshop that initiated this report and in the committee's subsequent discussions was encouragement of openness and participation in discussion and debate about both societal and technical challenges.

With the above in mind, the committee refers in this report to “the technical and scientific community” or “the technical community” and to “the public,” “segments of the public,” or “members of the public” depending on which term best fits the context.

### **Are There Available Alternatives to Geological Disposition or Surface Storage?**

A considerable amount of study has been devoted over many years to alternatives to geological disposal of HLW. Among those that have received the most consideration are disposal in the seabed, partitioning and transmutation<sup>4</sup> (P&T) of long-lived isotopes, and continued surface storage. P&T can reduce the amount of actinides and long-lived fission products, but its actual efficiency in practice is unknown, and inevitably some radioactive waste will remain. This waste will require management in a geological repository or in surface facilities.

These alternatives are discussed in [Chapter 7](#).

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<sup>4</sup> According to this concept, which is discussed in [Chapter 7](#), long-lived isotopes would be separated (“partitioned”) from other waste components and changed (“transmuted”) into other, shorter-lived isotopes by a nuclear process, for example, neutron irradiation.

## **Do National Programs Have to Choose Now Between Geological Repositories and Surface Storage?**

Many discussions of the need for geological repositories have taken the position that current generations have an ethical imperative to avoid imposing the burden of ongoing surveillance and management and, ultimately, disposal on future generations. At a time when many considered that assurance of the safety of geological repositories would easily be accomplished and demonstrated, this objective was accepted widely. As difficulties have emerged both with making the technical case for repository safety and with gaining public acceptance of repository programs, the feasibility of this objective has been increasingly questioned. The argument is predicated on acceptance of the assumption that a sealed repository represents less of a future burden than stored wastes for which one is still free to choose a disposal option. Many parties within the international HLW community now are considering the merits of a strategy involving emplacement of HLW deep underground in a facility designed for permanent closure but with the intent to carry out monitoring for a considerable period of time with an ongoing possibility of retrieval, as opposed to a program that involves relatively prompt closure of a repository and the absence of planned activities thereafter.

Several factors motivate ongoing study and monitoring rather than expediting repository closure as soon as the HLW can be emplaced. First, active monitoring of the response of the geological site and of the engineered barriers to the waste may lead to adjustments to improve the robustness of the containment system. Second, provisions for ongoing monitoring may be viewed by some members of the public as preferable, so that if very unlikely failures in containment or unexpected events should occur at the repository, effective and timely action can be taken to avoid releases of radioactivity into the biosphere. Third, retrievability may become desirable in the future because of the energy value of components such as uranium and plutonium in spent fuel.

The counter-arguments are that safe disposal is thought already to be feasible, and that delaying closure for a long time presents a greater hazard. Retrieval from a closed geological repository remains, in principle, possible for a very long time, although it may be comparable in cost to repository construction after the repository has been closed.

These issues are discussed further in [Chapter 6](#) and [Chapter 7](#).

## **Are New Initiatives Needed in International Cooperation?**

Most of the planning of HLW management has been through individual national programs. Most nations with commercial nuclear power reactors have a nuclear waste program or have plans to establish such a

program in the near future. The concept underlying these national programs is that a nation with commercial nuclear reactors will retain its own HLW, either in the form of spent fuel or as the waste residue from reprocessing, and will dispose of this waste in its own territory. The United States and several European nations are far along in planning HLW repositories, but no country has approved a design and commenced construction, although the United States has started operation of a geological repository for long-lived transuranic intermediate-level waste (the Waste Isolation Pilot Plant, see [Sidebar 4.1](#)). The national HLW programs regularly share technical data and the results of ongoing scientific research, and many scientific experts participate in multiple national programs. International conferences are held regularly, and international organizations such as the NEA, the International Atomic Energy Agency, and the European Union have promoted consensus building on appropriate principles and technology for a HLW program.

Several factors suggest that it may be appropriate to increase the extent of international cooperation on HLW. The motivating factors and potential new initiatives are discussed in [Chapter 9](#).

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## 2

# Principal Findings and Conclusions

This chapter presents the committee's principal findings and conclusions regarding the disposition of high-level waste (HLW).<sup>1</sup> Each broad finding or conclusion is discussed briefly in this chapter, and further information that led the committee to its judgments is presented in [Chapter 4](#) , [Chapter 5](#) , [Chapter 6](#) , [Chapter 7](#) , [Chapter 8](#) through [Chapter 9](#) . Recommendations derived from the committee's findings and conclusions are given in [Chapter 3](#) .

This chapter begins with the finding that the inventory of HLW is growing, which implies an increasing need to assure the safety and security of such materials. In many countries these materials are stored temporarily at or near the facility that produced them. While the committee believes that this practice is not generally sustainable in view of the growing inventory,<sup>2</sup> security concerns, and the decommissioning of many currently operating nuclear power reactors during the next several decades, the committee recognizes that radioactive waste management is a matter of national decision in each country. The committee also recognizes that for most countries there is no immediate urgency to implement a long-term alternative, since the present volume of radioactive waste is relatively small and manageable. Apart from continuing with current practices, there are only two available alternatives:

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<sup>1</sup> As discussed in [Chapter 1](#) , for convenience in terminology the committee uses the term “high-level waste” to include reprocessing waste, spent nuclear fuel (SNF) if it is considered to be a waste, and other nuclear materials designated for disposition along with reprocessing waste and SNF.

<sup>2</sup> About 25 countries have projected significantly increased inventories over the next 10 to 20 years. See [Chapter 4](#) .

1. implement new **storage** facilities, and
2. work toward emplacement in a repository (“**geological disposition**”), with the expectation that the repository eventually will be closed and sealed (“**geological disposal**”). See [Sidebar 1.3](#).

The advantages and drawbacks of both alternatives (and the likelihood of other options becoming available) must be evaluated as input for the necessary societal decisions. The benefits, costs, and risks associated with the two current options are of a radically different nature, so that a phased approach may enhance the benefits of both options.

The long-term storage alternative can provide safety and security, as proven by more than 50 years of operation of such facilities. It also fulfills an ethical goal of keeping future options as open as possible. It can be extended to very long times in the future, provided that the storage is continuously monitored and maintained and periodically rebuilt. However, this option also faces societal challenges: efforts to site new storage facilities typically encounter public resistance, and storage requires a continuing commitment of resources. There is uncertainty that future societies will have the stability to maintain the strict institutional controls needed to prevent intentional misuse of nuclear materials or the will to continue to provide resources for the monitoring and maintenance needed for safety.

Geological disposal, the approach recommended in previous National Research Council (NRC) reports (NRC, 1957, 1990) and by many other national and international scientific bodies, is the only available alternative that does not require ongoing control and resource expenditures by future generations. The science supporting this alternative has been developed by intensive work over the past 25 years. The view repeatedly expressed by a large fraction of the scientific and technical community is that geological disposal, correctly managed, is a safe approach to long-term management of HLW and that it best satisfies the ethical goal of minimizing burdens on future generations. Nevertheless, uncertainties remain, and some scientists feel that it is premature to commit fully to disposal. The biggest challenges to initiating geological disposition, however, are societal: there is a clear lack of public confidence and support in many countries for proceeding with siting and construction of geological repositories.

Whether, how, and when to move toward geological disposition or disposal are societal decisions for each country, to be made following estimation of the uncertainties and risks associated with this option and with its alternatives. Given the technical and societal uncertainties, a stepwise process that allows for continuing improvement of scientific understanding is appropriate for decision making. A stepwise process, embedded within a flexible and adaptive management system, is also

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appropriate to facilitate better communication with, and increased involvement of, the public to improve the basis for these societal decisions. International cooperation can help to achieve solutions to safe and secure disposition for all nations with responsibility for HLW.

### **TODAY'S GROWING INVENTORY OF HLW REQUIRES ATTENTION BY NATIONAL DECISION MAKERS**

*The present situation in the management of radioactive wastes worldwide is one in which—with some important, mainly defense-related, exceptions—safety and security are being achieved by storage on or near the surface. This safe and secure storage is feasible technically as long as adequate resources and political attention are devoted to it. However, inventories are increasing, and the duration of the hazard is so long that present and potential future problems must be anticipated, acknowledged, and addressed. The critical issues are the following:*

- *Public health and safety.* Although the surface storage of wastes is satisfactory in most cases, the current storage conditions for some inventories do not meet national standards.
- *National and international security.* Fissile <sup>3</sup> materials can be misused by terrorists or by governments for clandestine development of nuclear weapons. Safeguarding the excess materials from weapons dismantlement is of critical importance. It also is important to safeguard the growing amount of separated reactor plutonium and the spent nuclear fuel (SNF).
- *Ethics.* Equity and fairness to current and future generations cannot be achieved unless positive steps are taken to manage the waste inventory in the long term.
- *Nuclear energy.* In many countries, consensus that radioactive wastes can be managed safely is one of the important prerequisites for continued or expanded use of nuclear power. Both the antinuclear and the pronuclear factions in society should have a direct interest in objectively clarifying whether safe and economic long-term management is feasible. In practice, opinions of both groups are colored by their views.
- *Public trust and confidence.* Many members of the public are concerned about the hazards of radioactive waste and about its linkage to potential nuclear weapons proliferation. They are yet to be convinced that scientists and national leaders can find a reliable solution for long-term isolation of radioactive wastes.

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<sup>3</sup> Fissile materials such as uranium-235 and plutonium-239 can undergo nuclear chain reactions that release large amounts of energy. They are basic materials for making nuclear weapons.



An international overview of the problems with HLW and other long-lived wastes begins with the observation that there are substantial existing inventories of these wastes. The inventories are growing because of the continuing use of nuclear power, the growing pace of disarmament, the increased emphasis on cleaning up historic defense-related “legacy” wastes, the decommissioning of nuclear power plants, and the application of nuclear technologies in medicine, industry, and research. The growing inventory presents the same or similar challenges (both technical and societal) in many countries, and there is much ongoing international cooperation. There are, however, significant differences among countries—including the management option chosen for SNF; the types, quantities, and current disposition methods for wastes; and the societal values prevailing—so that a universal solution cannot be expected.

HLW presents potential *safety* and *security* problems. Safety refers to the risk of radiation doses to present or future generations because of inadequate isolation of radioactive waste from the biosphere. Most attention is paid in the technical analyses to potential releases of radionuclides from storage and disposal facilities, but other issues such as transportation safety also are relevant, and they are especially important to the public. Current practices, involving primarily storage of wastes at or near the production facilities, are regarded as safe by most national authorities. However, the growing inventory and the potential hazards involved suggest that this status quo cannot be sustained without a growth in risk, as new storage facilities are required. Moreover, there are also some urgent situations in which action is needed because adequate near- and long-term safety has not yet been achieved, particularly for defense-related wastes (e.g., U.S. Hanford Site tank wastes and Russian Northern Fleet and Mayak wastes).

The leading security concern is the danger of misuse of fissile materials leading to the proliferation of nuclear explosive devices. Proliferation is a significant near-term threat. Reducing this threat motivates centralization of fissile materials and restricting access to plutonium and spent fuel (NAS, 1994; Carter and Pigford, 1999). There is growing concern that the risks of misuse are increasing, in particular, because the dismantling of nuclear weapons is producing large stocks of such materials. The threat posed by SNF is much less, although not insignificant (see [Sidebar 1.1](#)).

The widespread practice of storing wastes at or near facilities where they were produced and the lack of progress toward an accepted long-term solution contradict intergenerational ethical objectives of fairness for both those who benefit from nuclear technologies and those affected by the waste. Achieving fair and equitable solutions to the waste problem has been, and will continue to be, a complex and difficult task. Neverthe

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less, developing equitable solutions is the responsibility of national decision makers.

In many countries, the use of nuclear energy has met with increasing opposition over the past decades. The debate encompasses various aspects of nuclear power, including operational safety, economics, and waste management. The feasibility or infeasibility of safe long-term management has been an especially contentious feature of the debate. Demonstration of safe long-term waste disposition has been made a formal prerequisite for continued use of nuclear power in some countries. Such a prerequisite can lead to attempts by antinuclear factions to hinder work toward a waste disposal solution. It can also result in attempts by pronuclear factions to push a solution through on a shorter time scale than is technically necessary.

Finally, and perhaps most importantly, a segment of the public has concerns and fears that radioactive wastes present a large and unmanageable threat. The challenge is therefore not just to identify options that are deemed suitable by technical experts for protecting the public, but also to assure that the decision processes and waste management technologies chosen have sufficiently broad public support. Support for any chosen technology will be difficult to achieve unless options for managing wastes can be presented, together with their consequences, and the public can participate in choosing among those options.

For all of the above reasons, the committee concludes that the challenge of achieving safe and secure disposition of HLW in a manner that is technically sound and publicly acceptable requires attention by national decision makers.

### **THE FEASIBLE OPTIONS ARE MONITORED STORAGE ON OR NEAR THE EARTH'S SURFACE AND GEOLOGICAL DISPOSITION**

*The presently feasible options for HLW management are monitored storage on or near the earth's surface, or geological disposition in a mined repository that can become the site for geological disposal, if a decision is taken that the repository be filled, closed, and sealed. A stepwise process to move eventually from storage to disposal is described later in this chapter.*

Although decisions on managing radioactive waste are the prerogative of each individual country, the committee believes that the widespread current practice of temporary storage at or near the various sites of its production is not sustainable for the long term in view of growing waste inventories, security concerns, and aging nuclear facilities. If HLW is not managed properly, serious risks to public health and safety and to security will result.

Safe and secure surface storage is technically feasible as long as those responsible for it are willing and able to devote adequate resources and political attention to maintaining the facilities. Such storage has been shown to be safe and secure over several decades of past experience, and the technologies involved are well understood. HLW and SNF in storage facilities are readily monitored and retrieved. Current storage practices are intended for periods of about 50 to 100 years. There appears to be no technical reason why this storage could not be extended indefinitely, with continuing resources for upkeep and expansion as needed. Surface or near-surface storage is a long-term option provided society is willing to commit to ongoing active management to assure the integrity of the storage facilities. Surface facilities will always have a limited lifetime (e.g., decades to centuries). If storage facilities are to be used beyond their design lifetime, they will have to be rebuilt. This is technically feasible but obviously creates a financial and societal burden on future generations.

Geological repositories will also require management, including monitoring and safeguarding, for many decades. The isolation of HLW from the environment in deep formations can help to assure security and safety by limiting human access. The initial capital costs of geological repositories are higher than those for surface storage facilities, although the final economic balance between options will depend strongly on financial assumptions. In choosing where to place the inventory of HLW over the next decades to several centuries, a society is confronted with decisions involving costs and risks, both long and short term, as well as how it might eventually progress toward a permanent, passively safe solution to waste management. Geological disposal is designed to provide passive safety and security. Storage also can provide ongoing safety and security, provided active management is continued. So can geological disposition, which is a reversible step toward geological disposal. *There are no other available choices.* All of the other known options either leave some HLW to be managed or cannot be implemented in the foreseeable future. Both surface storage and geological disposal involve uncertainties and risks. However, these uncertainties and risks differ in character in the two cases.

For surface or near-surface storage, the committee perceives the major uncertainty to be the confidence that future societies will continue to monitor and maintain the storage facility. Will society keep its technical expertise indefinitely? Will it be willing or able to continue committing resources? In particular, will a future society that may no longer be using nuclear power still possess the expertise and the will to continue maintaining surface facilities? Can wars, terrorism, cataclysms, or negligence jeopardize the safety and security of storage? Because HLW re

mains hazardous for a period of centuries to millennia, abandoned surface storage would pose a major risk to human health and safety.

For geological disposal, uncertainties and risks have three prime sources: (1) Have the geological properties of the site been well identified, and is the future behavior of the system (consisting of both geological and engineered barriers) sufficiently well understood? (2) Can natural geological processes significantly jeopardize the behavior of the system and make it unsafe (e.g., new faulting, volcanic eruptions, or climate changes)? (3) Can unforeseen human actions in the future jeopardize the safety of the site?

Selecting a disposition option should be done only when these different types of uncertainties have been compared and the preferred option has been chosen, based on an evaluation of the level of risk and public acceptance of each.

The growing inventory in temporary storage raises equity and ethical issues that influence the choice of socially acceptable methods to assure safety and security. These issues include the following:

- the nature of our responsibilities to future generations (the need to protect future generations over very long periods, the desire to minimize burdens, and the wish to keep options open);
- how to redress inequities between the beneficiaries of the activities that produced the wastes and those who fear the risks associated with transport, storage, and disposition;
- who will bear the burden of proof for addressing uncertainties in proposed options and for making decisions to proceed with one option; and
- how to avoid the extremes of communicating greater certainty than actually exists and of exaggerating the importance of imperfections, gaps, or potential inaccuracies in the state of knowledge.

Much of the societal concern is for the long term: what may happen after centuries or millennia. Here there are fundamental differences in views on whether geological disposition should be pursued now or deferred for a significant period of time. These differences arise primarily because of divergent judgments about

- the importance of the different types of uncertainties associated with storage and disposal (i.e., societal and technical uncertainties); and
- the priority allocated to conflicting ethical responsibilities to future generations (e.g., minimizing burdens versus maximizing choices).

These fundamental differences were reflected also in the views of the committee members. They strongly colored the preferences with respect to storage versus the early pursuit of geological disposition and also

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assessment of the needs for further research in the social and physical sciences. On the surface, monitoring and retrievability can easily be assured. In a deep repository, monitoring and retrievability also are possible and are made easier if one plans for a long period of retrievable emplacement as an interim step to disposal. Storage of HLW can provide safety and security. Nevertheless, the committee believes that it is not prudent to pursue only storage, without further development of the geological disposition option—**unless a society believes it can credibly commit to permanent maintenance of its storage facilities**. Storage leaves a potentially serious safety and security hazard on the surface; geological disposal is intended to do otherwise. Progress in geological disposition does not imply taking irreversible steps. The final decision to close and seal a geological repository will be made after decades of further observation and reflection within society, weighing the merits and uncertainties of continued storage versus geological disposition.

### **GEOLOGICAL DISPOSAL REMAINS THE ONLY LONG-TERM SOLUTION AVAILABLE**

*After four decades of study, geological disposal remains the only scientifically and technically credible long-term solution available to meet the need for safety without reliance on active management.*

Both safety and security are ongoing concerns for the existing HLW that is now stored on the earth's surface. The committee agrees that geological disposal is the only scientifically and technically credible long-term (i.e., many thousands of years) solution that is available to meet the need for safety **without reliance on active management**. Emplacement of the waste beneath the ocean or polar ice, which are technical variations of geological disposal that would also put the waste far below the earth's surface, are presently prohibited by international treaties. Disposal in space is not expected ever to be a practicable, safe technology.

With regard to long-term *safety*, there do exist several actual or potential technological ways to modify the characteristics of the waste and thereby reduce future uncertainties. These include storing the waste for long enough to achieve some radioactive decay, chemical modifications to make waste more stable physically and chemically, and nuclear modification using partitioning and transmutation to reduce the quantity of long-lived radionuclides (see [Chapter 7](#)). All leave residual long-lived wastes, which require continued management or geological disposal. Thus, there is no available technical alternative to eventual geological disposal for permanently removing the waste from the human environment.

The case is somewhat different for *security*. Technically feasible options for enhancing security do exist, such as burning fissionable materials in nuclear reactors. Therefore, the argument that geological disposal

is the only way to avoid the necessity for perpetual care and maintenance is not based directly on security concerns. However, geological disposal does offer obvious security benefits, because it would place fissile materials out of the reach of all but the most sophisticated potential builders of weapons. This is extremely important, because misuse of fissile materials that can be extracted from some types of radioactive waste may be the greatest hazard that radioactive waste presents to society.

### **GEOLOGICAL DISPOSAL IS SCIENTIFICALLY AND TECHNICALLY SOUND, BUT IMPORTANT CHALLENGES REMAIN**

*The scientific and technical basis for geological disposal is well advanced, but significant challenges remain for the characterization and performance assessment of specific sites. Nevertheless, the broad consensus in the scientific and technical community is that the knowledge database is adequate for supporting decisions in a step-by-step process leading toward geological disposal.*

The scientific and technical basis supporting the geological disposal concept has been built up over many years since the initial NRC report on the geological option was issued in 1957. This work has included fundamental studies on matrices for stabilizing the waste, other man-made barriers against release, and a variety of geological media in which a repository could be constructed. Research in specially constructed underground laboratories in several countries has included many interdisciplinary national and international collaborations. As in all scientific work, progress has been marked by surprises, new insights, and the recognition that for even the best-characterized sites, there always will be uncertainties about the long-term performance of the repository system. Providing convincing evidence that any repository assures long-term safety is a continuing technical challenge.

To address this challenge, significant effort has been devoted worldwide over the past 25 years to the development of safety assessment methodologies and to achieving international consensus within the technical community on suitable approaches. During the 1980s and 1990s, the recognized need for a common understanding of the safety of repository concepts being developed in different countries encouraged international discussions on methodologies and efforts to involve the public in these discussions. There exists today an extensive literature documenting the techniques, applications, and results of safety assessments (NEA, 1997a, 2000c, 2000d). This knowledge base makes it feasible to provide guidance and advice on safety assessments for radioactive waste disposal and to characterize the natural features, events, and processes important for a well-designed repository at a well-selected and characterized site. As documented in the 1991 "Collective Opinion" of the Nuclear Energy

Agency (NEA) of the Organization for Economic Cooperation and Development, the International Atomic Energy Agency (IAEA), and the European Commission (NEA, 1991b), the feasibility of performing assessments of sufficient quality to support decisions on implementation of geological disposition is accepted by technical experts within the waste management community.

In practice, there are many experts who feel confident enough about the state of current knowledge to advocate moving ahead now with repository implementation in correctly chosen locations. There are others who believe that a lot more research is needed before we even decide on the feasibility of permanent safe disposal. There are also those somewhere in the middle who support continuing the process leading to disposal, provided this remains stepwise and reversible. **The consensus of the committee reflects the views of this middle group.** The consensus that a cautious stepwise approach is the way to proceed was reached because those members who believe that the science and technology are already sufficiently mature recognize that the societal processes take time.

The committee believes that differences in confidence among these groups are related, at least in part, to differences in their views of what is required to demonstrate repository safety, especially in the level of scientific understanding of repository system performance available today. In light of this experience, much of the scientific and technical work has included too few confidence-building measures such as peer review, formalized quality assurance, transparent documentation, large-scale demonstration, and—of great importance—development of processes to assure open discussion among all involved parties. Finally, the committee found that national programs generally have not developed scientifically sound and objectively balanced considerations of alternatives to geological disposal. Perceptions by the public and some members of the technical community of bias or predisposition toward the geological option probably have offset the credibility of much scientific effort.

Recently, there has been an increasing awareness among those involved in technical and safety analyses that a broad perspective is needed to enhance confidence; narrow concentration on meeting specific regulations is recognized as insufficient (NEA, 2000b). The committee agrees with this judgment and concludes that simple, unsubstantiated reiteration of the technological conclusion that geological disposal is the preferred solution will be less constructive than assuring that the criteria for making decisions are made public and discussed.

### THE BIGGEST CHALLENGES ARE SOCIETAL

*Today the biggest challenges to waste disposition programs are societal in nature. Difficulties in achieving public support have been seriously underestimated in*



*the past, and opportunities to increase public involvement and gain public trust have been missed. Most countries have made major changes in their approach to waste disposition to address the recognized societal challenges. Such changes include initiating decision processes that maintain choice and that are open, transparent, and collaborative with independent scientists, critics, and the public.*

A complex of factors drives the high levels of public concern and lack of confidence in radioactive waste management programs apparent in most countries. These include the following:

- *Unrecognized need.* Many members of the public are not yet persuaded of the need for geological disposition of wastes. Meanwhile, the technical community has yet to convince the public of the long-term safety of the geological repository concept.
- *Public perceptions of risk.* Radioactive wastes are seen not only as significant dangers for health, safety, and the environment, but also as raising strong questions about the trustworthiness of institutions and their capacity to manage waste. Conventional safety analyses of repositories may not directly address the broader range of concerns that underlie public perceptions of risk.
- *Value conflicts.* Competing and conflicting values among different stakeholder groups (such as scientists, segments of the public, local communities, and national populations) make attaining any general consensus very difficult.
- *Equity and ethical dilemmas.* The management of HLW involves choices among competing and sometimes conflicting equity and ethical principles. Inherent conflicts arise between the ethical aims of minimizing burdens on future generations and maximizing their freedom of choice.
- *Distrust.* Low public trust in radioactive waste institutions and managers exists in many countries, influenced by a history of stop-and-start policies in this area, the failure to consult adequately in the past, and a more general decline of trust in social institutions across most industrialized countries. The issue of distrust is discussed in [Chapter 5](#).

The concept of risk based on the usual technical estimates of potential future radiation doses from repositories does not capture these broad factors driving public concerns. The concerns of the public are not likely to be changed solely by quantitative assessments, greater technical information, official reassurances, or proffered benefits to communities that host waste management facilities. Recognition of this reality has led to a shift in which the waste problem is no longer considered a purely scientific or technical task, but rather a sociotechnical challenge in which value choices are receiving new attention; institutional openness, transparency, and accountability are emphasized; and new means of engaging con



cerned segments of the public are sought. This also applies to other technology-related challenges such as biotechnology and climate change or the siting of other facilities that segments of the public may deem undesirable, such as airports, highways, dams, and chemical plants.

Social science research and understanding have been underemphasized in all national waste programs, as is evident when examining the highly technical activities and organizational structures of implementing and regulatory agencies. Sound research, analysis, and integration are indispensable in the social sciences as well as in the natural sciences and engineering. Today, significant gaps in knowledge exist concerning such central questions as why public confidence is apparently so low in the radioactive waste management area compared to other equally or even more risky human activities, how to best define and measure public confidence, how conflicts among ethical imperatives might be resolved, whether there are more effective means for engaging members of the public, and how institutions might best rebuild societal trust. Beyond this, compared to the physical sciences, there has been relatively little formalized social science expert overview and peer review of assumptions and institutional processes in the waste area.

The committee notes that many national programs already have recognized the societal challenges and are restructuring accordingly. Changes to enhance public participation in all phases of waste disposition efforts have been initiated by national legislation, regulation, and, most importantly, waste management organizations themselves. The committee regards this change as a positive and essential step in the development of waste management options.

### **WHETHER, WHEN, AND HOW TO MOVE TOWARD GEOLOGICAL DISPOSAL ARE SOCIETAL DECISIONS FOR EACH COUNTRY**

*Each country must choose whether, when, and how to move toward geological disposal. In structuring its national radioactive waste management strategy, each country will make judgments about the following:*

- *the safety and security of ongoing or new storage and of geological disposal;*
- *the stability of its societal structures;*
- *the willingness to make a continuing commitment of resources for maintenance and monitoring;*
- *the need for public support and confidence; and*
- *the fairness and equity of alternative solutions.*

*In any case, the decision process will be lengthy, and the time can be used to improve technical and societal approaches.*

Because radioactive waste can be stored safely on the earth's surface, implementation of geological repositories is not **necessary at any particular point in time**. Some countries will prefer to accept the risks and costs associated with longer-term surface storage until, or unless, sufficient national public support for geological disposition develops. Other countries may encourage or require emplacement of waste in geological repositories in the near-term future, preferring to accept residual risks associated with potentially inadequate repository performance, including the financial risk that waste will have to be retrieved if future information shows repository performance to be inadequate. Accordingly, there is a large variation in the timing foreseen for countries pursuing geological disposal, even when the ultimate need for such disposal has been accepted. For example, the United States, Finland, and Sweden have plans for implementing geological repositories early in this century; countries such as Germany, Japan, Switzerland, and the United Kingdom are considering dates near the mid-century. The Netherlands measures the time for implementation as 100 or more years. In Canada, decisions about if and when to implement geological disposition are formally open. France passed a law specifying that no national decision on geological disposition versus continued surface storage should be made before 2006. No country plans to close and seal a geological repository in less than 50 years.

Whatever choice is made, a number of years will pass before waste is emplaced in a central location, either a repository or new facilities to provide long-term storage. This period is appropriate to build the technical and social knowledge bases, the institutions, and the decision processes that will produce broad-based confidence in the solutions that eventually are chosen. Especially important will be efforts to consult, inform, and engage members of the public in weighing waste management options. It is important to consider how political decision makers can be presented with sufficient incentives to make them recognize that measures to advance toward long-term disposition of HLW and SNF should not be unnecessarily postponed or delayed.

Value judgments will enter into decisions on how and when to move from surface storage to a geological repository; values and cultures in different countries may lead to different choices. In each country, there is a need for a broadly based, deliberative process that takes into account ethical issues (values of, and burdens on, present and future generations), public perceptions, and choices available to future generations. The process chosen also will depend on the state of scientific knowledge behind the geological disposal concept and any potential alternatives. Making a choice among options requires that the advantages, drawbacks, and uncertainties of each should be understood and appreciated fully. Few countries have prepared an objective, comprehensive comparison of alternatives.

## A STEPWISE PROCESS IS APPROPRIATE FOR DECISION MAKING UNDER TECHNICAL AND SOCIETAL UNCERTAINTY

*Some—but not all—of today's uncertainties in predicting the future long-term behavior of a repository system can be reduced or eliminated by further research and development. However, for a very long time, "proof of safety" in the usual sense of these words will never be possible. This is also the case for many other technologies employed by today's civilization. For waste management, the long time scales give an added dimension, especially since the actions of future societies—particularly those in the distant future—cannot be predicted. Nevertheless, both our fundamental knowledge and our ways of dealing with uncertainty are advancing and will continue to do so during the course of a repository development program, which can last for many decades. A stepwise decision process can utilize this evolving knowledge to make sound decisions about repository siting, design, and operation.*

A stepwise decision process provides a means to improve knowledge and build confidence in repository development programs. Although a sound scientific methodology has been developed, it does not provide the capability to predict future repository behavior with the accuracy that would be required for complete assurance of containment over a thousand to a million years. How confident can one be in the results of these analyses? We must acknowledge and accept that neither a 100 percent level of safety nor 100 percent confidence in the reliability of the safety assessments is possible. This fact is true for every other comparable technical undertaking as well, but more attention has been devoted to the radioactive waste disposal issue than to most others. A commonly noted difficulty in quantifying the long-term safety of a repository is that there are no historical data with which to calibrate the methodology directly. This is, however, true for other technologies in which extremely low failure rates must be assessed.

The uncertainties in waste disposal do present formidable challenges, especially in what has been called *conceptual uncertainty*. This is distinct from normal uncertainties in data or calculational methods. In all cases, what is really important is the consequence of uncertainties about the behavior of the repository over long times. For data and methodological uncertainties, the influence on overall performance can be assessed more readily than for conceptual uncertainty. The latter is concerned with inherently incomplete understanding of the physical and chemical phenomena that control site and repository behavior and of the future events that might affect repository performance such as climate, tectonics, and human behavior. In addition, uncertainties in projecting future human actions at a storage or disposal site grow with time to be larger than the technical uncertainties. Such societal uncertainties include:

- the size and density of future populations,
- their living habits,
- their needs and values,
- their political stability, and
- their health and medical practices.

Although much uncertainty can be reduced by further research, some uncertainty will not be resolvable. Approaches for dealing with some such uncertainties have been developed. For example, the impossibility of predicting future human behavior often is handled by the regulator's defining "stylized" scenarios that specify the choices to be used in a safety analysis (e.g., drilling frequencies, eating habits). This makes the regulatory process more practicable. Such steps taken by the regulator to enhance practicability do not relieve scientists of their responsibilities to consider all credible information in the safety analysis.

Living with unresolvable uncertainties is inevitable in long-term radioactive waste management. This is also the case with other complex modern technologies. The issue is **whether the level of knowledge is adequate to provide the necessary scientific input to the societal decision base at each stage in the stepwise development process.** It will take, at a minimum, many decades before repositories are constructed, HLW is emplaced, and repositories are closed so that further retrieval, monitoring, or other active management essentially is terminated.

The view of the committee is that scientifically justifiable decisions can be made today to take the next steps in developing a properly characterized repository site and to proceed further toward the geological disposal option. A properly characterized site is one whose present-day behavior is well understood and for which there is high confidence that its future behavior in conjunction with engineered barriers will provide acceptable isolation of the waste from the environment. **In such cases, the committee believes that actions to continue along a stepwise repository development path are justified, as long as these actions are judged capable of providing acceptable safety and security, when the level of remaining uncertainty is considered.** The committee has defined retrievable emplacement of HLW in a repository as geological disposition (see [Sidebar 1.3](#) ). The decadal time scales required for repository development, combined with the robust safety characteristics of a well-designed repository, guarantee that moving forward in a stepwise fashion does not preclude parallel or subsequent development of other options. Hence, the important goal of being able to offer society a choice remains satisfied.

In summary, stepwise development is the most promising approach for the following reasons:

- scientific and technical uncertainties are expected to diminish (although not disappear) as knowledge advances;

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- societal uncertainties can also be reduced to some extent by appropriate studies; and
- society is given a greater opportunity to become familiar with the issues, to participate in the decision-making process, and to build public confidence through the process. For this process to be successful, it is necessary that the public be given comprehensible information.

### **SUCCESSFUL DECISION MAKING IS OPEN, TRANSPARENT, AND BROADLY PARTICIPATORY**

*National waste disposition programs in democratic countries cannot hope to succeed today without a decision-making process that facilitates choices among competing societal goals and ethical considerations. Proceeding in a stepwise fashion and maintaining choice at various stages provide important means for building increased public confidence.*

Based on its discussions of the adverse experience with closed decision-making processes in the past, the committee believes that a program to select major components of the waste management system (“deciding what to do”), including sites, facility design, and technologies, is more likely to succeed if it results from an open, participatory, and stepwise process of deliberation and decision making. The goal of this process is to secure a high degree of public confidence concerning the fairness and appropriateness of the decisions, including support from the communities that will host the facilities. A key aspect increasingly acknowledged in recent years is that this goal is more likely to be achieved if waste management programs develop in stepwise fashion, with midcourse corrections at each stage as needed. This process involves a growing breadth of interested parties in decisions as it moves to higher stages of commitment to a specific technological approach and site. Such a process accumulates and builds public confidence in the emerging waste management system. Alternatives are identified throughout this process so that choices among options can be reviewed at each stage.

Efforts are being promoted in many countries to establish a collaborative decision process that

- is open, transparent, and broadly participatory;
- addresses explicitly the values and ethical considerations that are implicit in alternative technical and policy choices;
- seeks more voluntary consent from communities that will host waste facilities;
- empowers a wider range of interested and affected members of the public;
- undertakes with interested scientists and segments of the public a full discussion of the need for safe waste disposition and the costs and risks of various alternatives, addresses the concerns of those in host

communities, and where appropriate, negotiates resolution of these concerns with them;

- provides compensation (in a moral and social as well as financial sense), as appropriate, for those in this and future generations who will bear burdens on behalf of others; and
- seeks to demonstrate, through its actions, that it is worthy of increased public trust, for example, through open discussion of the quality of information and by fulfilling its commitments.

### **SUCCESSFUL PROGRAM MANAGEMENT IS FLEXIBLE AND ADAPTIVE**

*A geological repository will be a first-of-its kind installation, with inherent uncertainties in its design, construction, and operation. Many of these uncertainties are equally important for long-term surface storage. Furthermore, we can, at best, make only educated guesses about the economic, societal, and political environment within which the waste management organization must operate during its active lifetime. A management system that is flexible, responsive to surprises, capable of midcourse corrections, and effective in its interaction with concerned segments of the public has the greatest possibility of success.*

In its 1990 report, *Rethinking High-Level Radioactive Waste Disposal*, the Board of Radioactive Waste Management of the U.S. National Research Council (NRC, 1990) summarized the issues constraining the choice of management systems for a process governing the long-term implementation of decisions. The issues raised were for disposal systems, but most are valid also for long-term storage concepts:

- Irreducible uncertainties exist in judging future risks of radioactive waste disposal or of long-term storage.
- An essential part of any management plan is how to operate with full public accountability as information about the risk changes with experience.
- Those involved in high-level waste management must avoid the trap of promising to reduce uncertainties to levels that are unattainable and recognize that the organization suffers most when it has understated risk or uncertainty.
- Consensus is difficult to reach in high-level waste management, given political controversy, conflicting value systems, and the variety of technical specialties involved in assessing system performance.
- A “perfect knowledge” approach is unrealistic, given inherent uncertainties, and runs the risk of encountering “show-stopping” problems and delays that could lead to a deterioration of public and scientific trust.
- Negotiation, persuasion, and compensation are fundamental parts of any program to manage radioactive wastes.



The management system should be flexible and responsive to surprises, that is, unanticipated societal or technical findings or events. Planning, constructing, and operating storage and disposal facilities, along with the necessary building of communication and trust with the public, will be a long process, extending over many decades. No geological repository for HLW has been constructed yet, so national programs will be pioneering a complex technological effort, and technical and societal surprises are inevitable.

Stepwise program implementation (“doing what is decided” in a timely, effective manner) is appropriate for the management system. There are two interrelated reasons for this. One is the previously mentioned argument that the scientific and technical basis develops in stages, each giving increased confidence in the reliability of the concepts, data, specific designs, and system analyses or else showing where the scientific and technical basis is in need of further improvement. The other reason is that society needs time to become familiar with the developing technical systems and appears to favor discrete development stages, each of which is preferably reversible. Adaptive management is discussed in [Chapter 8](#), and involving the public and technical communities in decision making is discussed in [Chapter 5](#) and [Chapter 6](#).

### **INTERNATIONAL COOPERATION CAN HELP ACHIEVE NATIONAL SOLUTIONS**

*International cooperation can bring benefits for all countries. International collaboration at the technical level already is extensive, but there are needs for better coordination at the strategic and political levels. Identical strategies will not result; national solutions will reflect different cultures, priorities, and legal systems. Cooperation especially can help less advantaged nations, for example, those with more limited financial means, small nuclear programs, or unfavorable geology. The cooperation can range from shared research programs to shared storage or disposal facilities offered by a host country to other nations. Sharing technology and facilities will reduce the cost burden for all of the cooperating nations and will greatly facilitate the establishment of internationally accepted standards.*

The management and eventual disposal of HLW present common challenges worldwide. Although how a country manages its waste is a national decision, the committee found that international cooperation is a significant asset to national programs. It is not necessary that every country tackle every problem independently or have national facilities for all waste management activities. In practice, cooperation in waste management among countries has been very active for many years.

The nuclear fuel cycle already is international, with relatively few countries providing services by supplying uranium, enrichment services,



and fuel fabrication to a wide range of customer countries. There are established procedures and mechanisms for keeping appropriate oversight and control of international activities—particularly in the transport and safeguards areas. For long-term management of wastes, an international context is even more appropriate because the time scales in question exceed those for which the stability of any national border can be guaranteed. The IAEA Convention on the Safety of Spent Fuel and on the Safety of Radioactive Waste Management accordingly contains explicit requirements for adjacent countries (IAEA, 1997a).

International cooperation originally concentrated on technical issues such as sharing methodological developments or data. Later, efforts were extended into the area of public information and communication—although this was more difficult because of cultural differences. The most urgent need for improvement today may be in the area of policy decisions. These need not be common to different national programs, but a common understanding of the justification for individual policy choices can improve communication and help make different approaches more explicable to the public in various countries. Progress in adopting a solution in one country serves as a positive example to other countries.

There is no reason that all countries must be self-sufficient in all aspects of the nuclear fuel cycle. Many countries import uranium, and some share reprocessing services, as noted in [Chapter 4](#). There is international agreement that close cooperation in waste management is to be encouraged (IAEA, 2000b). Although multi-barrier repository concepts have been developed that could provide safety in well-chosen sites in most countries, not all countries utilizing nuclear power are equally suited for storing or disposing of HLW. Some countries are limited in area or have no suitable sites for repositories. Some small countries may not have sufficient waste quantities to justify a dedicated HLW repository. Some may not have the resources to develop repositories or facilities that can assure safe and secure ongoing storage. In any case, the establishment of many small repositories is not an ideal approach from either an economic or safeguards point of view. In the current climate of growing concern over potential increases in the risks of proliferation of weapons or of misuse of nuclear materials by terrorists, the importance of maintaining rigorous controls over fissile materials is increasing. Given the resources, the technical expertise and the geological and environmental prerequisites for implementing a geological repository, the committee believes that not every country with long-lived wastes will be able to implement a national repository. Even a surface storage facility could pose problems for some countries. Accordingly, the committee believes that some regionally or internationally shared surface storage facilities or repositories eventually will become a reality.

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Although much is to be gained by international cooperation at all of the levels mentioned, a uniform approach to radioactive waste disposition is not expected. Differences in national waste management policies will result from the diversity of cultures, of specific problems, and of priorities. Some issues (e.g., those concerned with safeguarding fissile materials) demand a high degree of international conformity to agreed procedures. Other issues, such as the choice of method and the timing, can legitimately be treated differently in different nations.

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## 3

# Principal Recommendations

This chapter presents the committee's five principal recommendations, additional recommendations, and a brief discussion. These recommendations are based on the committee's findings and conclusions, which are summarized in [Chapter 2](#) and supported by information in [Chapter 4](#) , [Chapter 5](#) , [Chapter 6](#) , [Chapter 7](#) , [Chapter 8](#) through [Chapter 9](#) .

### PRINCIPAL RECOMMENDATION 1

*National organizations with responsibility for the management of high-level waste (HLW), together with the scientific and engineering communities (including social scientists), should provide the leadership and support for solving the problem of nuclear waste.*

Leaders in today's democratic societies have a technical, social, and ethical **responsibility to assure progress in developing and implementing options for the disposition of radioactive wastes**. The safety and security risks associated with the current stocks of HLW and spent nuclear fuel (SNF) make it imperative that the challenge be neither ignored nor postponed. Because the current situation in many countries does not present an urgent safety hazard and because the issue of radioactive waste management is extremely sensitive politically, there is a temptation to postpone or avoid decisions and actions. Nevertheless, the safety problem is immediate, especially in defense-related facilities in some

countries, and will grow elsewhere as more waste is generated and new management facilities become necessary. Moreover, security concerns will increase as more fissile material arises from dismantling nuclear weapons unless a disposition route for this material is prepared (see [Sidebar 1.1](#) and NAS, 1994). Natural and social scientists directly involved in addressing issues of long-term waste disposition should seek to assure that decision makers are fully aware of the benefits that would result from the emergence of a safe and societally acceptable solution.

The committee did not conclude that countries must proceed rapidly with construction programs. However, **actions are needed** to generate options, understand their implications, and involve the public in the choice of approaches to safe and secure disposition. These actions should be pursued in a manner and at a pace compatible with the status of scientific and societal knowledge and understanding. Leaders should plan and implement increasingly broad-based public discussion of responsibilities and options for waste management, recognizing that visions of what is right and acceptable may well change and develop over time as more parties are involved in the deliberative process.

## PRINCIPAL RECOMMENDATION 2

*National programs should direct their efforts beyond technical project development and implement processes that involve the public in decisions on how to assure safety and security.*

Recommended actions are the following:

1. Assure that **choice is available**. A decision is by definition a choice between at least two alternatives. In some cases, the choice may be only whether to proceed to the next milestone, without prejudicing further steps. Additional options should be planned and maintained as backup contingencies in case of surprises. The only foreseeable alternative to implementing geological disposition is prolonged storage. The committee recommends that radioactive waste management programs develop both the option for adequate storage, to assure that this capability is available for as long as it is needed, and the geological disposal option. Both of these management options should be available to the choice process. Each society will make its own decision—considering the relevant costs, risks, ethics, and uncertainties of both options—about whether to proceed with continued surface storage and the active institutional management it requires, or to proceed toward stepwise implementation of geological disposal.
2. Assure **adequate staff, leadership, and resources** for a process that will continue until final geological disposal if this option is chosen,

and indefinitely otherwise. National program schedules indicate that it will be at least 50 years until a repository is finally closed and sealed, and it may be much longer if extended surface storage is chosen. Means to assure that information is transferred from current to future generations will be necessary.

3. **Strengthen programs addressing societal aspects.** Historically, the policies, staffing, and structures of waste management programs have been heavily weighted toward technical and economic issues. Steps should be taken to redress the balance in order to assure equally high-quality work on social and ethical issues in waste management.
4. Recognize that **dialogue among the scientific and technical communities and the public** in support of decision making is an essential, ongoing part of the process. Scientists and technologists should be fully integrated into the efforts to maintain good communications. As in any field of science, the first step is that scientists actually working on the project have the stature and reputation that come from regular publication in the open scientific literature. Scientists with expertise relevant to a project must have opportunities for initiating new studies to verify and develop new concepts and to express their views on the safety of the project. Adequate resources should be provided for assuring effective public involvement. Explicit programs and possibly new organizational entities should be set up to assure continued dialogue among all interested and affected parties.
5. **Assure that the criteria and procedures used in decisions concerning HLW are established in advance and are seen as fair.** In a democracy the acceptability of controversial decisions at the societal level depends largely on the use of criteria that have been established and understood in advance and on the use of procedures that are seen as fair.
6. **Consider adaptations to on-going programs that can help increase public involvement and build increased public confidence in the decision process.** Some national programs are already well along in their decision processes. Some have used versions of the open and stepwise process recommended in this report. Others have not. While it is not expected that they would begin their process anew, adaptations to conform more closely to the recommended deliberative societal decision-making processes will benefit these programs.

### PRINCIPAL RECOMMENDATION 3

*For both technical and societal reasons, national programs should proceed in a phased or stepwise manner, supported by dialogue and analysis.*

Waste management programs should go forward deliberately to successive milestones as information and analyses are developed to support

their decisions, with the recognition that public concerns or new, unexpected scientific information may justify deliberate delays or reconsideration of previous decisions.<sup>1</sup> The justification for a phased process is that knowledge and understanding are developing in both the technical and the sociological areas. Whereas many believe the remaining scientific questions to be relatively minor, experience in numerous countries has proven that society is not ready to accept without question the technical judgments of experts. The key technical and societal recommendations with respect to stepwise procedures are as follows:

### Technical Actions

- Each national program **should prepare an objective, comprehensive comparison of realistic alternatives**, including a description of the current safety and security afforded by the status quo storage configuration over long time periods, perhaps several centuries. This comparison will provide a baseline for discussion of alternatives. Careful and comprehensive examination and comparison of uncertainties associated with each alternative are essential aspects of the stepwise process.
- Interim storage in surface facilities is necessary even in countries that are proceeding toward construction of repositories. The **availability and the safety and security of such storage facilities must be assured** for as long as these facilities are needed.
- Since surface storage cannot assure safety and security without ongoing active management, **nations with HLW should continue to develop the option of geological disposal** as the only currently foreseeable option for future implementation of a passive, inherently safe system.
- Those nations contemplating disposal facilities should also move ahead with the **identification and characterization of potential sites** for geological repositories, at a rate commensurate with the scientific knowledge and understanding available to support each step in the decision process.

Specific steps may include the construction and operation of underground research laboratories (URLs). Large-scale, integrated experiments in URLs can build public and scientific confidence in geological disposition in at least four ways: (1) demonstrating the feasibility of the technology, (2) having a specific and focused research program to develop and refine appropriate conceptual models of site behavior, (3) beginning to

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<sup>1</sup> As a follow-up to the present study, the National Research Council is beginning a new study to develop recommendations for a stepwise repository development process. The present committee strongly advocates this study.

gather long-term information for scientific validation that can accumulate through the decades of repository operation, and (4) making the technology more accessible to decision makers and to members of the public who visit the facility. In addition, some countries may wish to select some types of waste for early or pilot-scale emplacement based on favorable characteristics such as short half-life and robustness of waste form. Some types of defense waste may be examples. Early emplacement of such wastes should not foreclose other options.

### Societal Actions

- National programs should develop waste management strategies through **greater openness, transparency, and full public involvement** in decision making, including real opportunities for the public to influence policy choice.
- **Decision makers, particularly those in national programs, should emphasize monitoring and retrievability.** Demonstrated reversibility of actions in general, and retrievability of wastes in particular, are highly desirable because of public reluctance to accept irreversible actions. Retrievability provides public reassurance that one is able to deal with surprises. In practice, retrievability is feasible in all cases, but the different degrees of effort and cost required should be addressed in repository design studies. Monitoring is also desirable as evidence of vigilance in looking for surprises. Openness with the results of monitoring and an agreed-upon process for drawing decision implications from the data are also important.
- National programs should strive for high levels of **flexibility, adaptiveness, and resilience to surprise** in long-term management. Significant technical and social uncertainties will continue through the development and implementation of waste management systems. Management approaches capable of responding rapidly to events and new knowledge are needed.
- Decision makers, particularly those in national programs, should recognize that **decisions depend on cultures and contemporary social values.** Therefore, nations may legitimately make different choices in their waste management strategies or in the organizational and legal systems that determine these strategies. Safe and secure surface storage with continued commitment of resources may be chosen by some countries for long periods of time. However, ultimately a sealed geological repository will be needed for long-lived wastes if the burden of active care and maintenance is not to be passed on indefinitely. Each society must weigh the options for itself, and the extent to which any specific approach is appropriate will require different levels of evaluation in different countries.

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### Common Requirements

- Program decisions must be made in the face of uncertainty—that is, with clear recognition of limits to available knowledge. National programs should **use decision processes equipped to deal with uncertainty**. These decision processes should identify and describe important uncertainties associated with each of the alternatives, and they should include methods for acknowledging, clarifying, or reducing these uncertainties through further investigation and research. The limits of current scientific knowledge should be assessed and communicated to interested parties. Decision making in the face of uncertainty is the usual situation in many areas of science, technology, and society. Formal procedures for decision making under uncertainty are well established (NRC, 1996a).
- There is a **need in both technical and societal areas for research** that seeks new knowledge and for a flexible program that has the ability to incorporate this new knowledge to make wise decisions, thereby building public confidence. There is still work to be done in the physical sciences. However, the need is even greater for social and institutional studies aimed at improved understanding of public concerns, strategies for achieving greater social trust and conflict resolution, means for ethical assessment, and strengthening of institutions and institutional processes. Improved practices of social science oversight and peer review should also be instituted in all programs.

### PRINCIPAL RECOMMENDATION 4

*National programs should increase international cooperation by sharing information, coordinating policies, supporting international organizations, developing a consensus on international standards, and seeking other ways to assure that all countries achieve safe disposition of their radioactive waste.*

This should include the following:

1. **Sharing** underlying science and technology information, including collaboration on specific issues, for example, investigation techniques, generic data, and safety assessment approaches. Mechanisms and organizations are available for accomplishing this.
2. **Coordinating policies and strategies** to improve the worldwide quality of waste management programs, for example, harmonizing broad safety cultures and assuring that adequate storage and disposal capacity are available. Even countries with no nuclear power have radioactive wastes from medical, industrial, and research practices.
3. Improving and **supporting international organizations** whose role is to give advice, set regulations, or monitor operations. Examples are

the International Commission for Radiation Protection for radiation protection approaches and the International Atomic Energy Agency and the European Commission for the transport of spent fuel and wastes and for safeguards. Wider participation by nongovernmental organizations and independent scientists in the work of international institutions could be advantageous.

4. Harmonizing policies, laws, and regulations to achieve a global balance of factors relevant to managing radioactive waste, including the transfer of wastes between willing and competent partner countries. Laws, regulations, or ethical assertions that would prevent the transfer of HLW between willing and competent partner countries could preclude sound options to enhance safety, security, and economics.

### PRINCIPAL RECOMMENDATION 5

*National programs should take an integrated, comprehensive, and risk-based systems view to assure safety and security for HLW surface storage facilities and repositories, both in the implementation of the waste management program and in its regulatory oversight.*

This should include the following:

1. It is important to manage wastes to assure safety and security in surface facilities. This includes handling, interim storage, and transportation. Other environmental impacts, such as those associated with any major construction project, also should be evaluated and minimized, and costs must be considered. An informed decision on the relative merits and timing of moving to geological disposal is feasible only when the above considerations are evaluated together with the subsequent steps of waste emplacement in the repository, closure, and postclosure—including monitoring and retrievability.
2. The integrated approach recommended is not only technological. The public is becoming increasingly empowered in the debate on waste disposition, and a constructive relationship with waste management institutions will depend on **mutual** willingness to listen, evaluate, respect the positions of others, and modify entrenched positions when necessary. Social science research may assist in clarification of public attitudes and values and in institutional innovation to enhance opportunities for public understanding and participation in HLW management programs.
3. The ultimate decisions on whether to proceed with implementation of geological disposal will depend in large measure on **regulatory** decisions. From the more extensive list in [Chapter 6](#) of recommenda

tions and comments on how this process can be made to work, the key elements are highlighted here:

- A **“phased approach” to regulation** of a geological repository, as expounded 10 years ago in the Board on Radioactive Waste Management's *Rethinking High-Level Radioactive Waste Disposal* (NRC, 1990), remains sound advice. A key corollary is that the regulator must strive to avoid overly prescriptive rules too early in the multi-decade process of regulatory approval and oversight.
- Even when a particular country's legal system requires quite prescriptive regulations for a geological repository, there is a lot of room for **flexibility** at the level of the detailed regulatory guidance, decision making, and inspection programs.
- **Public involvement** in the process whereby the regulator arrives at the rules and regulations to be used in the approval process should begin at the earliest phases and continue throughout. This implies a fully open process in which the interested and affected segments of the public can challenge and comment on the approaches to be used by the regulatory body.
- There is inevitably a lot of uncertainty in any analysis of far future repository performance. This has led to consensus that the key **regulatory decisions should in general be based on more than a single numerical figure of merit**. Reliance upon quantitative performance assessments should be supplemented by the use of other figures of merit, including comparisons with other hazards faced by mankind and an overall judgmental criterion of the quality of scientific understanding.
- Stylized approaches in which the regulator defines for the repository implementer conditions to be applied in the execution of licensing calculations can be practical and transparent—in particular, when broad discussion is sought prior to establishing such guidance. This simplified approach does not, however, absolve scientists within or outside the implementing body from their responsibility to explore the range of conditions that might realistically be expected in the future at a repository site.
- It is broadly agreed that it is the **prerogative of the national authorities** in each country to decide how far into the future the specific regulatory compliance period should extend. This is a public policy issue, not a technical issue that science can address.

4. The analysis in support of an integrated, comprehensive, and risk-based systems view should include the following considerations:

- The critical issue with respect to safety and security assessment is the required or achievable level of confidence in the results of the analyses. Neither a 100 percent level of safety nor 100 percent confidence in the reliability of the assessments is possible. This is a fact that is true also

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for every other comparable technical undertaking, and it is important to assure that unique, unattainable requirements to the contrary are not placed on waste disposal.

- Safety assessment experts must communicate their belief that their calculated results, although imperfect, provide sufficiently reliable input for decision makers. Numerical results of analyses extending out to geological times, if presented without sufficient discussion of their significance, lead understandably to accusations of over-optimism, hubris, or even irrationality. To the extent that there is uncertainty in conceptual models, this must be made clear. As long as one can be accurate in assuring that the levels of release are low, precise estimates are not needed; even with some orders of magnitude of residual uncertainty, the calculated release may be clearly within defined safety goals or limits.
- All parties involved in the decision-making process should have a consistent and accurate perception of what safety and security analysis can and cannot do, so that they do not make sub-optimal or irresponsible decisions based on incorrect or biased perceptions.

### CLOSING COMMENTS

The committee recognizes that the recommendations summarized in this chapter will be difficult to implement and will require political and societal commitment to provide resources if progress is to be made. Evidence that led the committee to these recommendations, along with further discussion and suggestions for their implementation, is presented in [Chapter 4](#) , [Chapter 5](#) , [Chapter 6](#) , [Chapter 7](#) , [Chapter 8](#) through [Chapter 9](#) of this report.

## 4

# National Programs

This chapter provides an overview of high-level waste (HLW) and spent nuclear fuel (SNF) management in countries with appreciable inventories of these materials.<sup>1</sup> It focuses mainly on the status of the geological disposition option in these countries. The chapter is intended to summarize the country-specific information that led the committee to its findings and recommendations, rather than provide a comprehensive picture of national programs.

### INVENTORIES OF HIGH-LEVEL WASTE AND SPENT NUCLEAR FUEL

Since the nuclear age began some 60 years ago, substantial amounts of HLW and SNF have arisen from both defense and power production activities in many countries. The largest inventories are stored in the United States and Russia. Their current inventories are summarized as follows:

- The United States' inventory of commercial SNF was about 42,000 metric tons (mt) in 2000 (DOE, 2000).
- The United States has reported approximately 350,000 m<sup>3</sup> of HLW, mainly from former defense activities and stored in tanks at its Hanford and Savannah River sites (IAEA, 2000a).
- The SNF inventory from various types of reactors in Russia is about 8500 mt (Laverov, 1999a).

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<sup>1</sup> This chapter maintains a distinction between HLW and SNF because not all countries consider SNF to be a waste.

- Russia has a total of about 600,000,000 m<sup>3</sup> of waste at its defense sites, mainly Mayak, of which more than 25,000 m<sup>3</sup> is designated HLW and stored in tanks (Laverov, 1999a).<sup>2</sup>

The worldwide inventory is expected to grow significantly during at least the next 30 years, especially the SNF inventory. For example, the SNF inventory in the United States will nearly double to about 83,800 mt by 2035 (DOE, 2000). Although some countries are planning to phase out nuclear power, there are 36 power reactors currently under construction. China, for example, has seven reactors under construction. China expects to have accumulated 1000 mt of SNF by 2010 and 2000 mt by 2015 (Parizek et al., 2000). The 1996 and expected future SNF inventories in several other countries are summarized in Table 4.1 (IAEA, 2000a).

Reprocessing of commercial SNF is practiced in some countries; for example, France and the United Kingdom reprocess domestic SNF and, under contract, provide reprocessing services to other countries. HLW from reprocessing is returned to the country of origin. Inventories of vitrified waste from reprocessing accumulated through 1996 and projected to 2014 by countries reporting these data to the International Atomic Energy Agency are summarized in Table 4.2. The HLW inventory in these countries will more than triple between 1996 and 2014.

## EXAMPLES OF NATIONAL WASTE MANAGEMENT PROGRAMS

The information in this section has been taken mainly from *Radioactive Waste Management Programmes in OECD/NEA Member Countries* (NEA, 1998), and from the European Union Web site (<http://www.rwmeu.org>). Members of the advisory committee have contributed to and verified the information.

### Belgium

Belgium has one candidate site for a deep geological repository, the deep clay formation (referred to as Boom clay) beneath the area of its nuclear research center in Mol. Studies of the Boom clay have been conducted for 25 years. Since 1984, these studies have included the construction and operation of an underground research laboratory (URL), the High Activity Disposal Experimental Site (HADES). HADES includes an access shaft and two galleries at a depth of 230 meters where in situ

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<sup>2</sup> Russia designates waste as high-level if its activity exceeds 1 curie per liter. In the United States, most tank waste at Hanford and Savannah River is designated as HLW although its average activity is well below 1 curie per liter. Most of the tank waste is composed of crystalline salts and thick sludges.

measurements and large-scale integrated experiments take place. The Preliminary Demonstration Test for Clay Disposal (PRACLAY), completed in 1999, extends HADES with another access shaft, a 90-meter-long connecting gallery, and a 30-meter-long gallery for full-scale heating simulations of disposed HLW. In addition to scientific studies, PRACLAY will demonstrate construction techniques suitable for Boom clay.

Table 4.1 Spent Nuclear Fuel Inventories in Representative Countries

Country	Accumulated Quantity in 1996 (metric tons)	Projected Total Quantity in 2014 (metric tons)
Argentina	2409	4839
Bulgaria	655	256
Canada	5080	11000
China	None reported	2000
Czech Republic	507	1806
Finland	850	2100
France	8100	13500
Germany	8038	7000 <sup>a</sup>
Hungary	423	1400
Italy	285	233
Korea, Republic of	2869	15229
Lithuania	1300	2600
Mexico	113	587
Netherlands	3	0
Poland	603	720
Slovakia	626	1486
Slovenia	220	470
South Africa	605	2160
Spain	1960	4800
Sweden	3450	7700
Switzerland	1250	1970
Ukraine	3120	8217

Source: IAEA (2000a).

Table 4.2 Vitrified High-Level Waste Inventories in Representative Countries

Country	Accumulated Quantity in 1996 (m3)	Projected Total Quantity in 2014 (m3)
Belgium	210	845
France	800	3300
United Kingdom	680	1890

Source: IAEA (2000a).

<sup>a</sup> Inventory reduced by phase out of nuclear power and reprocessing. Information from the Gesellschaft für Nuklearservice, Essen, Germany.



The results of the preceding 10 years of research on HLW disposal will be presented to the government and used to identify research and demonstration priorities for the next decade. The current plan assumes that operation of a repository could begin in 2035 and continue for about 40 years until closure.

Presently, SNF is not considered a waste material in Belgium; instead, it is reprocessed in France at La Hague. Vitrified HLW will be returned to an interim storage facility located near Dessel, Belgium. The first return of vitrified HLW was completed in April 2000.

Belgium is storing its low- and intermediate-level wastes in specially engineered facilities at Dessel. This interim storage is intended to continue for 20 or more years. An inquiry is under way to determine candidate sites for eventual disposal of this waste.

### Canada

Canada has no candidate site for a deep geological repository. Based on a 16-year research program, Canada has developed a concept for deep geological disposal in plutonic (granite-like) rock in the Canadian Shield, a geologic region that includes a large part of central and eastern Canada. A URL established in Manitoba in 1990 is a major part of the research program.

SNF is considered a waste material in Canada. According to the Canadian concept, SNF would be disposed at a depth of 500 to 1000 meters with a series of engineered barriers that complement the natural barrier of the plutonic rock. SNF is currently stored in pools or in dry concrete canisters at the generating sites.

A joint statement by the governments of Canada and Ontario in 1978 directed Atomic Energy of Canada Limited (AECL) to initiate development of the deep geological disposal concept. Subsequently, a joint statement in 1981 required a full public hearing and approval by both governments before site selection could begin. An independent environmental assessment panel was appointed in 1989 and produced what is known as the Seaborn report (CEAA, 1998). Among the key conclusions in the panel's report were the following:

- From a technical perspective, the safety of the concept has been on balance adequately demonstrated for a conceptual state of development, but from a social perspective, it has not.
- As it stands, the AECL concept for deep geological disposal has not been demonstrated to have broad public support.

The report recommended that site selection should not proceed until broad public acceptance of a nuclear fuel waste management approach were achieved. As part of a plan for gaining public acceptance, the panel

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recommended developing options besides geological disposal and developing an ethical and social framework against which these options could be assessed. One response to public concerns has been designing the repository for long-term retrievability, which was not originally planned.

Low-level waste (LLW) in Canada presently is stored in the Port Hope area, at the Bruce nuclear power plant (NPP) and at the Chalk River Laboratories. A variety of options for developing near-surface disposal facilities for these wastes is being considered.

## China

China has one candidate site for a deep geological repository, the Beishan site located in the Gobi desert in the Gansu Province in northwest China. The repository would be in granite beneath the water table. China intends to begin its process to license the site and design a repository in 2020 and to begin disposing of waste in 2040. The Chinese government is beginning a program to increase its nuclear power generation significantly, and it is planning its waste disposal program coincident with this expansion.

SNF is not considered a waste material in China. China's policy for HLW disposal is based on the following guidelines:

- SNF will be reprocessed.
- Vitrified waste will be the final waste form.
- Deep geological disposal will be used.
- Granite will be the host medium.
- The repository will be designed as a shaft tunnel in the saturated zone.

Selection of the Beishan site resulted from an initial screening (1986–1989) that identified 21 districts and a further screening of five sites in northwest China. Social as well as technical factors were used in the site selection. Preliminary site characterization of the Beishan site began in 1989 and will continue until about 2010. In July 2000, drilling of the first of two boreholes began. The plan is for one of the boreholes to be drilled vertically to a depth of 700 meters. The second will be drilled on an incline to a depth of 500 meters (Parizek et al., 2000).

## Finland

Finland recently selected Olkiluoto as its candidate site for a geological repository. This decision was formalized by the government near the end of December 2000. This site was selected from among four sites (Kivetty, Loviisa, Olkiluoto, and Romuvaara) that were short-listed from an initial group of 102 potentially suitable sites identified in 1985.

SNF is considered to be a waste material, according to policy established in 1983. The policy also provides that a municipality in which a nuclear facility is proposed to be sited has the right to veto the proposal. Environmental impact assessments (EIAs) were begun in 1997 in the local municipalities of the four candidate sites. Discussion groups were set up, and results from the discussions were taken into account in the EIA process.

SNF will be encapsulated using a two-canister system consisting of a steel (inner) and a copper (outer) canister; see Figure 4.1. Canisters will be placed in boreholes drilled in the floors of tunnels, which are to be constructed at a depth of about 500 meters in crystalline rock below the groundwater table. In the absence of a physically disruptive event, the copper canisters are expected to maintain their integrity for millions of years.

Finland operates two repositories for its low- and intermediate-level waste. These are located in bedrock beneath the two nuclear power plant sites at Olkiluoto and Loviisa. The disposal zones are at depths ranging from about 60 to 110 meters. The two nuclear power plants also provide temporary storage of SNF. Finnish law prevents the import or export of radioactive waste for disposal.

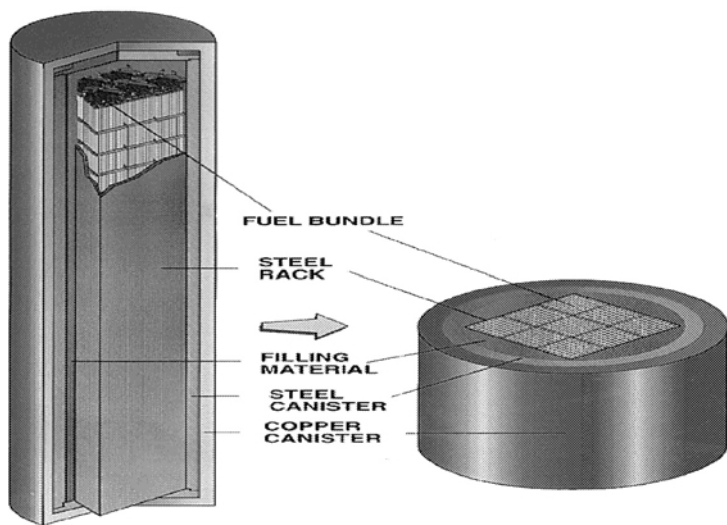


Figure 4-1. Scandinavian overpack design.

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## France

France has not selected a candidate site for a HLW repository, although it has begun construction of a URL located at Bure (Meuse Haute-Marne) in eastern France. In 1990, public opposition led to a moratorium on repository site selection. Subsequently, the Waste Act of 1991 established a legislative framework for disposition of high-level and long-lived intermediate-level wastes and initiated a 15-year research program in three areas:

1. separation and transmutation of long-lived isotopes in waste,
2. disposition in deep geological formations (via URL tests), and
3. immobilization processes and long-term surface storage.

The 1991 Waste Act shifted France's waste management emphasis from evaluating designated sites to creating a "responsible, democratic, and transparent" management process (Bataille, 1993). According to the 1991 Act, the government will submit an overall assessment of the three research areas to parliament by 2006. At the same time it will submit a draft law authorizing, if appropriate, the creation of a repository for high-level and long-lived wastes. A full debate in parliament must be held before the government can approve an application for the construction of a waste disposal site. Geological disposal must provide advantages over other options, in particular, separation and transmutation, and surface storage. Considerations of retrievability or reversibility must be included in repository design. The feasibility of SNF disposal in deep geological formations is also being studied.

In France, SNF is not considered a waste material; rather, it is reprocessed at the La Hague plant, and plutonium is recycled in mixed-oxide fuel. Recently, the amount of SNF reprocessed has been limited to about 75 percent of its annual production so that the production of mixed-oxide fuel matches the amount required. SNF from other countries that have contractual agreements with France is also reprocessed at La Hague. These countries include Australia, Belgium, Germany, Japan, Spain, Switzerland, and the Netherlands.

France has conducted extensive site characterization work during the last 10 years. The 1991 Waste Act specified creation of underground laboratories to conduct research on the geological disposition option. Initially, 30 candidate URL sites were selected, and four were short-listed; that is, local communities accepted that a surface reconnaissance program would be made. In 1996, three sites were presented to the government as potential sites for building URLs. In 1998, the government approved one site at the border of Meuse and Haute-Marne, and there France's first URL is now being constructed in a clay formation. The government also has required that a granite site be studied, since the 1991 Act requires that at

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least two URLs be built. The selection process for this granite site in Brittany and central France is encountering strong local opposition because preliminary site selection did not include consulting potentially affected communities. See [Chapter 8](#) for more detail.

France disposes of its low-level and short-lived intermediate-level wastes in two surface facilities. The Centre de la Manche opened in 1969, was filled to its capacity of 526,000 m<sup>3</sup> in mid-1994, and is now closed. The Centre de l'Aube has been in operation since 1992. Projects for repositories for very-low-level waste, graphite waste, and radium waste are under study.

### Germany

Germany has two candidate sites for deep geological repositories. The abandoned Konrad iron ore mine is planned for the disposal of all types of radioactive waste with negligible heat generation, including alpha-bearing waste. The licensing procedure is nearly finished, and the license is expected to be issued within a year. The Gorleben salt dome has been under investigation since 1979 to determine its suitability to host a repository for all types of radioactive waste, in particular SNF and heat-generating HLW from reprocessing.

The coalition parties of Germany's new government have concluded that the basic elements of the previous waste management concept have failed. A new national waste management plan will therefore be developed. A single repository in a deep geological formation is considered sufficient for the disposal of all types of radioactive waste including HLW and SNF. An expert group has been established to develop repository site selection procedures and criteria on a scientifically sound basis.

The Gorleben site will be included in the site selection process. However, according to the June 14, 2000, agreement between the federal government and the utilities, underground investigations at Gorleben will be interrupted for 3 to 10 years to clarify conceptual and safety-related issues (e.g., retrievability and human intrusion). The new federal government's policy foresees the start of operation of a repository at the selected site around 2030. Political considerations have also affected the Konrad repository project. The June 14, 2000, agreement addresses only the completion of the licensing procedure. The decision actually to use the abandoned iron ore mine as a low- and intermediate-level waste repository remains open.

SNF from Germany's light-water reactors has been reprocessed in France and Great Britain since the 1970s. During the Soviet era, SNF from East German power plants was reprocessed in Russia. In 1985, the federal government stated that in addition to reprocessing, methods for direct disposal of SNF should be developed. Since 1994, direct disposal

of spent fuel has been legally equivalent to reprocessing, and the aforementioned agreement of June 14, 2000, gives priority to direct disposal.

Germany has interim storage capacity for spent fuel in storage pools at its nuclear power plants and at four centralized dry storage facilities. Nuclear power plants at Greifswald and Rheinsberg, in former East Germany, were closed in 1991 because they did not meet Western safety standards. About 5000 spent fuel elements from these reactors are stored in a newly constructed storage facility at Greifswald. Another centralized storage facility is located at Gorleben. Shipments of spent fuel were stopped in Germany in 1998 because of surface contamination on transport casks and vehicles. It is expected that shipments will resume during 2001. To minimize spent fuel transport in the future, the new government is pursuing the concept of on-site dry interim storage facilities. Licensing procedures already have been initiated.

Germany has disposed of low- and intermediate-level waste at the two former salt mines, Asse in former West Germany and Morsleben in former East Germany. Waste disposal at Asse began in 1967 and ended in 1978. First emplacement in the Morsleben repository began in 1971. Emplacement was suspended in 1998, pursuant to an administrative court ruling. It will not be resumed. The current licensing procedure for closing this repository is expected to last several years.

## Japan

Japan has not selected a candidate site for a deep geological repository. The long-term program of geological disposal has been directed by the Atomic Energy Commission of Japan. Under the program, an implementing body for HLW disposal, known as the Nuclear Waste Management Organization of Japan (NUMO), was established in 2000. Its responsibility will be to screen and propose potential sites, perform site characterization, oversee construction, and seek a license with the intent of starting repository operations before 2040. As leader of the current R&D program for geological disposal, the Japan Nuclear Cycle Development Institute (JNC) recently published its second progress report (JNC, 2000). The law for the final disposal of HLW, which was promulgated in June 2000, gives guidelines for implementing geological disposal. The guidelines cover the administrative roles of the government, a stepwise site selection procedure, establishment of the implementing body, and a funding system.

Japan does not consider SNF to be a waste material. The JNC reprocesses a small portion of SNF at its Tokai plant, and resulting HLW is vitrified and stored at its Tokai Vitrification Technology Development Facility. Utility companies have long-term contracts with reprocessing companies in France and the United Kingdom. Vitrified HLW returned



from overseas reprocessors is stored at the HLW Management Facility at Rokkasho-mura. Japan's first commercial reprocessing plant is under construction at this same site and is scheduled to begin operation in 2005.

Japan is a relatively small country geographically, and it is subject to frequent earthquakes and active volcanism. Nevertheless, the government and industries consider that siting a geological repository within the country is necessary for secure implementation of the nuclear program, which produces more than one-third of the nation's electricity. The results of site evaluation studies are expected to identify geologically stable areas that are suitable for a repository (JNC, 2000).

A small-scale URL in crystalline rock near Mizunami City has been a major component of Japan's geoscientific research program since 1995. Construction of a second URL in a sedimentary formation near Horonobe is also being considered by the government. Japan is investigating the option of partitioning and transmutation as well.

LLW is disposed in near-surface facilities. LLW from nuclear power production is disposed at Rokkasho-mura, and some very-low-level waste from decommissioning a research reactor is disposed at Tokai-mura.

### **Netherlands**

The Dutch currently have no candidate site for a geological repository. Low- and intermediate-level waste is stored at a central site near Borssele. The site also will be used for treatment and storage of HLW. This follows the 1984 Dutch policy decision on radioactive waste, which included

- long-term storage (100 years) of all radioactive waste produced in the Netherlands, and
- research into the possibility of final disposal of this waste.

The Dutch do not consider SNF to be a waste. This material will be reprocessed in France and the United Kingdom, with the resulting HLW returned to the Netherlands starting in 2003. A naturally cooled storage vault is being built for this HLW.

Initial research for disposal in salt formations in the Netherlands has been completed. A broader research program that includes retrievability studies is in progress. Recently, public concerns have eroded political support for disposal and increased support for storage (NEA, 1999a). The Dutch are also conducting research on partitioning and transmutation.

### **Russia**

Russia has identified two candidate sites for deep repositories close to its former defense materials production plants: near the Mayak site in the southern Urals and in the Krasnoyarsk region. Studies are also in progress



to identify a site on the Kola Peninsula, and similar studies are planned for the Vladivostok region. Russia is thus taking steps to establish four geological repositories for its HLW and SNF.

SNF is not considered a waste material. Russia formerly reprocessed large amounts of SNF in its defense programs. The country is now following the concept of a “delayed” closed fuel cycle in which SNF is stored for future reprocessing and use in advanced fast breeder reactors. Direct disposal of some spent fuel is being considered. HLW from reprocessing is being vitrified at Mayak.

In 1995, Russia began a 10-year federal program entitled “Management of radioactive waste and SNF: Their utilization and disposal” (IAEA, 1995a). The program was initiated by the President of the Russian Federation on the basis of proposals made by industries, ministries, institutions, and citizens. The program covers all aspects of radioactive waste management. Priority items related to HLW and SNF include the following:

- reconstruction and new construction at nuclear power plant sites of storage facilities for SNF, some of which are out of compliance with current standards;
- development of technologies and equipment for containerizing SNF for long-term storage and disposal;
- construction of a URL for pilot-scale disposal of waste from Mayak; and
- construction of the first stage of the regional storage facility for waste produced at the mining and chemical complex in the Krasnoyarsk region.

Low- and intermediate-level liquid waste is disposed by direct injection into deep geological formations. Some 5 million cubic meters containing a total of about 250 million curies (corrected for decay to 1995) have been disposed by this method at the Krasnoyarsk deep-well injection site. The waste appears to have been contained between geological strata as intended (Parker et al., 1999, 2000). However, the approach is being phased out because it is not considered in line with better practices that include solidifying and packaging the waste (IAEA, 1995a).

## Spain

Spain has no candidate site for a geological repository. An earlier siting program was canceled due to public concerns (NEA, 1999a). The current policy includes the following:

- short-term storage of SNF at reactor sites,
- intermediate-term storage at a centralized facility yet to be built, and
- eventual disposal in a geological repository.

Spain maintains the once-through strategy for SNF; hence it considers SNF to be a waste material. Current research for SNF management includes international collaboration in studies of partitioning and transmutation as well as geological disposal. Upon completion of this research in 2010, Spain intends to reassess the options for final disposition of its HLW and SNF.

Spain disposes of its low- and intermediate-level waste at El Cabril, a shallow land repository with engineered barriers, in reinforced concrete containers. At the end of 1998, about 2500 containers, each with a volume of approximately 11 m<sup>3</sup>, were emplaced at El Cabril.

### Sweden

Sweden has no designated site for a geological repository. It has embarked on a stepwise process to designate a site, and the feasibility of siting has been investigated in eight municipalities. These studies were done only with the consent of the local population and include investigations of geology, land use, infrastructure, and societal aspects. Both the implementing organization, the Swedish Nuclear Fuel and Waste Management Company (SKB), and the Swedish Nuclear Power Inspectorate (SKI) have been active in providing public information and in assuring that the site environmental impact assessment is an open, broad-based process. Responsibility for radioactive waste management is divided between implementing and regulatory authorities as follows:

- the waste generators (e.g., the nuclear power producers and SKB) are responsible for waste management and disposal;
- the waste generator is responsible for funding the future costs of final disposal and decommissioning of NPPs; and
- every third year the waste generator must submit an R&D program on SNF disposal and decommissioning of NPPs (SKI reviews and recommends and the government decides).

SKB recently announced selection of the municipalities of Oskarshamn, Östhammar, and Tierp for underground site investigations. The program also includes further siting studies in Nyköping. After these proposals are reviewed by appropriate authorities, the Swedish government must approve the selections. Finally, the municipalities themselves must decide on whether to accept a site investigation, which could begin early in 2002.

Following a national referendum in 1980, Sweden decided to phase out its nuclear power—a process expected to take until about 2020. Accordingly, spent nuclear fuel is considered to be a waste in Sweden. SNF is stored at the Swedish Central Interim Storage Facility for Spent Fuel (CLAB) near Oskarshamn, on the Swedish East Coast. The residents of

Oskarshamn were involved in licensing the CLAB and in site studies there. After an interim storage period of 30–50 years, Sweden intends to dispose of its SNF in a granitic bedrock at a depth of about 500 meters. The fuel elements will be placed in a two-canister system that includes an iron (inner) and a welded copper (outer) canister; see [Figure 4.1](#).

Swedish environmental law has also required that SKB study the consequences of not receiving permission to dispose of the waste as planned. This study showed that extending the storage period at the CLAB for at least a hundred years would be possible, provided that control and maintenance continue for this period. The study found that with present rates of interest, it is not probable that a substantial delay of the program would require increased funding. Nevertheless, the position of the Swedish government is that there is a need to make progress in the waste management program and not to wait in the hope that future developments would provide better solutions.

In 1977, Sweden established a URL at Stripa in an iron mine, which had been excavated in a granite formation. This URL was the focus of much international research until its closing in 1992. Work began in 1986 to replace Stripa with another URL, the Äspö Hard Rock Laboratory near Oskarshamn. The facility includes an underground tunnel 3600 meters long that reaches a depth of 450 meters. Twelve organizations from nine countries, including Canada, Finland, France, Germany, Japan, Spain, Switzerland, the United Kingdom, and the United States, are participating in the Äspö project.

Sweden disposes of its low- and short lived intermediate-level waste at its Final Repository for Radioactive Operations Waste (SFR) located near Forsmark at a depth of approximately 50 meters. The SFR has been operating since 1988.

### Switzerland

Switzerland has one candidate site for a geological repository for its low- and intermediate-level waste, Wellenburg in the Canton of Nidwalden. A license application was submitted in 1994 but suspended in 1997 after citizens of the canton refused in a referendum to concede to the use of the site for a repository for low- and intermediate-level wastes. In response to the citizens' concerns, the implementation approach and repository design were modified to include

- increased public involvement in decision making through a stepwise decision process in which the initial approval would be only for an exploratory tunnel, and
- enhanced monitoring and simplified retrievability during a preclosure phase.

The inventory for a high-level waste repository will include SNF as well as vitrified HLW and transuranic waste from reprocessing. Two host rock options are being considered for geological disposal of this inventory: crystalline bedrock and clay. In either case, waste would be emplaced below the groundwater table. The next project milestone is the preparation of documentation to demonstrate disposal feasibility (including siting feasibility) in 2002; start of disposal operations is planned around 2050. Swiss policy also includes the option of disposing of this waste within the framework of a multinational cooperative project.

Switzerland has two URLs, one for each host rock option: the Grimsel test site in crystalline rock, operated by Nagra with strong international participation, and the international Mt. Terri rock laboratory in Opalinus clay, sponsored by the Swiss National Hydrogeological and Geological Survey.

Until repositories become available, all categories of radioactive waste are in interim storage. Storage locations include the nuclear reactor sites and a central facility for medical, industrial, and research waste located near Würenlingen. A central facility for SNF and HLW returned from reprocessing is under construction, also near Würenlingen.

In connection with revision of the Nuclear Energy Law, in mid-1999, an expert group was established by the Swiss federal government to assess the different long-term waste management options. This expert group did provide conclusions and recommendations, including the following:

- Geological disposal is the only method for isolating radioactive waste that fulfills the requirement for long-term safety (on the order of 100,000 years).
- Social demands concerning waste disposal are oriented toward the principle of reversibility, and therefore, the concept of actively-managed monitored long-term geological disposal is proposed.
- Geological disposal taking into account the concept of actively managed monitored geological disposal for all waste types should be foreseen in Swiss legislation.

### **United Kingdom**

There is no candidate site for a geological repository in the United Kingdom. Thus far, siting efforts have been aimed at disposing of long-lived intermediate-level waste, which falls under the responsibility of United Kingdom Nirex Limited—a company founded by the nuclear industry with the support of the government. An early program to establish a single deep site for this waste was abandoned in 1985 following public protests. After an extensive public consultation process, another site selection process led to investigations at two existing nuclear sites, Sellafield and

Dounreay, with Sellafield designated the preferred site in 1991. In 1995, Nirex applied for permission to excavate a URL at Sellafield, but the application was denied by the local planning authority and the denial upheld by the Secretary of State for the Environment after Nirex's appeal was heard at a public inquiry. This failure prompted an inquiry by the House of Lords, which published the results of its public hearings (House of Lords, 1999). Some of the key recommendations resulting from the inquiry were to establish a board to set criteria for selecting disposal sites, to engage the public in decision making, and to recognize uncertainty as an integral part of science and technology (Tombs, 1999).

SNF is not considered a waste material in the United Kingdom. SNF from the U.K. Magnox<sup>3</sup> reactors and some SNF from advanced gas-cooled reactors (AGR) are reprocessed at Sellafield. Magnox SNF cannot be stored for very long after removal from the reactor, so it is systematically reprocessed. SNF from prototype fast reactors has been reprocessed at Dounreay. The primary waste from reprocessing is vitrified, and the vitrified HLW is stored for cooling for at least 50 years. SNF from the U.K. Sizewell B pressurized water reactor is stored at the reactor site, and AGR fuel not currently designated for reprocessing is stored at the Sellafield site. HLW disposition is the responsibility of the U.K. government. Sellafield also reprocesses foreign SNF on a contract basis. HLW from this reprocessing is vitrified and returned to the country of origin.

The United Kingdom has disposed of its LLW at two shallow land sites, Drigg and Dounreay, since the late 1950s. The total volume is approaching a million cubic meters, about 95 percent of which is disposed at Drigg. Investigations for a further disposal site for LLW and operational ILW were undertaken by Nirex during 1986 and 1987. However, this program was canceled when Nirex determined that a single deep facility for all ILW and LLW would be more cost-effective.

### United States

The United States has one candidate site for a deep geological repository for HLW and SNF, and it has one deep geological repository for transuranic waste in operation (see [Sidebar 4.1](#)). For HLW and SNF, the candidate site is Yucca Mountain, Nevada. The U.S. Congress limited site characterization to this single site in the 1987 Nuclear Waste Policy Amendments Act. Previously, the Department of Energy (DOE), the organization responsible for implementing waste management, had identified several potential sites, including Yucca Mountain; Deaf Smith County, Texas; and Hanford, Washington.

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<sup>3</sup> Magnox refers to the magnesium alloy in the cladding material of the fuels used in these gas-cooled reactors.

The United States considers commercial SNF to be a waste material. Currently, most commercial SNF is stored at reactor sites in pools and, increasingly, in dry storage casks (NWTRB, 1996). In addition, it is expected that HLW and SNF stored at DOE defense sites will eventually be stabilized and disposed in a geological repository. The DOE Savannah River Site is currently vitrifying its HLW. Some weapons-grade plutonium in excess of defense needs will be declared as waste and co-disposed along with vitrified HLW from the Savannah River Site.

The United States began considering geological disposal of HLW in 1957, after the National Research Council recommended salt deposits as potentially suitable for this purpose. Investigation of a salt formation near Lyons, Kansas, disclosed technical problems that resulted in rejection of the site. Attention shifted to monitored, retrievable (“away from reactor”) storage while a final disposal solution was being developed.

The 1982 Nuclear Waste Policy Act established a process for siting, developing, licensing, and constructing a geological repository. It also placed primary responsibility for SNF storage on its producers—DOE defense sites and commercial nuclear power plants. At that time geological disposal was expected to be available in 1998. In 1995, however, DOE projected that a repository probably would not be developed until 2010.

DOE completed a viability assessment of its Yucca Mountain site in 1998. Since then DOE has made substantial progress in characterizing Yucca Mountain. DOE believes that it remains a promising site and that work should proceed toward a decision on whether to recommend the site to the President of the United States. If the site is recommended for development as a repository site, then a final environmental impact statement will accompany the site recommendation. If Yucca Mountain is subsequently designated as the repository site, then a license application for construction authorization by the U.S. Nuclear Regulatory Commission will be developed. Under current plans, waste acceptance at the repository could begin in 2010.

LLW is disposed in shallow land facilities at several locations in the United States. Most commercial LLW is shipped to Barnwell, South Carolina. Envirocare in Utah receives very-low-level waste, for example, from facility decommissioning. LLW from defense programs has been disposed generally at the DOE site where it was produced, primarily Hanford, the Savannah River Site, and the Idaho National Engineering and Environmental Laboratory.

## CONCLUSIONS

The national program summaries in this chapter illustrate the worldwide effort devoted—as yet without success—to finding acceptable sites for geological disposal of HLW and the portions of SNF that are consid



#### **SIDEBAR 4.1 THE U. S. WASTE ISOLATION PILOT PLANT: A UNIQUE GEOLOGICAL REPOSITORY**

The Waste Isolation Pilot Plant (WIPP) is a deep geological repository for disposition of U.S. defense-generated transuranic waste (TRU), primarily contaminated clothing, tools, equipment, and debris resulting from the manufacture of nuclear weapons and cleanup of weapons production sites. WIPP has sufficient planned capacity to accommodate the entire inventory of U.S. defense TRU waste—estimated to be about 175,000 m<sup>3</sup> by volume and having a total activity of about 7 million curies, primarily from the roughly 13 mt of plutonium that is estimated to be contained in the waste (NRC, 1998, 2000b).

The WIPP site is located in the semiarid desert of southeastern New Mexico. The repository consists of mined shafts, tunnels, and waste disposal rooms in 250-million-year-old bedded salt about 650 meters beneath the land surface. WIPP opened in 1999 and is currently receiving a few shipments of waste per week from several weapons production sites. The waste is being shipped in boxes and 55-gallon drums for direct emplacement in the repository. Once the repository is filled with waste, the access tunnels and shafts will be backfilled to the surface and permanently sealed. The repository is expected to receive waste until about 2035.

WIPP is the world's first specially constructed deep geologic repository for long-lived radioactive waste, and its establishment is the result of almost four decades of scientific and technical work, beginning with the investigation of a potential site near Lyons, Kansas, by the U.S. Atomic Energy Commission in the 1960s. The WIPP site was first identified in 1975, and in 1979, it was designated by the U.S. Congress as a research and development facility for demonstrating the safe disposal of radioactive waste. During the next two decades, the U.S. government conducted an extensive program of scientific and technical investigations to assess the suitability of the site. These investigations culminated in 1996 with an application to the U.S. Environmental Protection Agency for certification to open the repository. Certification was granted in 1998.

The success of WIPP probably can be attributed to the following factors:

- The WIPP site proved to be a very suitable host for a TRU repository. It is located in a sparsely populated, semiarid region with little potable groundwater, and the bedded salt matrix is expected to provide an effective long-term barrier to the migration of transuranic radionuclides.
- From its beginning, the WIPP project had strong programmatic and scientific leadership.
- There was (and continues to be) public support for WIPP in communities near the repository and in New Mexico generally, probably for three reasons. First, the WIPP project provides jobs and economic development opportunities. DOE and the community both benefited from working cooperatively. Second, there is a long history of involvement of New Mexico in national defense activities—Sandia National Laboratories and Los Alamos National Laboratory are two of New Mexico's largest employers—and the WIPP project is viewed by many citizens as a legitimate national defense activity because it provides a solution to the defense transuranic waste problem. Third, no commercial waste is to be sent to WIPP.
- The WIPP project has been subjected to intense external scientific and technical reviews during most of its history. Beginning in 1978, the U.S. government provided funding to the state of New Mexico's Environmental Evaluation Group and the U.S. National Academies to conduct independent technical evaluations of

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various aspects of the WIPP project. The U.S. government also requested a peer review of the WIPP performance assessment from an expert committee under the auspices of the Nuclear Energy Agency and International Atomic Energy Agency. These reviews have improved the WIPP program and increased its credibility. The compliance certification process was carried out transparently according to rules agreed on in advance by all participants.

- Defense transuranic waste has a relatively low radionuclide content and produces relatively little heat. Consequently, there is expected to be little thermal energy generated in the repository to promote processes that could lead to the loss of containment.
- The engineered barrier system was modified to respond to technical concerns identified during the performance assessment studies (e.g., backfilling materials were introduced).

Although some of these factors are site or waste specific, there are lessons from the WIPP program that can be applied to other repository siting efforts—most notably, the importance of choosing a suitable site; allowing sufficient time to undertake the scientific and technical investigations necessary to demonstrate its suitability; and obtaining external, independent scientific and technical reviews of these investigatory efforts. These factors are discussed in more detail in [Chapter 6](#) and [Chapter 8](#).

ered waste. Nevertheless, national programs have made measurable progress. The reasons this progress has been slower than foreseen in most countries include the following:

- The development and acceptance of disposal technology has proved less straightforward than expected.
- The technical issues associated with site selection and, more particularly, site characterization are more complex than assumed earlier.
- The sociological and political problems raised by disposal projects were greatly underestimated.

The siting of centralized interim waste storage facilities has also encountered opposition, even though storage is a well-established technology that maintains options for monitoring and retrieval. Several countries, including Finland, Germany, Japan, Sweden, and Switzerland, have succeeded in siting centralized facilities while the United States, for example, has not.

Despite the lack of successes in siting geological repositories, there remains within national programs the general consensus that geological disposal is the only feasible, permanent solution to the HLW problem. There is also a general recognition, however, that technical answers alone are inadequate for deciding societal issues.

## 5

# Societal Issues in Radioactive Waste Management

Placing high-level radioactive waste (HLW) in a deep geological repository has been the solution accepted by the technical community for more than 40 years. However, there is only one such repository operating, the Waste Isolation Pilot Plant in the United States, and it is not for HLW.<sup>1</sup> In spite of strong support by the technical community, geological repositories have been opposed by large segments of the public in many countries:

The delays that have occurred are partly due to operational causes, but mainly reflect institutional reasons, in large part associated with insufficient public confidence. (NEA, 1999a, p. 32)

The committee concurs with this judgment by the authors of the recent report prepared by the Nuclear Energy Agency (NEA) of the Organization for Economic Cooperation and Development (OECD).

This chapter describes how the delays in implementing the policy of using deep geological repositories for disposal of nuclear waste are, at least in part, traceable to concerns, attitudes, perceptions, and different views among the public. Lack of cooperative interaction with the public is a root cause. Although interested and affected citizens may lack technical expertise, they do have strong, legitimate views regarding what they want. The views and political power of the citizens determine policy in a democratic society. The major limiting factor to the progress to date of national programs has been lack of public support and confidence.

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<sup>1</sup> The Waste Isolation Pilot Plant is certified to receive transuranic wastes, as noted in [Chapter 1](#) and [Chapter 4](#). See especially [Sidebar 4.1](#).

Radioactive wastes have confronted industrial democracies with a confounding and perplexing societal challenge. Siting radioactive waste facilities, in particular, has emerged as a difficult undertaking, primarily because this is where general misgivings about safety and fairness crystallize into specific opposition. Underneath lie deep social issues concerning links between peaceful and military uses of nuclear energy, the transport of nuclear materials, accountability of nuclear institutions, obligations to future generations, fairness of decision processes, and a host of other questions. Compounding all of this has been the historic underestimate of the difficulty of securing societal acceptance of waste disposal facilities. Nuclear pioneer Alvin Weinberg is widely quoted as recognizing, "We nuclear people have made a Faustian bargain with society" (Weinberg, 1994, p. 176). The difficulty of societal acceptance has been confirmed by independent assessments in a number of countries (e.g., OTA, 1982; Office Parlementaire, 1990; CEEA, 1998).

As the following quotes suggest, waste management institutions today face important challenges:

There is a need to view waste management in a wider societal context. In particular, issues such as sustainability, equitable distribution of potential risks and economic reality, are likely to become increasingly prominent, in response to heightened international awareness. (NEA, 1999a, p. 6)

In recent years, waste management institutions have become acutely aware that technical expertise and technical confidence in the geologic disposal concept are insufficient, on their own, to justify to a wider audience geologic disposal as a waste management solution, or to see it through to a successful implementation. . . . Overall confidence must be developed in a much wider audience. . . . (NEA, 1999b, p. 21)

To face these challenges, the committee considers that systematic research into social issues is needed. Deeper understanding of past difficulties encountered in interacting with segments of the public outside the technical community must be sought. New ways of conceptualizing the management task and its social environment must be developed. Innovative practices, and perhaps institutional design, may be called for and, indeed, have been undertaken in many countries. This chapter reviews current knowledge and identifies areas in which knowledge gaps remain.

The chapter is structured to offer insight into why many programs today appear to face insufficient support and confidence on the part of the public. If program managers have not succeeded in developing sufficient societal confidence today, it reflects *both* past practices *and* the important fact that the underlying situation, as suggested above, is very complex. A number of issues are discussed in this chapter to describe

this situation. Some pathways forward are identified and are considered in detail in [Chapter 8](#).

## THE ROOTS OF CONCERN

Many aspects of nuclear technology are associated with negative images, and these associations have a history dating back to the beginning of the twentieth century (Weart, 1988). Specific research has been conducted on social perceptions of industrial, natural, and everyday risks. Some trends have been identified (Slovic, 1992). “Nuclear power stands out in [survey] studies of risk perception as unknown, uncontrollable, and dreaded, with the perceived potential to produce immense numbers of fatalities, even in future generations” (Slovic et al., 1991b, p. 685; see also Slovic et al., 1979; Slovic, 1987). Nuclear waste tends to be perceived in a similarly negative way (Kunreuther et al., 1988; Slovic et al., 1991c). A Japanese-American comparative survey found that the fear of radioactive waste was as intense as the dread of a nuclear accident or even nuclear war (Hinman et al., 1993). Perceptions of radioactive waste in turn contribute to negative views of geological repositories through a process of “guilt by association” (Slovic et al., 1993, p. 78). To persons with particularly high concern, repositories represent a risk of involuntary exposure of populations to “catastrophic effects of siting” (Kraft and Clary, 1993, p. 107). Persons view not only deep geological repositories, but surface facilities as well, as being highly risky to neighboring residents (Charron et al., 1999).

In the 1980s and early 1990s the Nevada Nuclear Waste Project Office funded much of the available in-depth U.S. research<sup>2</sup> on public attitudes toward high-level nuclear waste and the social impacts of repositories.<sup>3</sup> The scope of perceived risk was demonstrated to be wide (Slovic et al., 1991a). Radioactive wastes, according to these studies, are seen by large segments of the public as a significant danger for health, safety, and the environment. As discussed below, perceptions of radioactive waste and its management are also tied up with questions of trust and credibility.

Review of studies conducted in different places and with different methods shows that citizens' reactions to nuclear waste and views of repository siting are remarkably similar, whatever their place of residence or walk of life (Rosa et al., 1993, p. 317). Results from surveys of

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<sup>2</sup> One of the researchers, Roger Kasperson, is now a member of the Board on Radioactive Waste Management and a member of this committee. The final summary report is *State of Nevada Socioeconomic Studies of Yucca Mountain 1986–1992* (Chalmers et al., 1993).

<sup>3</sup> The U.S. 1987 Nuclear Waste Policy Amendments Act designated Yucca Mountain, Nevada, as the sole site to be characterized for the first U.S. deep geological repository for spent nuclear fuel and high-level defense waste.

Nevada residents do not differ substantially from surveys of people who live elsewhere in the United States or in other countries. Although people interviewed in surveys seldom spontaneously mention nuclear waste as one of their major personal worries (unemployment typically holds that place), representative samples of national or international populations systematically rank radioactive waste as high on the list of risks for themselves or society (Slovic et al., 2000; Sjöberg et al., 2000). Such interviewees also feel that it is very important that their national or local government reduce this risk (Sjöberg et al., 2000).

The recent report *Europeans and Radioactive Waste* (European Union, 1999) gives a typical portrait of perceptions. Sixteen thousand persons replied to this 1998 survey. Eight out of ten Europeans interviewed believe that *all* radioactive waste is very dangerous. Asked about the potential consequences of an underground repository if one were to be built near their home, nine out of ten Europeans polled were very or fairly worried about the transport of waste, impact on their health, impact on the local environment, and safety over the centuries.

Studies in both the United States and Canada find that underground repositories for HLW evoke words such as “dangerous, toxic, death, sickness, environmental damage” (Slovic et al., 1993; Hine and Summers, 1996). There is also concern among potential neighbors of a radioactive waste facility about an indirect, or *stigma*, effect, whereby fear of nuclear waste may create a very negative image of their community or region and lead to a significant drop in tourism or in consumption of products that come from the area (Office Parlementaire, 1990; Slovic et al., 1991c; Avolahti and Vira, 1999). Stigma effects with consequent large economic losses have occurred after suggestions of radioactive or chemical contamination. Examples include: shunning of residents and products of an entire province after localized release of radioactive cesium from discarded medical equipment in Goiânia, Brazil (Curado et al., 1991), boycott of a U.S. region's apple crop following news that the agricultural chemical Alar was a potential carcinogen (Friedman et al., 1996), and the refusal of France and other European countries to accept British beef after possible links between bovine spongiform encephalopathy (BSE, or “mad cow” disease) and human Creutzfeldt-Jakob disease were announced in the United Kingdom (Balter, 2000). These are examples of the “social amplification” of perceived risk (Kasperson et al., 1988), whereby interpretations of events are transmitted by opinion leaders and the media, resulting in measurable economic and social impacts that go far beyond those suggested by technical estimates of physical risks.

It is fair to note that negative economic consequences have not been recorded systematically in all areas neighboring existing nuclear sites (examples include continuing tourism near French fuel reprocessing and intermediate-level waste storage sites, and in England's Lake District

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near the Sellafield nuclear complex, and the rapid tourism-spurred growth of Las Vegas, Nevada, near the former U.S. nuclear test site). However, evaluations or projections of economic impacts conducted by different parties can produce widely divergent conclusions (Barthe and Mays, in press).

Not only do many members of the public in many nations regard radioactive waste with concern, they do not believe that it is feasible today to manage it. Data collected from 56,000 Europeans from 1990 through 1995 (Eurobarometers 33, 35, 39, and 43)<sup>4</sup> showed that eight out of ten citizens polled believed the “problem of nuclear waste disposal has not yet been solved” and that disposal at sea or underground “cannot be done without contaminating the environment” (Reif and Melich, 1992, 1993, 1995; Reif and Marlier, 1997). Representative samples of the Swedish public and officials elected to local health and environment boards agreed that a “satisfactory solution” for the problem of nuclear waste does not exist at this time (Sjöberg, 1996). Three quarters of Europeans polled today agree, “The fact that no country has yet decided to dispose of highly radioactive waste shows that there is no safe way of getting rid of this waste.” About half do think that “this proves that all the possibilities and all the risks are carefully studied before a decision is taken” (European Union, 1999, p. 50).

Such a public vision of HLW as unmanageable is fostered and maintained at least partly by the news media's highlighting controversy over radioactive waste. Eight out of ten Europeans polled agree that the lack of national decision on disposal “shows how difficult and politically unpopular it is to take decisions about the elimination of any toxic waste” (European Union, 1999, p. 50). Events such as citizen mobilization against waste transport to Gorleben in Germany attract attention and serve to amplify public concerns: “. . . in many cases, mass media create public interest in a conflict, and also [offer] ‘interpretative packages’ that give a symbolic significance to the conflict” (Lidskog and Litmanen, 1997, p. 74). Media reports of even relatively peaceful exchanges between, for example, a mediator and members of the public in a local community are often accompanied by images or titles suggesting political risk or turmoil (Mays and Poumadère, 1996; Mays et al., 1998). The very fact that communities express high concern or are pitted in conflict with authorities—frequent

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<sup>4</sup> The traditional standard Eurobarometer (established in 1974): About 1000 representative face-to-face interviews per member country are carried out between two and five times per year with reports published twice yearly. The data (and tabulations) utilized from this material were made available by the Inter-university Consortium for Political and Social Research (ICPSR). The data for the Eurobarometer were originally collected and prepared by Jacques-Rene Rabier, Helene Riffault, and Ronald Inglehart. Neither the collectors of these original data nor the consortium bear any responsibility for the analysis or interpretations presented here.



events in the history of facility siting—increase others' perceptions of physical risk (Sandman et al., 1993).

The negative perceptions and judgments expressed by the public in surveys are often diametrically opposed to nuclear technologists' responses to the same questionnaires (Drottz-Sjöberg, 1999; Flynn et al., 1993). Contemporary citizens tend to perceive nuclear energy and nuclear waste issues more pessimistically than does the nuclear technical community (Tanaka, 1996). The divergence in view cannot be attributed solely to a lack of public understanding or familiarity with radioactivity or with technical aspects of waste management. Providing information to the public is an ongoing need. In the European Union, about one-third of persons polled state they are “not at all well informed” about radioactive waste (European Union, 1999, p. 50). However, much experience has shown that applying a “knowledge fix” (providing technical information on the assumption that people will then automatically subscribe to a view-point), like applying a “technological fix” or a “judicial-legislative fix,” has not changed peoples' perceptions or reduced opposition to repository siting (Rosa et al., 1993). Public opposition to repositories is not limited to persons with a low level of understanding of technical issues (Kraft and Clary, 1993) nor to persons lacking information (Allen and Marston, 1993; Mays, 1993).

The research reported above indicates that HLW elicits widespread concern and opposition. Negative images of radioactive waste and lack of confidence in disposition proposals are widespread among members of the public. Although the prospect or presence of any kind of industrial activity near peoples' homes is often a source of concern, HLW management activities face these added handicaps. Change in such ingrained perceptions is not likely to be easy and likely will require a process of societal discussion over many years (Rosa et al., 1993).

### **A LEGACY OF DISTRUST**

Public attitudes toward nuclear waste may derive in part from concerns over nuclear weapons. “Nuclear energy was conceived in secrecy, born in war, and first revealed to the world in horror. No matter how much proponents try to separate the peaceful from the weapons atom, the connection is firmly imbedded in the minds of the public” (Smith, 1988, p. 62). Nuclear institutions in many countries were founded under the “defense secrecy” model that reserved decision power to a small group of technological experts (Jasper, 1990). Siting attempts conducted under that model may have set the scene for public distrust of future waste management efforts (Kemp, 1992).

In the 1960s and 1970s, when national programs first began actively to face the waste problem, public opinion in regard to nuclear technology

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had already begun a downturn (Rosa and Freudenburg, 1993). Both the public policy sector and private industry failed to anticipate the opposition that would be expressed when plans became known, leaving them poorly prepared to respond effectively (Albrecht et al., 1996).

Although the consensus on a mined geologic repository was arrived at for reasons that were eminently logical at the time, there had been no broadly based public engagement in the discourse . . . acceptance of the choice by the broader society was presumed. . . . (Dreyfus, 1999, p. 1)

Local siting efforts for both low- and high-level waste facilities also began in a climate of opposition to nuclear power. Concerned local segments of the public found ready allies and resources in the larger environmentalist and civil rights communities. Fear and concern linked to the emergence of “toxic communities” (Edelstein, 1988), marked by residential toxic exposure to environmental contaminants, sharpened distrust (Vyner, 1988; Albrecht et al., 1996).

Tactical opposition by groups opposed to nuclear power has been a factor in the slow progress toward arriving at societal agreement on acceptable approaches to radioactive waste management. Over the years, the arguments used by nuclear opponents have invoked operational safety of reactors, economics of nuclear electricity, and “the unsolved waste problem.” This last argument has proven particularly powerful, lending the strong impression that long-term safe waste management is the Achilles' heel of nuclear power. Accordingly, some opposition groups have made it a policy to refuse constructive participation in seeking solutions until or unless a prior commitment to close down nuclear power is made. In some countries, for example, Sweden and Switzerland (Swedish Stipulation Act 1977, Swiss Atomic Law 1979), there has been a legal requirement for waste projects to be developed as a prerequisite to continued reactor operations (SFS, 1977; Swiss Federal Council of Ministers, 1979). This helped assure that the industry devoted sufficient resources to the problem but also further polarized attitudes of pro- and anti-nuclear groups. In Sweden, the 1980 referendum in favor of phasing out nuclear power has apparently led to less rejection of the concept of geologic disposal. Recently, in Germany, a government-industry consensus on ceasing nuclear power has also led to opposition groups' cooperating in efforts to establish repositories (AkEnd, 1999).

The language of waste management has not been conducive to reversing public distrust:

To an outsider, the issue of what to do with high-level radioactive waste introduces a morass of obscure jargon and abstruse questions. An almost measureless bulk of documents, data, and technical reports describes the technology of nuclear waste management. (Jacob, 1990, p. 164)

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In 1982, the U.S. Office of Technology Assessment concluded, “The greatest single obstacle that a successful waste management program must overcome is the severe erosion of public confidence in the Federal Government that past problems have created” (OTA, 1982, p. 10). The U.S. Secretary of Energy was sufficiently concerned about the pervasiveness of this problem to commission a special task force in 1991 “to recommend measures the Department might take to *strengthen public trust and confidence* in the civilian radioactive waste program” (SEAB, 1993, p. 1). The Task Force eventually found that “[b]y any conceivable indicator, the Department rouses little trust and confidence from *any* sector of the public” (SEAB, p. 36) and that the lack of trust and confidence is a “direct consequence of various publics’ experience with the Department in the past. It is not an irrational action nor . . . a manifestation of the ‘not in my back yard’ [NIMBY] syndrome” (SEAB, 1993, p. 37).

Complicating this legacy of distrust is the fact that trust in government and industry leadership is easily lost and hard to rebuild (Slovic, 1993). The record of siting attempts contains much to undermine local trust in decision makers and processes, even when these attempts were conducted in good faith. Trust-destroying events in the broader nuclear field continue to occur. After the Three Mile Island reactor accident in the United States in 1979, the Chernobyl reactor accident in the Ukraine in 1986 resulted not only in widespread contamination but also in loss in the credibility of the responsible authorities (Poumadère, 1991; Sjöberg et al., 2000). Much media attention is given to safety lapses of all kinds—both to grave accidents and to incidents ranked low on the International Atomic Energy Agency (IAEA) scale of severity. These events, as well as highly publicized militant attitudes against nuclear power, provide a context influencing public attitudes toward HLW and may trouble efforts to establish confidence in waste management institutions. Modifications to waste management regulations, standards, and guidelines, unless carefully prepared, justified, and explained, may also undo confidence. The impossibility of countering these trust-destroying messages by purely technical arguments is increasingly being acknowledged by interested parties (NEA, 1999b).

The lack of public trust in experts, industry, and government is not a phenomenon peculiar to radioactive waste disposal. Today, similar attitudes are perceptible in other controversial areas, such as genetic modification of foodstuffs. A general decline in deference to traditional authority (Laird, 1989) and in social trust is seen across nations (Pharr and Putnam, 2000; Putnam, 2000). Participants in the Irvine workshop session devoted to the question of public interactions pointed out that distrust in the waste domain is multilateral. Institutional representatives may distrust the public as much as members of the public distrust them. To the extent that the same individuals repeatedly find themselves seated

at the negotiation table and that communities and institutions recall repeated clashes and failures to achieve agreement, it is difficult to start afresh (Stoffle et al., 1991).

Social distrust is thus widespread in the nuclear waste domain, is deeply seated, reflects broader trends in society, and has a continuing history of events to maintain it. New initiatives will encounter and be handicapped by this legacy. Programs and institutional mechanisms predicated upon assumptions of trust, consensus, and cooperation generally have been unsuccessful (English, 1992). Ray Kemp, in his plenary talk at the Irvine workshop, suggested that procedures designed to function even in the absence of trust, rather than designed primarily to gain trust, will be more viable (Kemp, 1999). Experience from environmental dispute resolution indicates that persons may be willing to suspend distrust in exchange for increased decision power, greater information, more citizen control, and compensation for risk and burdens (Amy, 1987; see also Lake, 1987, 1994; O'Riordan et al., 1988). Thus, there may be new ways in which relationships with stakeholders can be made less reliant on traditionally understood trust, deference, and cooperation, while focusing on building confidence in organizations charged with waste management.

Institutions involved in waste management are making efforts to merit greater confidence and to create contexts in which mutual understanding can be developed. Recent examples include meetings of the NEA (NEA, 1999d, 2000b), Project Dialog run by Sweden's Nuclear Power Inspectorate (SKI), and a stakeholder forum in the United Kingdom. Such undertakings are increasingly taking into account lessons and concepts from the field of risk communication (NRC, 1989b). An NEA Forum on Stakeholder Confidence affords institutional partners an opportunity to exchange experiences and to analyze the impacts of new communication patterns on waste management organizations, including training needs (NEA, 2000b).

Even unsuccessful efforts in siting may ultimately help build confidence if they demonstrate that central authority will respect the wishes of local communities.

The feasibility studies in Storuman and Malå in the early and mid-nineties ended, from SKB's [Swedish Nuclear Fuel and Waste Management Company's] point of view, as what would seemingly be called a "failure". This, since the company left both communities once the population voted against further involvement in the site characterization step. But, because SKB acted fully in accordance with its own policy and respected the outcome of the referendum . . . this whole experience became trust building. (Thegerström and Engström, 1999, p. 381)

Subsequent Swedish candidate communities have insisted upon empowerment, both financial and institutional (Ahagen et al., 1999), and

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relationships with implementers have been conducted in a manner less vulnerable to distrust. The mayor of Oskarshamn, Sweden, the site for that country's central spent nuclear fuel (SNF) storage facility and a potential location for a geological repository, has expressed confidence in the public processes now being used by the implementing and regulatory authorities (Carlsson et al., 1999).

Many programs report the usefulness of public tours of underground research laboratories (URLs) and sites being characterized for possible use as repositories. In Sweden, 14,000 visitors came to underground laboratories in 1999 to inform themselves about the technologies involved and get a feeling of what an underground storage site represents. In the United States, about 45,000 visitors have taken advantage of the Department of Energy's (DOE's) offer for a visit to the Yucca Mountain site and discussion with project scientists about site characterization activities (Benson, 2001).

Such program shifts reflect an increased willingness to seek ways of avoiding or minimizing confrontation with communities and to act in a more open, accountable manner. Although welcome, such changes do not resolve all of the problems linked to the legacy of distrust. The conditions under which social trust in institutions may be recovered once lost, or may be enhanced, are complex and insufficiently understood at this time. Both experience and research indicate that such transformations do not happen quickly (Flynn et al., 1992; LaPorte, 1999). Social trust and its determinants are complex and multifaceted (Cvetkovich and Löfstedt, 1999). Transferring experience across countries and cultures may be difficult precisely because the relationships among trust, law, and political action can differ in subtle ways. In the meantime, many programs will have to shape new initiatives under conditions of considerable social distrust (Kasperson et al., 1992).

## VALUE JUDGMENTS AND ETHICAL ISSUES

Decisions on managing nuclear waste (like other aspects of nuclear technology) traditionally have been framed as predominantly scientific and technical. It was assumed that technical experts could produce the support and analysis needed for a policy choice and that implementation of the resultant policy would also be a relatively straightforward technical task.

These assumptions, however, have been challenged in practice, in particular when siting efforts bring the policy decision to public attention. At that time, the legitimacy of both policy content and process comes under scrutiny. In the plenary session of the Irvine workshop (see [Appendix B](#)), Dan Dreyfus, a former director of the U.S. HLW program, pointed out,

The decision process set forth in law contemplates only the acceptance or rejection of the site based upon a notion of a measurable technical standard. There is no substantive course of action set forth for an alternative. In effect, the policy presumes that the social decision to rely upon a mined geologic repository has already been made. (Dreyfus, 1999, pp. 2–3)

This comes about in no small part because the policy process has failed to afford sufficient mechanisms for basic policy choices to be debated by concerned segments of the public.

Over time, it has become apparent that the decisions at hand are not purely scientific and technical, but involve value choices:

Social acceptance of a [nuclear waste management] strategy will ultimately depend upon comparisons among the degrees and kinds of risk to be taken and considerations of equity among current and future stakeholders. These are value judgments. They can be informed, but not decided, by science and technology. (Dreyfus, 1999, p. 4)

The recognition that “science alone can never be an adequate basis for a risk decision” has grown in many areas of societal management of technology (NRC, 1996a, p. 26). Value judgments are often implicit. There have been increasing demands, and increasing efforts, to make them more explicit—and transparent—in nuclear waste management (see, e.g., Andersson, 1999) and to incorporate differing value perspectives, as well.

It is accepted . . . that [the waste management] community alone cannot decide on strategies with ethical, economic and political dimensions. Rather, an informed societal judgment is necessary. (NEA, 1999b, p. 23)

Nuclear waste management decisions involve a wide spectrum of issues implying value judgments. These include tension among local and centralized decision levels, burdens that must be borne by more than one generation, and many types of scientific and societal uncertainty. Different stakeholders are concerned and are likely to bring not only different perspectives to the decision process and its outcomes, but also different abilities to participate (English, 1999). For example, the views of many citizens may not necessarily be represented by advocacy groups or elected officials. Because radioactive waste will be hazardous for many generations, another key question is how the interests of future generations should be represented in the societal decisions on managing HLW.

In practice, the generation of radioactive wastes occurs largely through nuclear power production, and this implies that the debate on equity should logically be extended to include the intergenerational impacts of using nuclear energy. This report does not tackle that contentious issue directly. However, the highly polarized views held today are familiar. The pro-nuclear faction argues that an acceptable waste solu

tion benefits future societies by allowing increased use of nuclear power, and hence reduced use of fossil fuels. This conserves resources for the future and limits greenhouse gas emissions. The anti-nuclear faction maintains that continued use of nuclear power presents unacceptable safety and environmental hazards.

### **Intragenerational Equity**

For the current generation, two types of equity questions apply to the management of radioactive waste:

1. *Distributional equity.* Do persons and communities have equal access to the benefits of the waste-generating activities? How are the myriad positive and negative impacts of these activities and disposal programs distributed over geographic regions, generations, and social groups?
2. *Procedural equity.* Are the institutional arrangements and procedures by which policies are formulated and implemented fair to different groups? How is the burden of risk allocated across society? Are stakeholders involved in setting the standard against which decisions will be judged to be fair, and indeed in making the decisions?

A geological repository, or any centralized waste storage facility, will create inequities due to the fact that different individuals and groups will experience widely varying mixes of benefits, costs, and risks. The inequities may be unexpectedly extensive. Kates and Braine (1983) show that gains and losses associated with a hazardous waste site linked to the nuclear waste reprocessing facility at West Valley, New York, affected more than a dozen locations stretching across the United States. Even with careful attention to compensation, gains and losses are never commensurate. The gains are often economic, whereas losses are less tangible. Siting discussions can potentially create or deepen divisions among groups, who have different views and will benefit unequally from the employment and development a facility may offer (Drottz-Sjöberg, 1999). The stress on potential host communities has lasting effects, whether or not a facility is sited (Brown et al., 1989; Albrecht et al., 1996). These may be considered collateral effects of radioactive waste management processes, and research on ways of reducing such effects should be conducted.

Not only distributional equity, but also procedural equity, is at stake in past tendencies to site facilities in communities where high unemployment rates and limited access to political power undermine community opposition and the ability of local peoples to challenge centralized decisions (Blowers and Leroy, 1994). Such equity problems have been the primary focus of an emergent environmental justice movement in the United States but have challenged programs in other countries as well.



An avowed siting criterion of “political feasibility” can produce a sense of unfairness (Blowers et al., 1991; Kemp, 1992). However, some members of the public also contest basing site decisions on purely technical criteria. Increasingly, programs are testing voluntary or “mixed-mode” blends of directed and voluntary siting approaches, with better public response (Richardson, 1998). Today it is increasingly common practice to improve decisions by systematic accounting for a wider scope of concerns and criteria through, for example, multi-attribute analyses, or Environmental Impact Assessment (see Chapter 8, especially [Sidebar 8.2](#)).

Although similar problems of equity are encountered in the siting of any potentially hazardous facility, problems in siting a radioactive waste facility may be particularly complex:

- it will be the first facility, or among the first, of its kind;
- the risks it poses are long-lived and uncertain or unknown;
- radioactive wastes are highly feared by members of the public; and
- the past record of failure to take local concerns into account has often done little to inspire local confidence in the management authorities.

In situations in which distributional equity is impossible to obtain, the fairness of decision procedures becomes of paramount concern to members of the public (Easterling and Kunreuther, 1995). Perceived fairness and legitimacy of procedures are needed to site any controversial waste facility (see discussion in [Chapter 8](#)). As an example, the 1982 United States Nuclear Waste Policy Act had more than 35 individual procedural requirements aimed at assuring fairness. These provided for balancing the needs of a majority of the U.S. population with the rights of those in host areas who would bear the burdens and for negotiation as the process by which decisions would be made. Procedural equity, including the evaluation of more than one site and the maintenance throughout the process of multiple options, was a key component of the nuclear waste program. This architecture was abrogated by the Nuclear Waste Policy Amendments Act of 1987 (Public Law 100-203), which legislated that only the Yucca Mountain site in Nevada would remain under investigation (Flynn et al., 1995). The 1987 act contributed to a view shared by some in Nevada that “the federal government has violated standards of procedural equity in forcing a repository on Nevada without the state's consent” (Easterling and Kunreuther, 1995, p. 146).

Conflicts have arisen in other countries, including France and the United Kingdom, where prospective host communities perceived that early siting approaches involved decisions that were lacking in transparency and unfair to local interests (Office Parlementaire, 1990; Kemp, 1992). In both cases, community opposition formed to challenge decisions on the grounds of both distributional and procedural equity. In



France, a moratorium was called on underground laboratory siting, and parliamentary hearings were held to investigate viewpoints on equity and ways of developing a more acceptable and transparent process. An outcome was the Waste Act of 1991. In the United Kingdom, original HLW repository candidate sites were abandoned, and public consultation was one tool used in a subsequent attempt to determine acceptable siting criteria for a deep repository for low- and intermediate-level waste.

Analysis of responses to that U.K. consultation showed in particular that challenges to siting decisions are inadequately explained by the widely cited notion of "NIMBY." Respondents used a variety of justifications, considered many dimensions of the siting issue, and entertained alternative solutions (Kemp, 1990). Principally non-NIMBY objections were found also in the 1992–1993 public inquiry regarding Germany's Konrad mine. These dealt with justification of the repository, waste characteristics, long-term safety, and transport of the waste. A study in Canada concluded that NIMBY may miscast or obscure understanding of public attitudes to projects (Armour, 1991).

Future initiatives in radioactive waste management in Europe, North America, and Japan may well continue the trend seen in some countries toward placing equity issues in a central position along with scientific assessments. Designers of institutions and processes geared to winning social equity for communities affected by waste storage and transport are necessarily recognizing that multiple equity problems exist simultaneously. These may be exacerbated by past decisions, experience, and perceptions of past inequitable treatment for a host region. Continued attention should be given to how society may recognize and offer compensation to communities and regions that perform a service to their nation by accepting radioactive wastes.

### **Intergenerational Equity**

Intergenerational equity concerns are raised by the fact that long-lived nuclear waste poses a risk over many generations. In addition, any major policy decision implies future actions of implementation. Intergenerational ethics were addressed early by the waste management community (NEA, 1984, 1994, 1995a) and have been debated extensively (e.g., MacLean and Brown, 1983; MacLean, 1986; KASAM, 1988, 1998; AECL, 1991; IAEA, 2000b; NAPA, 1997; NEA, 1999b; Stockholm Environment Institute, 1999). Typically, discussions of the need for geological repositories have framed an ethical imperative:

[T]hose who generate the wastes should take responsibility, and provide the resources, for management of these [spent fuel and radioactive waste] materials in a way which will not impose undue burdens on future generations. (NEA, 1995a, p. 13; see also NEA, 1994)

This ethical belief has persisted in the technical community, is consistent with “polluters pay” and sustainability principles, and appears to be shared by members of the public (see polling references below). The IAEA Safety Convention contains provisions, both administrative and legal, to assure this goal (IAEA, 1997a).

Some in the technical community and national program leaderships have interpreted this view to imply that nuclear waste repositories should be constructed and sealed as quickly as technically possible. This view is now being challenged by recognition that there are valid reasons for deferring repository closure or for continued use of surface storage. These include the following:

- uncertainties in long-term safety,
- desire by members of the public to be assured of safety via continued monitoring and retrievability,
- possible future need to recover plutonium in SNF for its energy value as nuclear reactor fuel, and
- prospect of new approaches (including social ones) to treat and manage the wastes.

Thus,

[A]n equally valid ethical concern has been raised that this generation should not foreclose options to future generations, or hinder their ability to make decisions. (NEA, 1999b, p. 22; see also NAPA, 1997)

Although generally a majority of persons polled consider that it is the duty of our generation to resolve the problem of nuclear waste (on average 54 percent, with a country high of 70 percent in the Eurobarometer 50.0 survey), one-third of the citizens of the European Union surveyed in 1998 spontaneously affirmed that *both* this generation and future generations should be responsible for developing and implementing a solution.

A dichotomy thus arises between minimizing future burden and maximizing future choice. Different parties and groups give different weightings to the two ethical objectives, and these weightings result in a preference for different methods of waste management. Okrent (1999) argues that exceptionally high safety demands placed on radioactive waste management systems divert resources and attention from other pressing environmental issues. Other issues, over time, may become more prominent, too. If the worst fears about global warming turn out to be correct in the next 50 to 100 years, there will undoubtedly be less resistance to energy technologies that do not generate greenhouse gases. Reconciling the two ethical objectives presents a serious societal challenge.

## DISCUSSION: TOWARD AN EQUITABLE SYNTHESIS

Each of the disposition alternatives discussed in this report, surface storage or a repository with closure deferred and lengthy retrievability, creates a requirement for active management and further resource expenditure by future generations. If future generations fail to provide adequate active management, then safety and security may be compromised. National cultures vary, and a debate exists as to the urgency of placing HLW deep underground. The committee views this issue as essentially a value judgment about how best to assure safety and security of these dangerous materials and equity for both current and future generations, and expects that different societies will make different decisions. The committee's concern is that whether the disposition path chosen is extended surface storage or underground placement, it must be implemented with adequate resources over time so as to provide reasonable assurance that the waste management goals of safety and security will be met.

It cannot be assumed that ethical positions worked out by experts will be representative of public views. Local and national consultation can identify the views on fairness of different sectors of the public, thereby offering guidance to HLW management institutions on the values and obligations to which they are held. It is to be expected, as well, that the distribution and allocation of risks and benefits will change over the time periods at issue here. Although achieving full agreement on the issues— including equitable distributions of risk and benefit— is not expected, a well-conceived deliberative process can gradually make evident to all parties those areas in which agreement exists or can be obtained. It can also identify areas of divergence.

In no society will a complete consensus [on HLW management solutions] ever be reached. Ultimately, governments are responsible for making decisions that meet with an appropriate level of public support and provide the framework in which the necessary actions can be taken. (NEA, 1999b, p. 23)

Rather than seeking universal acceptance by individuals—which is impossible to achieve in a pluralistic society—researchers in the field of technology assessment suggest that the acceptability of decisions at the societal level should be sought. Societal acceptability means that decisions are justified by agreed criteria and procedures for decision making. The results of democratic procedures thus may be legitimate even if they do not lead to complete acceptance (Grunwald, 2000).

In societal discussion of such difficult ethical challenges as those presented by radioactive waste management, considerable efforts over many years, attention-focusing national or local events, and repeated opportunities for individuals and groups to work out views must be organized. Consensus in this context may usefully be defined as “achievement of a

sufficient concurrence of view at various stages to legitimize a decision to proceed with a particular course of action” (RWMAC, 1999, paragraph 3.4). Consensus must be regarded as specific to a given context and apt to evolve (Bataille, 1993). Even

[C]onsensus on values, such as safety and protection of the environment, does not translate simply, directly, or straightforwardly into agreed-upon social policy—hence, again, the importance of deliberative and broadly participatory decision processes. (Short, 1999, p. 337)

## CONCLUSIONS

The discussion in this chapter indicates a shift toward new thinking and approaches in HLW management. Not only is attention needed to “doing what has been decided,” but also to “deciding what to do.”<sup>5</sup> These decisions must involve a wider range of players than previously has been the case and require a careful integration of societal and scientific information.<sup>6</sup> At least two levels of decision are implied: (1) choosing between management alternatives and (2) choosing among implementation strategies. At any stage in deciding between the major alternatives—disposing of nuclear waste in a repository or storing the waste in an interim storage facility—society (i.e., the public and political authority) must compare two types of uncertainties and decide which is more acceptable, or whether a combination of the two is preferable. These are the uncertainty of the behavior of a repository in the long term, including the deleterious actions that can be brought about inadvertently by human intrusion, and the uncertainty of the capacity for society adequately to monitor and maintain an interim storage facility, given the fragility of human societies over the long term. These two uncertainties are of different natures; they must, however, be compared. Facing this challenge will require significant development of analytic and deliberative capacities in society.

As G. Jacob noted,

While vast resources have been expended on developing complex and sophisticated technologies, the equally sophisticated political processes and institutions required to develop a credible and legitimate strategy for nuclear waste management have not been developed. (Jacob, 1990, p. 164)

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<sup>5</sup> Thanks to Andrew Stirling, University of Sussex, for his observation of this distinction during the Irvine workshop.

<sup>6</sup> Some national programs are already well along in their decision processes. Some have used versions of the open and stepwise process recommended in this report. Other national programs have not. Although it is not anticipated that they would begin their process anew to conform to the recommended deliberative societal decision processes, consideration should be given to adaptations that can help increase public involvement and build increased public confidence in the decision process.

The decision about waste disposal is not taken once and for all, nor will it be common to all places where it occurs. Choosing among management alternatives—deciding what to do—and constructing a management system that enjoys widespread public confidence and support will require the active involvement of technical, political, and citizen partners. Rather than being viewed as a handicap or a threat to current progress, the structural time lapse implied for learning, for institutional revamping, and for developing the capacity to choose among uncertainties can be viewed as a valuable opportunity to build both the scientific and the societal knowledge needed to successfully manage HLW and SNF.

## RECOMMENDATIONS

Although public concerns on nuclear power and nuclear waste have been the subject of policy controversy in the United States and most other countries for more than two decades, few national programs have made a priority of social research into these topics. If one accepts that the delays in implementing current policy are at least in part the result of public perceptions and concerns, then it follows that better understanding of these perceptions and concerns, and an effort to bring policy and institutional processes into alignment with their implications, should become an important near-term goal. Only with a dedicated and sustained effort will social science research become a fully functioning support to the nuclear waste management process. Targets for this research should include not only public perceptions and concerns, but also the design of improved organizations, institutions, and deliberative decision processes. This would include study of incentives that social institutions can create for long-term responsibility in management of radioactive waste.<sup>7</sup> Concerted, durable, and adequately funded efforts will be necessary to define and perform needed studies and to monitor their integration with HLW policy process and policy implementation. While such efforts have not yet been organized, the following two recommendations may help focus the effort to be made:

1. A substantial, peer-reviewed social research effort should be mounted to provide constructive input for policy initiatives aimed at managing nuclear waste safely, securely, and equitably.
2. Existing review structures should integrate social science competence and counsel to provide continuing peer review and to monitor policy developments in light of research knowledge and evolving societal views on equity and ethical issues.

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<sup>7</sup> Incentives for responsible long-term management of common resources are the subject of another current NRC report, *The Drama of the Commons* (NRC, in press).

## 6

# Scientific and Technical Issues in Radioactive Waste Management

Geological disposition of high-level radioactive waste (HLW) and spent nuclear fuel (SNF) is scientifically sound, but important challenges remain. This chapter discusses how scientists and technologists are addressing the challenge of analyzing the long-term behavior of a geological repository and endeavoring to present their results convincingly to other scientists, regulators, and concerned members of the public. The first part of the chapter describes the scientific basis on which repository behavior can be analyzed. The second part of the chapter describes the quantitative methodology, known as performance assessment, which has been developed for such analyses by the waste management community, and the measures taken to enhance confidence in its reliability. Emphasis is placed on the necessity for the methodology and for the results it delivers to be acceptable not just to scientists employing it, but also to a wider circle of interested and affected parties, including the broad scientific community, regulators, and the public. The third part of the chapter highlights the specific problems faced by a regulatory body in arriving at binding decisions in light of the unavoidable uncertainties remaining in the technical analyses. Finally, some examples are given of how policy decisions can ultimately affect technical issues in program implementation. The chapter ends with the committee's conclusions on the methodology and results of performance assessments for geological repositories.

### GEOLOGICAL DISPOSAL

Practically, geological disposal does not represent a major construction challenge. All of the techniques required to build a repository, encap

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sulate the waste in a series of containers and barriers, emplace the waste, and close the repository are established or could be developed from established practices, and the associated cost is entirely compatible with the economics of energy production. A well-designed repository represents, after closure, a passive system containing a succession of robust safety barriers. These barriers are designed not solely to provide increasing levels of safety, but also to give increasing confidence that the overall system will remain safe even if individual barriers do not perform as well as they are designed to do. Our present civilization designs, builds, and lives with technological facilities of much greater complexity and higher hazard potential. In spite of these facts, there is a long-standing, intense debate on the feasibility of implementing “safe” repositories, that is, repositories that cause no harm to humans or to the environment.

The reason for much discussion is that extraordinarily **long time scales** must be considered explicitly in the analyses of repositories. There are inevitable **uncertainties** in the models and data used for these analyses and in the nature of events that might occur far into the future. There are particular uncertainties due to the **role of the geological medium** in isolating waste placed into a repository. Earth scientists are accustomed to descriptive, deductive reconstruction of the past, but for the purpose of a repository, they must develop quantified, inductive assessments of future system behavior. These factors make it a challenging task to analyze reliably the future evolution of the system. In practice, these difficulties are mitigated by two important facts. First, the engineered barriers can partially compensate for uncertainties in the understanding of the geological medium. Second, a single exact prediction is not needed; rather, understanding the range of potential future changes and assuring that these do not present unacceptable risks is a more correct description of the challenge. Long-term uncertainties also arise in analyses for the disposal of nonradioactive toxic wastes and for managing fossil fuel reserves. All such analyses require good science that will illuminate the physics, chemistry, and other mechanisms that will dominate repository behavior over the long time scales involved.

Nevertheless, the common perception is that for geological disposal specifically, one must be able to predict the future accurately—and it is **beyond** established engineering practices to predict accurately for many thousands of years how the waste and the repository will behave. It is also beyond established practice to predict accurately whether or not some of the radionuclides disposed in the repository may move through the geological formations and eventually come in contact with human beings and the environment in the future and cause them harm. As emphasized above, however, the challenge is not to accomplish these impossible tasks, but rather to assess the range of potential future behaviors with sufficient confidence to allow the appropriate societal decisions to be made.



Another important issue when evaluating the geological disposal option is physical security. Assuring security requires that safeguard controls over the fissile materials (particularly spent fuel or plutonium) be maintained in order to prevent their clandestine use for nuclear weapons development or to prevent the misuse of highly hazardous radioactive materials by terrorists (NAS, 1994). Disposal in deep sealed repositories is considered one of the most effective ways to prevent undetected recovery of nuclear material (Peterson, 1998). Although it is not impossible to reopen a repository and recover the stored material, such an action would require heavy equipment, long times, voluminous extraction of earth and sealing material, and high costs.

### SCIENTIFIC BASIS FOR MODELING

The time scales of concern for deep disposal are so long that **direct** observations or measurements of temporal alterations in actual repository system components are of limited value (although much can be learned from studies of analogous systems existing in nature). Assessment of future repository performance must be based upon **modeling** of the physical and chemical processes involved. The basic considerations for modeling are the following:

- The laws of natural science that govern key processes such as corrosion, fluid flow, and mass transport do not change with time. However, our knowledge of these laws may be incomplete and may develop as more experience is gained. The issue is to know which laws apply during the relevant time scales so that we can assure proper application of current knowledge to be able to identify key parameters with sufficient accuracy.
- The retrospective geological database actually extends over very much longer time scales (billions of years) than the lifetimes of most radioactive elements. Although knowing the past does not mean that one knows the future, history does give some confidence-building information about geological processes and rates of change.
- Predictions of actual system behavior are not required. It suffices to provide conservative (or pessimistic) estimates of impacts that can reasonably be expected. However, this assumes that unknown effects—those neither expected nor accounted for in the analysis—will not materialize in significantly detrimental ways. The problem is to know whether the underlying concepts being used will result in a truly conservative estimate.
- As long as one can be accurate in assuring that the levels of release are low, precise estimates are not needed; even with some orders of magnitude of residual uncertainty, the calculated release may be clearly within defined safety goals or limits.

The major models that are needed for making these predictions can be grouped into three categories: (1) behavior of the waste package (i.e., the waste itself and its surrounding containment), (2) behavior of the host rock in the immediate vicinity of the waste, and (3) transport of nuclides from the waste package to the environment. These are described below.

### **The Behavior of the Waste Package**

The approach used in modeling the waste package is to conduct short-term experiments (up to a few years) that bring the material (i.e., the canister, spent fuel, or solidified waste material) into contact with a leachant. The leachant is typically water containing additives so that its composition matches the expected composition of water within the repository. Corrosion or leaching models are fitted to the experimental results, and a model is used to extrapolate the results to very long time periods.

Understanding of the interaction mechanisms (such as surface corrosion, pit corrosion, solubility, or coating of waste by insoluble films) has made very significant progress in the past 20 years and has benefited from progress in materials science. Furthermore, significant efforts have been devoted to studying ancient natural objects as analogues of the waste package material (e.g., volcanic glass, archaeological copper, bronze, or iron) to determine if the models can reproduce the inferred degradation. There is little experience, however, in modeling the behavior of modern materials derived from new compositions and fabrication methods. Quantifying the uncertainty of extrapolations with these models from short-term experiments to tens or hundreds of thousands of years is still a major challenge. Nevertheless, it is accepted by the scientific community that wastes encapsulated in glass or ceramic material can last for many thousands of years in a suitable geological environment and that containers can be designed and built with similar lifetimes.

Other challenges are to predict the oxidation state of the leached radionuclides, and therefore their solubility (the effect of radiolysis being taken into account), and to predict the potential chemical forms of these radionuclides. Some of these chemical forms, or “species,” may have much greater mobility in the environment than others.

### **The Behavior of the Host Rock in the Immediate Vicinity of the Waste Package (the “Near-Field”)**

The behavior of the host rock will be affected by the temperature of the waste package, the chemical composition (as a function of time) of the water contacting the waste package, the mechanical properties of the rock, and the water content and water velocity close to the waste package.

Conductive heat transport is probably the best-understood phenomenon. As long as conduction is the dominant heat transport mechanism, one can be confident of being able to predict temperatures in space and time. This is because the uncertainty and spatial variability of heat conduction parameters of both man-made material and natural geological media are small, and therefore the uncertainty in the temperature distribution as a function of time is small.

Numerous heat transfer experiments have been made worldwide, including large-scale in situ tests in rock laboratories, for example, in Sweden (Stripa and Äspö), Belgium (Mol), Germany (Asse), France (Fanay-Augères), Spain (El Berrocal), Switzerland (Grimsel), and the United States Waste Isolation Pilot Plant [WIPP] (Brewitz et al., 1999). In the United States, a major, more complex heat transfer experiment at Yucca Mountain is in progress. It includes measurement of convective heat transport, water vaporization, and condensation in the geological medium, which are difficult to analyze. If a decision is made to allow temperatures in the volcanic tuffs to rise well above 100 °C, then there is considerable additional uncertainty because of the effects described above.

Methodologies for hydrogeochemical modeling of the near-field environment have also been developed and tested. They are generally based on the measurement of the present composition of the water; on its potential evolution due to temperature increases; and on the nature of the host rock, the waste package, and possibly a surrounding buffer material. The roles of the buffer are to protect the waste physically and to restrict access of water and transport of radionuclides. Most often, clays and sometimes salt are used as a buffer material. At Yucca Mountain in the United States, the waste package, according to the current design, is surrounded by air, and possibly shielded by an “umbrella” constructed of titanium alloy, which would prevent drops of water from falling on the canisters (DOE, 1998b).

Laboratory or in situ experiments are also being conducted to confirm the hydrogeochemical modeling. A large body of results (see, for example, NEA, 1999d, 2000c) gives confidence in the scientific approaches developed, although some residual uncertainties deserve more work, for example:

- *Modeling the complex interactions between some wastes, waste forms, and buffers.* These interactions occur for intensely radioactive waste from fuel reprocessing or if cement, bitumen, or degradable cellulosic material is present. The latter two materials are generally excluded from geological repositories because they may be flammable or support biological activity.
- *Understanding the potential natural evolution of the chemical composition of the groundwater.* In some cases, there already is spatial variability in

the observed composition, and it may be anticipated that changes will occur. The salinity is often variable (e.g., in Sweden), which is assumed to derive from past events during a glaciation or upward percolation of deep fluids. The oxygen content may also change with time, and there is evidence in the mineralogy of the rock that some oxidizing phases occurred. Predicting these changes is very uncertain and difficult.

The mechanical behavior of the rock is a complex function of its physical properties, the natural in situ state of stress, the geometry of the openings, and the thermal and chemical evolution. Thermal stresses are particularly important to determine and have been studied extensively during in situ thermal experiments. Depending on the rock type, stress can produce additional fracturing, or increased plasticity and convergence of the openings. The transport and geochemical evolution of fluids in the near-field may seal or open fractures and thus locally change the permeability. The main issue in mechanical modeling is the evolution of the permeability of the host rock in the vicinity of the waste and, for those repositories that are backfilled or are constructed in a plastic rock (clay, salt), to assess the effectiveness of the natural sealing of the voids and discontinuities surrounding the waste.

The natural evolution of the stress field due to tectonics, the probability and effects of earthquakes, and the effects of mechanical loading by ice during glaciation have also been studied in various programs. Historical records of earthquakes, plate tectonics, and theoretical modeling are used. The residual uncertainties are a function of the host rock (crystalline and volcanic rocks being much more sensitive to fracturing than clay and salt). The uncertainties potentially are significant and must be compensated for as far as possible by conservative repository design.

Knowing the flux of water in contact with the waste package is necessary to model the chemical degradation of the waste. This flux will vary throughout the repository due to small-scale spatial variability of the rock. There have been attempts to estimate this variability (e.g., in granite in Sweden) by using stochastic discrete fracture flow models at the small scale (SKI, 1996). The validity of these models is still debated, and the data base on which they are built is site specific. The models depend on detailed observations of the frequency distribution of natural fractures, plus those generated by mechanical effects. In many cases, an average fluid flux or maximum fluid flux is assumed. During the construction of a repository, observations of the flux at the time of the opening of the deposition cavity can be made and, for emplacements in which the fluid flux would be high, discarded. Even so, the evolution of this fluid flux due to thermomechanical and hydrogeochemical mechanisms, and to tectonic evolution in the long term, is quite uncertain. Upper bounds based on judgment are generally used in evaluations of safety.

## Transport of Radionuclides from the Near-Field Environment

Radionuclide transport out of the waste form and repository (the near-field environment) through the more distant geological host medium (often called the far-field or the geosphere) to that part of the environment accessible by humans (the accessible environment) is probably the most uncertain area of modeling. The theory for transport of solutes in natural media is reasonably well developed, but actual measurements have yielded surprises in the magnitude of the travel distance and direction (see [Sidebar 6.1](#) and [Sidebar 6.2](#)). These measurements force examination of whether the established theories apply in all cases. Even if classical behavior is assumed, transport models require detailed information on both near-field and far-field properties (i.e., properties of the geological medium between the repository and the accessible environment) of the repository system. Given the spatial variability of natural media, this is a formidable task. Clays and salt, which are relatively homogeneous media, generally have less spatial variability in physical and chemical properties than crystalline and volcanic rocks but are harder to characterize because low-permeability experiments are very difficult at large spatial scales.

Moreover, radionuclide migration experiments in a medium that has been chosen because it should confine the waste for very long times can be conducted only over very short distances (e.g., meters) for periods of a few years. Such migration experiments have been conducted in several underground research laboratories (URLs), for example, at Mol (Belgium), Grimsel (Switzerland), Stripa and Äspö (Sweden), El Berrocal (Spain), and Fanay-Augères (France) (see, for example, Kickmaier and McKinley 1997; Brewitz et al., 1999). These experiments have very significantly improved understanding of radionuclide transport in geological media.

It is, however, well known from experiments done elsewhere in more permeable media that transport parameters are scale dependent; consequently, the parameters measured at small scales cannot always be used to represent phenomena at larger scales (Matheron and de Marsily, 1980). The scale issue is related to the heterogeneity of natural media and, in particular, fractured media.

Another difficulty encountered in modeling radionuclide transport in geological media is that of properly accounting for the numerous coupled hydrogeochemical interactions that take place among the solutes, host rock, and particulate or colloidal matter that may be present. Much has been learned about these complex interactions, mostly in laboratory experiments and also in some of the transport experiments done in URLs, as mentioned above. A large number of thermodynamic equilibrium constants for these interactions have been measured for the most important nuclides and the most common rock types. Studies of these interactions

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are made more difficult by the spatial heterogeneity in rock properties, which so far has not been included in the models.

Beyond the difficulties of measuring the properties of geological media at large spatial scales and understanding the complex coupled processes that occur therein, accurate representation of these properties and processes in the transport model remains a major challenge. This challenge is sometimes referred to as the *conceptual model problem* (NRC, 2000a). Simply stated, a transport model is only as good as the conceptualizations of the properties and processes that govern radionuclide transport on which it is based. If the model does not properly account for the physical, hydrogeochemical, and when appropriate, biological processes and system properties that actually control radionuclide migration in both the near- and far-fields of the repository system, then model-derived estimates of radionuclide transport are very likely to have very large—even orders-of-magnitude—systematic errors (see [Sidebar 6.1](#)).

The present state of the art for transport modeling involves the use of many different kinds of numerical models to represent radionuclide migration in the environment. These models have large numbers of parameters that are difficult to estimate. Further, they are frequently based on highly simplified or even incorrect conceptualizations of the highly uncertain physical and chemical properties along the transport pathway. Special complications arise from the fact that in deep crystal systems very saline waters that contain methane and other gases are expected. Geochemical models for such fluids are not yet fully developed and transport considerations are very difficult. Only short-scale (tens of meters) direct validation of these models have been done.

Attempts have also been made to use natural analogues to understand long-term behaviors of natural systems (see, for example, Miller et al., 1994; McKinley and McCombie, 1995; Smellie et al., 1997; EC, 1998). Analogues are natural or man-made systems that have existed for long times, whose characteristics can be measured today and whose evolution through time can be modeled using the same methodologies employed in safety assessments (see the following section). In contrast to laboratory experiments that have well-defined initial conditions but limited time scales, some analogue systems have evolved over time periods even longer than those envisioned for repositories. Although there are often inherent difficulties in specifying precisely the conditions at the outset and throughout the history of the analogue system, the study of relevant systems can provide useful data for the analyst, enhanced understanding for the scientist, and increased transparency for the public.

It is, however, difficult to transpose the data inferred from the study of analogues to actual disposal sites, since the parameters of the models are site specific. Consequently, the use of environmental tracers (such as oxygen-18, deuterium, tritium, carbon-14, noble gases, and strontium iso



topes) to provide a better understanding of transport at potential repository sites is a very active area of current research.

The implication of the foregoing discussion of the scientific basis for modeling seems clear to the committee. To the extent that repository systems rely on geological media to provide a long-term barrier to radionuclide migration to the environment, it is essential that the fundamental system properties and processes that govern transport behavior be well understood and appropriately implemented in those models. In many disposal concepts, one approach to this challenge of understanding complex geology is to use other safety barriers to reduce the importance of the geological medium. A durable waste form and container, along with an effective, low-permeability buffer material around the waste packages, will reduce the performance requirements on the geology. However, long-term safety cannot be achieved and demonstrated without an adequate understanding of the geological structures and processes. Hence, gaining this understanding remains a major scientific challenge for repository development programs (see [Sidebar 6.2](#)).

#### **SIDEBAR 6.1: THE CONCEPTUAL MODEL PROBLEM**

The importance of accurate conceptualizations of subsurface properties and processes in radionuclide transport models can perhaps be best illustrated using two examples from the ongoing effort to clean up environmental contamination at U.S. national defense sites, which is being undertaken by the U.S. Department of Energy (DOE). Several major defense sites are located in the arid western United States, where the groundwater table is located tens to hundreds of meters below the earth's surface and the unsaturated zone above the water table is composed of highly heterogeneous rocks and sediments. When the sites were first established during and following the Second World War, it was thought that the arid climates and thick unsaturated zones would protect the groundwater from radioactive and chemical wastes discharged into the shallow subsurface. This is the same argument made to support a geological repository in a deep, fractured unsaturated zone at Yucca Mountain.

Transport models seemed to confirm these initial predictions and further indicated that radionuclide transport through the unsaturated zone to the groundwater at these sites would not occur for hundreds or even thousands of years. Recent "surprise" discoveries of radionuclides in groundwater at two of these sites (Idaho National Engineering and Environmental Laboratory [INEEL] in east-central Idaho and the Hanford Site in eastern Washington), however, have prompted a reevaluation of this assumption. Now, similar data involving bomb-era radionuclides (chlorine-36) from the Yucca Mountain site provides further evidence that the observations at INEEL and Hanford may apply to a geological repository site (see [Sidebar 6.2](#)).

At INEEL, recent monitoring of groundwater near a shallow land burial site (the Radioactive Waste Management Complex) containing radioactive and chemically hazardous waste confirmed the transport of low levels of plutonium and other con



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taminants through the unsaturated zone to the aquifer some 200 meters below. This migration was neither expected nor predicted from existing transport models, even though radionuclide travel time through the unsaturated zone has been the subject of intense debate at INEEL for almost four decades. In the 1960s, the National Research Council Committee on Geologic Aspects of Radioactive Waste Disposal visited the site and published a report on this issue (NRC, 1966). The report noted (p. 5) that

The protection afforded by aridity can lead to overconfidence: at both sites it seemed to be assumed that no water from surface precipitation percolates downward to the water table, whereas there appears to be as yet no conclusive evidence that this is the case, especially during periods of low evapotranspiration and heavier-than-average precipitation, as when winter snows are melted.

Indeed, since 1960, estimates for travel time through the unsaturated zone at INEEL have decreased by almost four orders of magnitude, as illustrated in the figure below.

At the Hanford Site, billions of gallons of liquid waste containing millions of curies of radioactivity have been disposed in the ground on the central plateau (referred to as the "200 Area") of the site. Initial field investigations of this site and subsequent transport models suggested that the 90-meter-thick unsaturated zone underlying the 200 Area would bind many of the released radionuclides, preventing their migration to groundwater (GAO, 1989, 1998). In 1997, however, DOE reported that cesium-137, technetium-99, and cobalt-60 had migrated deeper than expected, in some cases to groundwater (DOE, 1999b), along with some metals and chemicals.

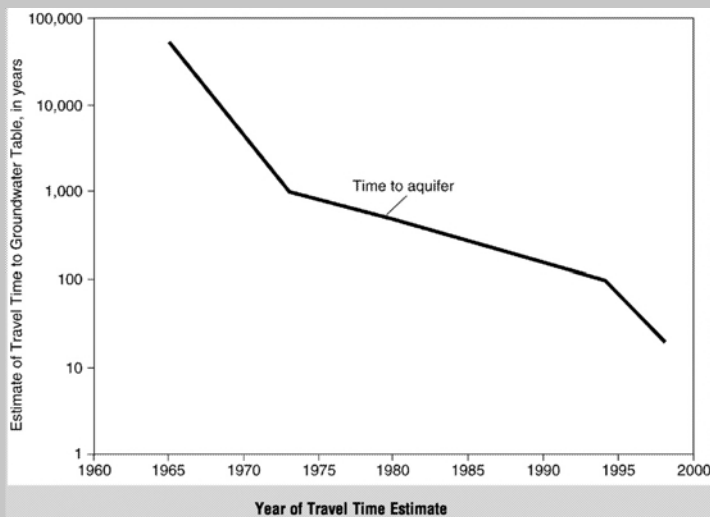


Figure 6.1 Changing estimates of travel time for measurable amounts of any mobile radionuclide to reach the water table beneath INEEL (NRC, 2000a)

The lack of accuracy of model predictions in these two examples can be attributed to incorrect conceptualizations of the hydrogeologic system at the sites, including improper simplifying assumptions, incorrect transport parameters, and overlooked transport phenomena. These problems reflect both an inadequate understanding of transport processes in geological media and poor implementation of current understanding in the transport models.

The impact of this “conceptual uncertainty” is very difficult to determine in performance assessment (see discussion in text). This is well captured in a quote from Konikow and Ewing (1999) who, comparing long-term predictions of natural systems with a game of chance, remark:

In hydrogeologic and geochemical systems, . . . we do not know the odds. In fact, we probably do not even know all of the rules of the game (or perhaps even which game we are playing); that is, for these natural systems there will be uncertainty in the conceptual models and in the complex non-linear coupling between models.

Most national programs have responded to conceptual uncertainties in the modeling of transport in geological media by placing more reliance on engineered barriers. Within the geological setting, the engineered barriers can be well characterized and can be emplaced under quality-assured conditions. This increases confidence in the understanding of their behavior, although it does not remove all conceptual uncertainties associated with understanding the far-future evolution of the engineered barriers and does not obviate a need to understand the behavior of the geological media.

### **SIDEBAR 6.2: GEOLOGICAL BARRIERS IN REPOSITORY SYSTEMS**

The geological media surrounding a repository provides a barrier to migration of radionuclides to the accessible environment. The geological media may retard the movement of groundwater or bind (sorb) many of the radionuclides that escape from the repository; alternatively, the groundwater flow system itself may provide effective isolation from the accessible environment. The net effect is to increase groundwater travel times from the repository to the accessible environment and thereby allow time for radioactive decay to reduce radionuclide concentrations.

Most repository designs utilize geological media as one of several barriers to radionuclide migration to the accessible environment. The Swedish design, for example, calls for a repository constructed in a fractured granite formation with a clay backfill below the groundwater table, with SNF encapsulated in copper canisters. The clay functions as a low-permeability buffer that greatly limits access of groundwater to the container and also retards any radionuclides that may be released from the wastes. The U.S. design, on the other hand, calls for the construction of a repository in the unsaturated zone in an oxidizing environment. The waste will be encapsulated in corrosion-resistant metal canisters, and the canisters will be surrounded by titanium drip shields to protect them from percolating water (DOE, 1998b). [Figure 6.2](#) illustrates this engineered barrier option for Yucca Mountain, as well as the general concept of engineered barriers.

Predicting the long-term behavior of water and radionuclide transport in the near- and far-field environments is a major challenge in all of these programs. In the U.S. program at Yucca Mountain, for example, it was initially assumed that

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water flow from the surface, through the repository some 250 meters below, and then into the groundwater some 350 meters below the repository horizon, would occur over thousands of years. It was further assumed that any radionuclides released from the repository would be readily sorbed onto the volcanic rocks that surround and underlie the repository. Recent scientific work suggests that some of these initial assumptions may reflect an oversimplified understanding of the geological system at Yucca Mountain. Recent geochemical and isotopic measurements suggest that some water has migrated from the surface of Yucca Mountain to the repository level during the past 40 years (Fabryka-Martin et al., 1998). Other research under way at the nearby Nevada Test Site suggests that small amounts of plutonium may be capable of being transported through groundwater on microscopic particles known as colloids (Kersting et al., 1999). Both of these findings remain to be confirmed through additional work at the site.

These recent findings have had at least two significant impacts on the program at Yucca Mountain. First, they have sparked renewed efforts to understand the properties of and the processes that operate in the geological system. The geological barrier is an essential feature of any repository. These findings have also prompted the redesign of the engineered barriers in the repository to reduce the potential for radionuclide migration from the near-field environment—similar in many respects to the strategy being used by the Swedish program. Thus, the new findings have led to an increased effort to understand the geology as well as add protection through engineered barriers.

This example illustrates the importance of having a good understanding of the geological media if it is to be relied on to provide a barrier to radionuclide migration. The Yucca Mountain program was used to make this point because site-specific scientific investigations are at an advanced state compared to most other programs. All national programs must emphasize sound, objective scientific research throughout their site-specific investigations and must maintain the flexibility to respond to unexpected results. These programs must have specific, focused research on identification of the appropriate conceptual models for their sites.

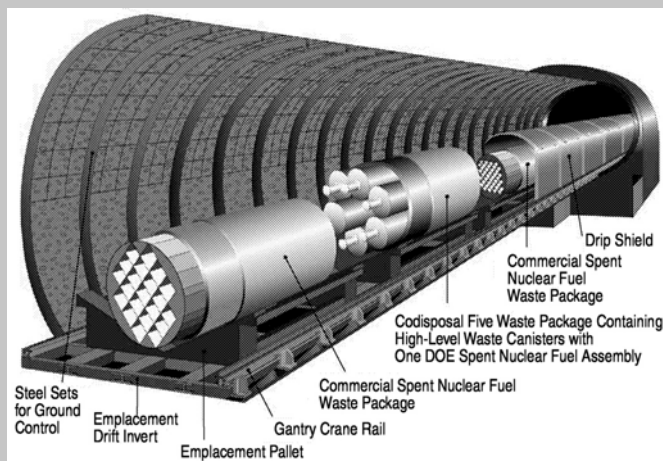


Figure 6.2 Engineered barrier system.

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## PERFORMANCE ASSESSMENT METHODOLOGY

Based on the extensive research summarized above, it has been possible, despite the open questions remaining, for interdisciplinary teams of safety assessors—including representatives from the fields of engineering, physics, chemistry, earth sciences, and mathematics—to develop over the past 20 years a safety assessment methodology capable of providing an important part of the decision basis required before implementation of geological repositories.

Basically, this methodology can be used to make quantified estimates, or “predictions,” of the possible future behavior of repositories and to also quantify the uncertainties in these predictions. This is called *performance assessment* (PA) (see [Sidebar 6.3](#)). The methodology is well documented and has been widely applied in many national programs (NEA, 1991a, 1997a, and 2000d). It has also been judged by the technical community as a sufficiently reliable tool for input to decision making (NEA, 1991b).

However, a **direct** demonstration of the reliability of the performance assessment methodology, including a rigorous and complete **proof** that the models used are correct, is not possible. Accordingly, the acceptability of project decisions based, at least in part, upon the results of safety assessments will depend on the level of confidence placed in the methodology by the technical experts within the implementer and regulator organizations, political decision makers, and the public. The following sections expand on the principles, technical approaches, and confidence-building measures that have been developed for analyzing the safety of geological repositories.

A typical PA includes the following two main elements:

1. The central element is an analysis of the most likely behavior (often called “normal evolution”) of the repository. If the repository site is chosen properly and the repository design is appropriate, then the PA should show that it is most likely that nothing harmful will ever happen and that the waste will be confined in the repository, or in its immediate vicinity, for the length of time in question. The length of time over which such an analysis is made may be specified by a regulation (e.g., 10,000 years) or may be unbounded. If the length of time is not bounded, then the analysis is made until the time when all radionuclides have decayed to levels that would result in radiation exposures near the natural background. Many PAs in different countries have predicted high levels of safety for normal evolution scenarios (NEA, 1991a).
2. Equally important is an analysis of the probability, and thereafter the consequences, of natural developments that might lead to loss of confinement of the waste. This can be caused by an adverse evolution of the geological setting of the site (e.g., faulting or volcanism), adverse evolu

tion of the environment (e.g., climate change, glaciation, accelerated erosion), unanticipated early weakening of some of the components of the natural or engineered barrier system because the site does not behave exactly as expected (e.g., early corrosion of the waste package, enhanced leaching rate and solubility, faster groundwater flow), or the existence in the system of unexpected negative features that may jeopardize the confinement (e.g., undetected manufacturing defects in a canister, an undetected geological fault). The probability of such a loss of confinement should be small for a suitable site. Proper site selection is therefore an important aspect of repository design, but it can only reduce the probability of release, not eliminate it.

In all cases, the occurrence of a release, even in the distant future, must be evaluated in terms of the potential harm it can cause. One therefore has to estimate the effect of the radionuclides released by a repository on humans and the environment. Current practice is to make such estimates by assuming that the living habits of humans in the future will be identical to those observed today.

In this respect the PA must also include an entirely different class of human-induced events—most importantly, the accidental “intrusion” of humans into the repository at some time in the future by drilling, underground excavation, or other means. Current practice is to assume that the PA includes only those events that could take place if the existence of the repository is forgotten (NEA, 1995b; NRC, 1995). An intentional intrusion into a known repository is considered to be outside the current generation's responsibility. In practice, such inadvertent intrusion scenarios must be highly “stylized” in that they are simplified and approximated, since it is impossible to try to analyze what the future society's technology will look like. The likelihood (or probability) of such intrusion scenarios depends on the properties of the site (e.g., existence of natural resources) and is sometimes quantified as a function of the present rate of drilling in the area.

### **SIDEBAR 6.3: PERFORMANCE ASSESSMENT**

Performance assessment is a formal quantitative methodology for estimating the long-term behavior of a candidate repository system, including the site. PA should be used iteratively throughout repository development, particularly once a candidate site has been selected and studied in detail. The results of this analysis are used in an application to the regulating authority for licenses to construct, open, fill, and close the repository. The important steps in the PA methodology are listed below:

1. Characterize the waste to be disposed and its near-field environment, both the present properties and the way in which these properties may change in the future.

2. Characterize the repository design including the engineered barriers, both for its present-day properties and for its potential evolution.
3. Characterize the selected site, both for its present-day properties and for its potential evolution.
4. List all the features, events, and processes (feps) that will act on and within the repository. Internationally agreed-to lists of feps can be used as checklists for this task (NEA, 2000a).
5. Screen all of the relevant feps that apply to the selected site and planned repository.
6. Assess the probability of occurrence of the selected feps.
7. Construct models of repository behavior for each selected fep and for all the couplings of feps that may occur. Verify these models and validate them against observations that have not also been used for establishing the model.
8. Estimate (or measure) the uncertainty of each of the parameters needed for each model. Determine if alternative sets of models (with their relevant parameters) could be used to assess conceptual model uncertainty.
9. Group those feps into a number of "scenarios":
  - those that are certain to occur within the repository, as it evolves with time;
  - those natural feps that may occur with a low probability; the time of occurrence of these external feps may be random, and
  - the human-induced feps, i.e., the various human intrusion scenarios.
10. In some countries, regulations prescribe the feps that have to be studied, both natural and human induced. This clearly simplifies the task of those carrying out the PA, but it does not guarantee that the choice is more realistic or complete and may even decrease confidence in the result. To avoid such a decrease in confidence, the prescribed feps should be considered by the PA analyst as the *minimum* set required.
11. The consequences of each scenario are calculated with the models. In most countries, the consequence of a scenario is a dose or risk to a human in a well-defined population known as the *critical group* (NEA, 1997b). The risk here is defined as the probability of occurrence of a scenario, times the dose received, times the probability of harm from that dose. The outcome of a consequence calculation has to be compared with a predetermined criterion, which is defined by the safety authority (acceptable release, acceptable dose, and acceptable risk). The proposed repository design and siting will not be acceptable if the criterion is not met.
12. A sensitivity analysis of the results of the PA to the uncertainty in the parameters of the models, to the uncertainty of the conceptual models, and finally to the scenario uncertainty is generally made to demonstrate robustness. If some uncertain parameters are found to change the outcome of the PA significantly, these parameters should receive more attention through additional research and experiments or through modification of the repository design before the PA is finalized.
13. The decision of the safety authority is not based solely on a single criterion being met—for example, an acceptable release within a prescribed time period—or even on a series of such numerical criteria, but on an overall judgment of whether the site is safe, the various calculations performed by the applicant being the only elements for making the decision.
14. The final judgment of the safety authority has to be acceptable to both the political authorities and also to the public for a positive decision to be possible. In most countries, no such decision can be taken without a democratic process (see [Chapter 5](#)).

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## DISCUSSION: UNCERTAINTY AND CONFIDENCE BUILDING

The preceding discussion in this chapter has described performance assessment, the approach developed by the waste management community to try to understand and quantify the risks associated with geological disposal. The questions are whether scientists judge this to be an effective way of evaluating the suitability of the repository option and whether other people will be convinced that it is a well-grounded and feasible approach. The most fundamental technical problem in applying performance assessment concepts, which were originally developed for nuclear reactor safety studies, to repositories concerns the geological part of the system (see [Sidebar 6.1](#) ). This is why many designs try to compensate for these difficulties by including a robust engineered system to reduce the consequences of geological uncertainties.

In attempting to model a geological system the basic question is: Have we used the correct conceptual models (see [Sidebar 6.1](#) ) representing the geological and other processes, to make the assessment? This uncertainty, which cannot be easily quantified, can be reduced by using alternative conceptual models and should always be kept in mind. There is a danger that a legalistic, prescriptive regulatory environment or a project forced to meet deadlines can induce scientists charged with developing a performance assessment to assume that they have no uncertainty in their conceptual models (see [Sidebar 6.1](#) , [Sidebar 6.2](#) ).

The purpose of PA is to quantify the probability and the consequences of repository failure. The aim is to compare predicted repository performance against a regulatory, as well as a common-sense, standard of risk. Adjustments can be made to the design of a repository if a PA shows that these are needed to align estimates based on assessment of possible repository performance with acceptable levels of risk. However, a repository can never be proved in advance to be absolutely safe over the entire period of its operation. Neither a 100 percent level of safety nor 100 percent confidence in the reliability of the assessments is possible. This is a fact that is true also for every other comparable technical undertaking, and it is important to assure that unique, unattainable requirements to the contrary are not placed on HLW disposal. Some probability of future failure will always exist. The PA analysis must compare the uncertainty that remains in this estimation against an acceptable level of uncertainty.

Either PA can contribute to convincing observers of the adequacy of a repository proposal, or it can have the converse effect of discouraging confidence. Interested parties may challenge the PA methodology and assumptions or question the adequacy of design adjustments. Furthermore, there are differing perceptions in society of what constitutes *acceptable risk* and of how much *uncertainty* in analysis is tolerable. Indeed these terms are loaded with many meanings. At the present time, probably a

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relatively small segment of the public and of political decision makers agrees on the definitions of acceptable risk and uncertainty developed by the waste community in its professional and scientific practice. In the opinion of the committee, these notions will require extensive discussion and debate among the various stakeholders over the coming years before any broad consensus can be obtained (see [Chapter 5](#)). Furthermore, these residual risks and uncertainties must be compared with those for alternative management options—for example, surface storage—for any given period of time.<sup>1</sup>

The following sections, based on analysis by the committee of what has happened in the past in national programs, review some of the steps that may be required of the scientific analysis of a repository in order to bridge the gap between those doing the analysis and the rest of the community. The goal should be that all parties involved in the decision-making process have a consistent and accurate perception of what PA can and cannot do, so that they do not make sub-optimal or irresponsible decisions based on incorrect or biased perceptions.

All of the decisions within the PA process can be taken only if there is sufficient confidence in the procedures and in the results of the assessments. Building confidence in the safety of geological disposal requires a range of measures (NEA, 2000b). One important measure concerns the technical issue of building confidence in safety assessment methods. A common approach to this task is comparison of calculated results with experimental values obtained in the laboratory or the field. The fact that feasible measurement times are always much shorter than the time scales of relevance for disposal systems is obviously a great limitation here. Nevertheless, agreement between calculation and experiments under a range of relevant conditions can enhance confidence in understanding the mechanisms involved and can also provide a database for extrapolation. Extensive laboratory programs, as briefly referred to elsewhere in this chapter, have studied the behaviors of all materials in the repository system (waste matrices, container materials, cements, rock types). In the field or in URLs, large experiments have simulated key aspects of rock mechanics, hydrogeology, and hydrochemistry, increasing confidence in the ability to model key transport processes in groundwater. The combination of short-term, exact experiments and observations with long-term analogue studies can also contribute to elimination of unsuitable models and to increase confidence in the models retained for the final safety assessments.

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<sup>1</sup> The use of risk numbers for comparison among alternatives (“relative risk”) rather than for assurance of adequate safety (“absolute risk”) has been emphasized in many reports on nuclear safety. See, for example, Lewis et al. (1978).

There remains, of course, a large element of human judgment in this methodology, as in most other technical assessments. It is important to explore ways to inform this judgment such that the quality of the technical work and reliability of products used in a repository can be judged appropriately. Natural analogues may be useful in this regard if they are understandable and reassuring to a wide public despite the inherent difficulties of quantification. Other common approaches to inform judgments include the use of open and objective reviews of technical work, and impartial and unbiased elicitation of expert opinion on issues where human judgment remains of key importance.

Efforts to raise public confidence have also been widely undertaken by the scientific and technical community. In their 1991 collective opinion on safety assessment methodology (NEA, 1991b), representatives of the Nuclear Energy Agency (NEA) of the Organization for Economic Cooperation and Development (OECD), the International Atomic Energy Agency (IAEA), and the European Commission (EC) expressed their belief that adequate (although not perfect) methods were available for assessment of the safety of a waste repository. However, this opinion, formulated by experts within the waste community, continues to be challenged at the broad level by nuclear opponents and many members of the public. At the detailed technical level, a debate on the validity of specific models continues within the technical community. It is therefore not surprising that decision makers and the public reserve judgment or are led to "choose sides."

At the technical level there must be increased recognition that **perfect** solutions are not possible on repository-relevant time scales, nor indeed are they required for justifiable project decisions. It is more important that scientists concentrate on understanding the effects of uncertainties in current models and data and on providing reasonable assurance that these current approaches will not underestimate potential releases of radioactive materials from repositories.

At the wider level, it is crucial that safety assessment experts communicate their belief that their calculated results, although imperfect, provide sufficiently reliable input for decision makers. To this end, presentation of results is very important. The non-expert looking at typical results from PAs will be confused by complex, probabilistically expressed results. The specialist, if confronted by simple scenarios, treated purely deterministically, will quickly ask for the associated probabilities. No one outside the radiation protection field will fully grasp the meaning of extremely low-dose predictions if a perspective on their health effects is not provided. Numerical results of analyses extending to geological times, if presented without sufficient discussion of their significance, lead understandably to accusations of over-optimism, hubris, or even irrationality. To the extent that there is uncertainty in conceptual models, this must be made clear.

When waste management specialists are considering how to reach out to other communities to achieve a common understanding of key issues, it is useful to start asking the questions: “Who are the stakeholders; in which order, and in what way should they become involved?” (See also [Sidebar 1.5](#)). The committee has identified four general groups of stakeholders for this analysis. These include the general scientific and technical community, regulators, elected officials, and concerned citizens. How science and scientists interact with each of these groups is discussed below.

### **The Scientific and Technical Community**

It seems clear that HLW disposal in any country cannot occur if the scientific and technical community does not support it. This community includes (1) scientists and engineers directly involved in the project who prepare the technical material that goes into the tools and models used in PA; (2) scientists and engineers involved in various review groups, at the local, national, or international level; and (3) members of the scientific and technical community not involved in the project, who may have some knowledge of the issue, or who have acquired the esteem and respect of their colleagues and the public because of the quality of their work. How does this scientific community arrive at its judgment?

As in any field of science, the first step is that the scientists actually working on the project have the stature and reputation that brings respect for their work from colleagues. Agencies involved in the preparation of a repository project should be aware of this requirement, applying not just at the top scientific levels, but at all levels. Evaluation of the feasibility of HLW disposal is a scientific challenge, and the highest-quality and most up-to-date science needs to be used. Independent expertise, including international expertise, should be used to complement the work of inhouse staff. The findings of the scientific staff need to be published regularly in the open scientific literature. This should not be considered by the agency as a secondary aim, but as a major requirement of the work.

Scientists involved in the programs must also have some opportunities for launching new studies in order to verify and develop new concepts. For instance, the examples concerning transport processes in [Sidebar 6.1](#) and [Sidebar 6.2](#) should motivate the examination of processes and mechanisms that were not anticipated when many national programs started one or two decades ago. It is necessary that new ideas be examined, which implies that scientists inside and outside the project can submit proposals and receive funding for performing work designed to disprove the prevailing conceptual model or to collect data that may support an alternative conceptual model. Of course, there must be a limit to the work that deserves to be funded; that decision, however, should not be

pend on the responsible agency alone, but also on external agencies experienced in funding scientific research.

Scientists with expertise relevant to a project must be able to express their views on the safety of the project to their peers, before the project enters the licensing phase. The National Research Council report on the Waste Isolation Pilot Plant (NRC, 1998), which came out about a month before the Department of Energy (DOE) applied to the Environmental Protection Agency (EPA) for compliance certification, was an excellent example of such an activity.

Scientists will be more easily convinced by a formal argument (the “safety case”) that an engineered system is safe if the design of the system is robust. The concept of robustness can be applied to repository systems as follows (McCombie et al., 1991):

- A robust repository system has (1) simple geology, physics, chemistry, and design; (2) large safety factors; and (3) some degree of redundancy.
- A robust performance assessment is characterized by (1) being based either on well-validated, realistic models or else on clearly conservative models and data; (2) assuring that all potentially negative processes are analyzed; and (3) being relatively insensitive to parameter and conceptual model changes.

For example, the robustness of the assertion that an engineered barrier is long-lived can be sought from archaeological evidence or from physical principles and short-term measurements. This approach led the Swedes and the Finns to select copper as the canister material (see [Figure 4.1](#)). Copper is known to be stable in reducing environments, both from the existence of native copper and from archaeological artifacts. Corrosion can also be estimated using the basic principles of metal corrosion thermodynamics. Both approaches provide confidence that this material will last for millions of years in favorable environments. The role of the geological barrier is then to maintain this favorable environment.

### **The Regulators' Dilemma**

The first role of a regulator is to decide the rules for demonstrating compliance that the implementing agencies should obey; then the regulator has to establish for the remaining stakeholders the credibility of its decisions by making clear why these rules are necessary and sufficient to convince the regulator of repository safety. The regulator's second role is to decide if the license application, which is made by the implementing agency, meets these requirements. Both roles require that the regulator has scientific credibility and that the same rules as those described above for science at the implementing agencies apply also to regulators. This

includes the need for scientists at the highest levels, sufficient scientific staff, publications, room and funding for independent research, and expression of independent scientific views.

In comparison to communicating with general scientists and the public, the interaction of regulators with implementers should be a more straightforward, technical task. This is not to say that the role of regulators is unimportant. Rather, experience shows that regulators should be in constant interaction with the implementing agencies. Regulators directly or indirectly interact with implementers with respect to the methods they should use to show compliance, the data they should collect, and the nature of the evidence they should provide. Furthermore, regulators have to understand the PA methodology very well. Only if regulators are convinced that the science behind the PA is good, and if the PA estimates of performance meet regulator-established requirements both quantitatively (i.e., meeting the numerical requirements in the regulations) and qualitatively (i.e., demonstrating in nonnumerical terms that the repository will be safe, using, for example, a convincing safety case), will regulators endorse and approve the licensing application.

The ultimate application of the safety assessment methodology is in the preparation of a full safety case for licensing a repository. There are three categories of requirements:

1. The **repository system** itself must be based on a robust disposal concept, good engineering and technology, and a suitable site.
2. The safety analysis requires a convincing **safety case** (robust models based on sound data), proper regulatory framework, and transparent presentation at all levels.
3. The **regulatory process** depends on having a competent implementing body, a competent regulatory body, and proper communication among all stakeholders.

Today, particularly with respect to nuclear activities, there is insufficient public and political trust to permit unquestioned acceptance of projects worked out only among technical experts in the implementer and the regulatory agencies. As in all highly technical initiatives, trust and confidence must be engendered in wider circles, and this requires that all experts be answerable to a wider audience. The special challenges of involving the public in nuclear and radioactive waste issues are dealt with in detail in [Chapter 5](#) and [Chapter 8](#).

Although no deep geological repository for long-lived wastes has yet been licensed through a standard procedure,<sup>2</sup> regulators and implementers are relatively confident that workable procedures have been, or can be,

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<sup>2</sup> The WIPP is a special case, certified by the EPA for limited types of DOE waste (see [Sidebar 4.1](#)).

developed. This is not to imply that there are no open issues. The following list provides some of the topics currently being discussed among regulators (NEA, 1997b):

- Time perspective—there are no scientific reasons for specific cutoff times such as 10,000 years—but are there policy reasons (NRC, 1995)?
- How can the safety of geological disposal be evaluated using the established regulatory concept of “reasonable assurance”?
- Should regulators require investigation of alternatives to geological disposal?
- What is the role of the regulator in site selection and choice of disposal method?
- Legal and regulatory issues—what are the roles of government agencies and regulators?
- What should the regulatory attitude be toward retrievability?
- How should human intrusion be treated when the future actions of society are unpredictable?
- How should the first 100-year-period risks (such as proliferation, transportation, and worker health) be weighted relative to the 10,000-year risks or to the maximum risks at any time?
- How can a reasonable decision be arrived at—setting up a decision process, participation, and a stepwise implementation process?

The last item leads to the heart of the “**regulator's dilemma**”—how to organize a regulatory approach to enable solid and accepted regulatory decisions to be made in light of the uncertainties, some of which are in fact not resolvable. [Sidebar 6.4](#) provides a summary of the committee's views on regulatory issues related to geological disposal.

#### **SIDEBAR 6.4: SUMMARY OF COMMITTEE VIEWS ON REGULATORY ISSUES RELATED TO GEOLOGICAL DISPOSAL**

The following points summarize the committee's views of regulatory issues connected with geological disposal.

1. A “phased approach” to regulation of a deep geological repository, as expounded 10 years ago in the Board on Radioactive Waste Management's *Rethinking High-Level Radioactive Waste Disposal* (NRC, 1990), remains excellent advice. A key corollary is that the regulator must strive to avoid over-prescriptive rules too early in the overall multi-decade process of regulatory approval. A second corollary is that, in general, a “compliance” attitude and philosophy is an inappropriate way for the regulator to approach the major yes-or-no decision; the regulatory yes-or-no decision for a geological repository will always require a good deal of judgment, not merely a cookbook compliance-type finding. At some very fundamental level, the implementer is always responsible for showing that the site



- is safe. Programs should be careful that a prescriptive regulatory approach does not induce a compliance attitude rather than a “safety” attitude.
2. Public involvement is essential in the process whereby the regulator arrives at the rules and regulations to be used in project approval. Public involvement should begin at the earliest phases of the rule-making process and continue throughout. This implies a fully open process, in which the public can challenge and comment on the approaches to be used by the regulatory body.
  3. As stated explicitly in regulatory documents from many countries (USNRC, 1998; EPA, 1999), “proof” that the proposed geological repository meets any specific set of regulatory standards cannot be had in the ordinary sense of that word. This is because of the very long time frames involved, including but not limited to our inability to understand changes in human behavior over such a long period.
  4. Even when a particular country's legal system requires quite prescriptive regulations for a deep geological repository, there is substantial room for flexibility at the level of detailed regulatory guidance, decision making, and inspection programs.
  5. The regulatory body's ability to adopt and utilize a less prescriptive system that involves relatively more judgment is very much tied up with how much trust that body enjoys with the broad public. The more trust, the more deference is afforded the regulatory body to exercise judgment instead of relying on prescriptive yes-or-no findings, and the more likely is acceptance by the public of the regulator's decisions.
  6. The corollary is that if a regulatory body has engendered mistrust and hostility among key sectors of the broad public, then it is typically forced into both more prescriptive and less flexible regulatory decision-making situations, and more conservative rules and decision criteria. This is because the political repercussions of any decision, where broad trust is absent, can become so uncomfortable for the regulatory body that it finds itself needing much more regulatory “margin” to make any decision.
  7. There is inevitably a lot of uncertainty in any analysis of future repository performance, no matter how well it is done. This is true even of those parts of the analysis, such as the geological, hydrological, metallurgical, and chemical aspects, that ought to be more “science based.” This has led to suggestions that the key regulatory yes-or-no decision should in general be based on more than a single numerical figure of merit. The approach of relying on a single figure of merit could be supplemented by use of one or more quite different figures, including an overall judgmental criterion, namely, Does the safety case make good technical sense?
  8. It is important to emphasize the value to every country of the principles incorporated in the *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management* (IAEA, 1997a). Internationally agreed-upon principles for radioactive waste management are discussed in Chapter 9 (see [Sidebar 9.1](#) ).
  9. Both the repository developer and the regulatory body should take a systems view of the analysis of future repository performance. Insights gained from a systems view are not just the sum of the insights from analysis of the details: understanding the “forest” is more than just a sum of understanding various individual “trees.”
  10. How far into the future the specific regulatory compliance period should extend is primarily a public policy issue, not a technical issue that science can address.



11. The job of regulating a first-of-a-kind repository is intrinsically one of gradual learning and refinement. Nobody should expect that a regulatory body could put into place in 2000 a set of regulations that would govern for, say, 100 years. The phased approach also allows regulations to develop and to take account of new knowledge gained during the lengthy phases leading ultimately to closed and sealed repositories.
12. It is broadly agreed that while a regulator should require the developer to put into place a monitoring system to measure various relevant repository performance parameters, it is an incorrect regulatory approach to make such monitoring an essential feature of assuring safety (IAEA, 1997b; ANDRA 1998). Regulators do not believe that such monitoring could be relied on for long enough—centuries or millennia—to identify flaws in the repository's safety case, which will likely emerge (if at all) only centuries or millennia in the future. This is not to say that monitoring that does in fact detect a repository failure or surprising behavior should be ignored.
13. Finally, it is important to consider how the regulator can structure a program for communicating effectively with the public.

### **The Link Between Scientific and Societal Responsibility**

In the past few years, more attention has been paid to the issue of increasing public involvement in the process leading to final disposal. In essence, there is pressure to structure a process that assures accessibility of all relevant information, gives adequate opportunity for public input and questions, retains options for as long as possible, and remains reversible should new evidence show that better options have become available. The most conspicuous result of these developments has been an intensive debate on monitoring repositories, on phased or stepwise implementation programs, and on measures needed to guarantee reversibility of steps—including retrieval of emplaced wastes.

The technical community accepted the validity of these points rather grudgingly. Originally, it was often pointed out that no scientifically meaningful monitoring programs could be proposed and that retrieval was a scenario that could be excluded by proper planning and execution of disposal projects. Now it is widely accepted that “confidence monitoring” to address public concerns is a legitimate exercise, even if scientific considerations indicate that the probability of detecting a malfunction is negligible even for centuries or millennia. It is also accepted that retrievability, or more generally reversibility, which was always feasible in principle, can be made more straightforward (“enhanced”) without unacceptable negative impacts on repository safety (IAEA, 1997b). In short, there has been an increase in the readiness of insider “experts” to listen to public concerns and to work toward allaying them. This very fact should

contribute to enhancing the public's involvement in geological disposal decisions.

Both the scientifically based performance assessment and the public processes associated with making choices about nuclear waste are complex and inherently uncertain. Those on both the technical and the public sides of this issue may wish that the other side were certain, but neither scientific understanding nor societal decision making are completely predictable. Importantly, there is a large potential for negative interaction between these two uncertainties. Scientists may wish to treat technical uncertainty through the calculation of risk. However, scientific uncertainty, or even the perception of scientific uncertainty, can easily cause public entities to fight a project. Public opposition can elicit a “bunker mentality” on the part of the implementer. The net result is a lack of true dialogue and the potential for suboptimal or even irrational decisions. Stirling (1999) refers to the tension between narrow notions of “sound science” and the “precautionary principle”<sup>3</sup> as a “dichotomy trap,” in which productive and creative “solution-oriented” thinking is impossible.

Both public interest organizations and technical implementers should be enjoined to act responsibly. It is not responsible to obfuscate the potential risks of a geological repository when communicating with the public. Nor is it responsible to take irreversible action when the risk cannot be sufficiently quantified. On the other hand, it is not responsible to block any action designed to reduce significantly the risk to society, merely because some risk remains. Invoking the precautionary principle in this regard can cause great harm by preventing appropriate waste management. There is no path forward that is risk-free, including taking no action. It is important that society make wise choices concerning the wastes that already exist and require management.

Rather than seeing the public need to be cautious as being in contradiction with a science-based management process, it is possible to view this caution as entirely consistent with sound scientific practice. In responding to intractable problems in risk assessment such as “ignorance” (“we don't know what we don't know”) and “incommensurability” (“we have to compare apples and oranges”), the role of precaution then becomes the same as the adoption of a stepwise approach in which difficult or irreversible decisions are taken only when commensurate with understanding. It is nearly impossible to quantify risk when we are also uncertain of the appropriate conceptual model underlying the phenomena of interest. The issues involved in gaining public acceptance under conceptual uncertainty include acknowledging the importance of ignorance and

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<sup>3</sup> The precautionary principle as a concept is a matter of intense debate in the risk community as well as in the international legal community. A recent summary describes its various formulations (Foster et al., 2000).

the subjectivity of the trade-offs and “framing assumptions” that necessarily condition any analysis. A rational response both to ignorance and to the implicit element of uncertainty in analysis is to broaden out the appraisal process systematically in such a way as to consider a wide array of different issues and options, contingencies, and possibilities and forms of effect, and to include a diverse range of disciplines and stakeholder groups, to provide for careful long-term monitoring, and to place the burden of persuasion on the developers rather than the regulators.

These choices make sense from a technical perspective, and they also allow a constructive dialogue with the public. In a measured and incremental application of an approach, Stirling recommends that “science should be on tap, not on top” (Stirling, 1999, p. 29). There can be no simple analytical, instrumental, or institutional “fixes” for the complexities encountered in the management of technological risks. Policy making must obviously be based on available scientific information, but science on its own is not enough. In this way, it is possible to integrate technical and socioeconomic factors in the management of risk by examining different technological options and evaluating their flexibility, resilience, and diversity. The recognition and active accommodation of dissenting voices in the societal debate is simply an extension of that crucial principle of quality in the scientific process: organized skepticism. Transparency is an essential means to the end of full public engagement. Inter- and intradisciplinary scientific conflicts should not be concealed. The full implications of uncertainties should be acknowledged. Alternative assumptions and value judgments should be explored fully.

Such an incremental approach, which makes sense from the technical standpoint, also offers a way to provide for the open-ended societal learning that is an essential quality of the successful waste management program. In this regard, there is a distinct difference between processes for *deciding what to do* and the process for *doing what's decided*. The two should not be confused. Societal acceptance will be more likely if the government's role is to facilitate the first process and not anticipate the result by sponsoring particular solutions. As the societal appraisal process illuminates the consequences of adopting different framing assumptions in interpreting the available science, then it becomes the role of the government to make incremental decisions and to be accountable transparently for the inevitable political and value-laden elements in such decisions.

In addition, a stepwise program is scientifically beneficial since it allows decisions at each step to be commensurate with the status of the science base at that time. Moreover, the reduced pace of development that these interactive processes and deliberately phased schedules imply for implementation programs affords more time for building public and political participation in the decision. These gains are to be set against the unavoidable increases in time and resources needed to carry out reposi

tory projects. Further aspects of the interaction with the public are discussed in [Chapter 5](#) and [Chapter 8](#).

## CONCLUSIONS

The challenge of safely managing HLW and SNF is not only a scientific issue. Indeed, the key areas in which problems have arisen, and new approaches may be needed, are more concerned with societal issues. Scientists and technologists involved in waste management have recognized this increasingly in past years and have shown a readiness to become involved more directly in these issues. Nevertheless, scientists have a prime, continuing responsibility to try to identify, understand, and communicate to the public the technical issues that influence the general debate. The corresponding conclusions widely agreed to by the committee and, it believes, also by the scientific and technical communities, are summarized below.

### Science, Technology, and Performance Assessment

Based on the preceding discussions, the following can be concluded:

- The necessity of modeling the long-term performance of a repository is universally recognized. Quantitative results from assessments provide a necessary input for decisions throughout disposal system development. The calculated results do not, however, provide hard criteria that obviate the need for human judgment. Safety assessments alone are not the only considerations governing the acceptability of any disposal facility.
- The feasibility of performing assessments of sufficient quality is accepted by technical experts within the waste management community. A somewhat lower level of confidence exists in wider scientific circles, and in limited segments of the public severe reservations are still expressed. Some of the remaining differences in views could be narrowed if assessors made clearer that their aim is not to analyze the future exactly, but rather to scope the range of potential future behaviors of the repository system and the consequences of the remaining uncertainties.
- Specific parts of the modeling chain for geological repositories will continue to be developed and refined. In particular, there is a critical need to focus explicitly on the conceptual models that underlie the calculations. It is these studies that will illuminate the physical and chemical principles that dominate the behavior of the repository. It is fundamentally necessary to identify the appropriate conceptual models before we define the appropriate parameters characterizing the site and then try to understand the statistical variability associated with these parameters. The common time scales for implementation of HLW repositories leave many years for potential improvements. These developments may ease the difficulties in

future licensing procedures; nevertheless, they will not result in perfect models that produce unquestionably accurate results. The requirements for human judgment and expert opinion will remain.

- The critical issue with respect to safety assessment is the required or achievable level of confidence in the results of the analyses. Neither a 100 percent level of safety nor 100 percent confidence in the reliability of the assessments is possible. This is a fact that is true also for every other comparable technical undertaking, and it is important to assure that unique, unattainable requirements to the contrary are not placed on radioactive waste disposal.
- The extensive technical efforts that are being put into specific, technical validation programs, centered around comparisons of calculations, experiments, and observations of analogue objects, should be complemented increasingly by further confidence-building measures. These include peer review, more formalized quality assurance, transparent documentation, large-scale demonstration experiments, and—of great importance—development of processes assuring open discussion among all involved parties.

### Confidence and Trust

- Confidence of the experts within the waste management community in the feasibility of safe geological disposal is documented in, for example, the collective opinions prepared by the OECD-NEA (NEA, 1991b). This confidence is not shared by sufficiently many members of the public and decision makers to allow rapid development of geological disposal projects.
- Performance assessments alone do not engender sufficient confidence in safety. Demonstration of sound scientific work (e.g., by transparency, peer review) and admission of indirect evidence (e.g., from natural or man-made analogues) are also necessary.
- The technical community now acknowledges the necessity of devising concepts and procedures **explicitly** aimed at raising public confidence. These include concepts for monitoring and retrieval of emplaced wastes and procedures for implementing repositories in a phased or stepwise manner. Maintaining a capability for reversibility of steps during the long processes leading to a closed and sealed repository is a major factor in enhancing public confidence.

### General Conclusions

- A phased or stepwise approach to implementation of repositories can offer a proper compromise between minimizing future burdens and maximizing future choice. Properly designed and sited repositories can

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have a long period of monitored controls and enhanced retrievability before being converted into their final closed state.

- Adequately safe geological repositories can be implemented with various combinations of carefully selected host rocks, sites, and engineered barriers as long as decisions are taken commensurate with understanding. It will never be possible to demonstrate that any one site is the “safest” choice. Factors other than long-term safety will also determine or even dominate siting choices.

## 7

# Alternatives to Geological Disposition

Geological disposition, as conceived by national programs worldwide, is the emplacement of current and future high-level radioactive waste (HLW) inventories in repositories that have been mined and constructed in deep formations. In conducting its study of the geological disposition option, the committee found three alternatives to this concept:

1. surface storage, either in-place where the waste was generated, or at consolidated locations;
2. alternatives that require advanced separation processes, including partitioning and transmutation (P&T) and disposal in outer space; and
3. geological alternatives to mined repositories, for example, seabed or borehole disposal.

The choice is not whether to put the waste in a repository or leave it on the surface for the order of 10,000 years. Rather, the choice is how and when to remove spent fuel from decommissioned reactors and where to put the fuel in order to assure safety and security. The major choice for nuclear programs in coming decades is how to assure the safe and secure control of HLW and spent nuclear fuel (SNF) while at the same time developing an option for geological disposal so that an ongoing commitment to active management can, at some future time, be brought to an end.

Geological disposition and surface storage (see [Sidebar 1.3](#) ) are the only options that the committee found to be feasible now or in the foreseeable future, as described in this chapter. Furthermore, the committee found that moving from surface storage to geological disposition is a



societal, rather than a technical, decision for each country and that this decision need not be rushed. Geological disposition followed by closing the repository (geological disposal) is nevertheless the only permanent and final solution to the waste problem. The committee recommends that all countries maintain this option in their national planning.

This chapter begins with a discussion of surface storage, then compares its advantages and disadvantages with those of geological disposition, and finally summarizes the committee's views on these two options. This chapter also gives a brief overview of partitioning and transmutation, which could reduce but not eliminate the need for geological disposition, and the other alternatives.

## SURFACE STORAGE

Currently, most if not all, SNF and HLW are in surface (or near-surface) storage. Storage technologies have been used safely for half a century.<sup>1</sup> SNF storage, primarily at reactors, has not been seriously questioned on safety grounds. For example, the U.S. Nuclear Regulatory Commission has concluded that such storage is safe for at least the life of the reactor's operations, that is, for at least 40–60 years (USNRC, 1999). Assessment of the Swedish centralized storage facility, CLAB, showed that it could safely store SNF for 100 years or more (Söderman, 1997).

Safe storage in surface or near-surface facilities can be achieved by packaging SNF and HLW in suitably engineered structures or robust containers to assure that radioactive materials will not be released. The security of surface or near-surface storage can be achieved by restricting access of individuals and groups that might divert fissionable material for weapons use or use radioactive material for acts of terrorism. The technical community agrees that excellent safety and security have been achieved in most existing HLW and SNF storage facilities.

From a technical point of view, there has been no urgent need for final disposal facilities because of the recognized high level of safety of interim storage facilities, the relatively small volumes of long-lived radioactive waste from civilian programs, and the storage time needed to allow adequate cooling of the more radioactive waste before geological disposal can take place. (NEA, 1999b, p. 9)

As noted in the above quote, storage can be technologically advantageous by providing time for the wastes to cool thermally through radioactive decay, and societally advantageous, by allowing more time for delib

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<sup>1</sup> The committee notes instances, especially regarding defense wastes in the United States and Russia, where storage conditions are not satisfactory. These have arisen primarily because the storage facilities, such as tanks, are well past their design lifetimes. Such examples illustrate the fact that storage facilities require continuing surveillance and maintenance.

erative decision making. Another 1999 Nuclear Energy Agency (NEA) review included the following regarding extended surface storage:

In virtually all countries, some period of interim surface storage to allow decay of radiation and heat generation has always been recognized to be necessary or valuable. This interim storage is often at a centralized location, but can also be at individual facilities. . . . More extended storage has been accepted as unavoidable because of delays in implementing disposal for both HLW and spent nuclear fuel. There are, in addition, arguments that favor extended (though not “indefinite”) surface storage. . . .

Postponement of disposal is advocated by some scientists and decision-makers who believe that more time is needed to prove the geologic disposal concept more completely and/or to allow public confidence to increase. (NEA, 1999a, p. 29)

Technologies are available now for HLW and SNF to achieve safe and secure storage, as well as for the transport and handling required to move waste from present locations to long-term storage facilities or repositories. However, public and political opposition to these activities is not necessarily less than that to geological disposition. Long-term storage will require continued funding for maintenance. This funding must be either from a continuation of nuclear power or by commitments from governments (Dejonghe, 1999).

Extended surface storage as an option has not yet been objectively addressed through performance assessment of likely scenarios (see [Sidebar 7.1](#) ). The NEA has recognized this and recommended that such assessments be made (NEA, 1999c).

### **SIDEBAR 7.1: THE LEAVE-IN-PLACE OPTION**

For use in the Yucca Mountain Environmental Impact Statement (EIS), the Department of Energy (DOE) examined only two leave-in-place scenarios, neither of which is likely:

1. societies and institutions similar to today exist, and storage facilities and waste forms are maintained and monitored for 10,000 years; and
2. institutional control is lost after 100 years.

For both scenarios the spent fuel and the HLW are kept at 77 existing utility and DOE sites stored in above-ground concrete modules or below-ground storage vaults. In scenario 1, facilities are repaired in 2060 and replaced every 100 years. Costs for this scenario are quite high. In scenario 2, facilities are repaired in 2060, maintenance stops in 2116, and memory of the purpose of the facilities is assumed to be lost. These scenarios include the three types of waste that are of greatest concern to the U.S. program: commercial SNF, SNF from DOE sites, and vitrified HLW from DOE sites. The commercial spent fuel canisters fail after 1100–5400 years; the DOE spent fuel canisters, after 800–1400 years; and the HLW canisters, after 500–1200

years (Walker, 1999a, 1999b). The DOE analysis begs the practical question of the longevity of the operations at the 77 sites themselves; it simply assumes that funds are available to support the activities specified in each scenario.

The proponents of surface storage do not argue that surface storage would be a permanent solution, as implied by the DOE EIS analysis scenarios, but rather that it should be examined as an interim approach that might be in place for one to perhaps several centuries. The DOE EIS analysis indicates no environmental or health problems through the first century of storage. It is this alternative of one to several centuries of delay that requires detailed, objective analysis.

### **SOCIETY'S TWO AVAILABLE DISPOSITION OPTIONS: GEOLOGICAL REPOSITORIES AND SURFACE STORAGE FACILITIES**

For the purpose of this report, geological disposition (see [Sidebar 1.3](#)) is considered to be the emplacement of waste into a repository. The repository would remain open, and authorized access to the waste would be possible, for example, for inspection or retrieval. Permanent geological disposal would result from closing and sealing the repository. Surface storage is the de facto disposition option being used today in all countries with HLW or SNF. Both options require control by responsible societies and institutions until permanent disposal is achieved.

For the geological disposal option, long-term safety is provided by the geological characteristics of the site and the protection afforded by engineered barriers that are part of the repository design. The main features, events, and processes (feps, see [Sidebar 6.3](#)) influencing the safety of this waste disposal system are slow natural processes (such as groundwater movement, climate changes, and erosion), rapid natural processes (such as earthquakes and flooding), processes caused by waste disposal (such as groundwater thermal convection, radiation damage to the waste package, and changes induced by mining operations), and human intrusion. The main uncertainties in assessing future repository system behavior arise from uncertainties in these feps, for example, groundwater movement in fractured rock, permeability changes induced by movements in existing faults, temperature-dependent kinetics of groundwater-host rock physicochemical interaction, and long-term changes in population density (Laverov, 1999b). These are issues that the technical community believes do not pose insurmountable difficulties for geological repositories.

Achieving safety and security over decades, centuries, or millennia involves a different mix of uncertainties for surface or near-surface storage than for a geological repository. Facilities on the earth's surface are subject to weathering and a variety of other processes that eventually could breach

the HLW storage facilities and containers. In contrast, physical and chemical conditions deep underground are relatively stable and predictable, even on geological time scales. The behavior of future human societies will be critically important for surface storage. Human access will be much easier for a surface facility than for a geological repository. Surface storage involves uncertainties in whether future generations will continue to provide the resources to assure safety and security. Performance of a geological repository involves uncertainties in the geological setting and in the changes that may occur over time in engineered barriers, as well as the possibility of deliberate or inadvertent human intrusion.

Surface storage has many proponents who stress that such storage would be protective of public health and safety for several centuries.<sup>2</sup> Others argue that selecting surface storage only delays the inevitable decision on geological disposal. For example, according to T. Varjoranta, chairman of the European Radioactive Waste Regulators' Forum, "... open-ended storing of the waste due to delaying the decisions necessary to obtain the far-reaching solution is, from the safety perspective, the worst option containing most uncertainties" (Varjoranta, 1999, p. 35). Ramon Gavela, Director of Science and Technology in the Spanish National Waste Management Company (ENRESA) commented that "[l]ong-term storage is more meaningful as an option if an advanced fuel cycle is chosen. . . . otherwise, it is simply a delay that increases the risk of repository disruption and creates the feeling that no final disposal solution exists" (Gavela, 1999, p. 113).

If surface storage is intended as a long-term alternative, the waste management strategy should address the effectiveness of controls to restrict access and assure containment integrity and the degree of confidence that can be placed in these controls. The preceding chapters (especially [Chapter 4](#) , [Chapter 5](#) and [Chapter 6](#) ) describe the status of current national programs to accomplish siting, licensing, and construction of geological repositories. The pace of development was much slower than was anticipated when these national programs were established. The lack of public support for repositories, which has been largely responsible for the delays, is not likely to change rapidly. Even if repository programs do resume the planned schedules, the scheduled pace for waste emplacement assures that a substantial surface storage capacity will be needed for at least 50 years in the United States and even longer in some other countries.

The committee does not believe that societies have to make a final choice now. Surface storage has been advanced by many proponents as an interim measure for the order of a century or two. Irrespective of the planned duration of surface storage, **the committee recommends that**

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<sup>2</sup> About 300 years is a reasonable period for which waste facilities can be kept under societal control (IAEA, 1999).

**geological disposal be pursued now as an option. The decision as to whether to implement this option, the timing, and the detailed technical choices in implementing geological disposal should be made, at an appropriate time and after appropriate deliberation, by the political leadership of each country with a responsibility for HLW.**

While the societal choice remains open, steps can be taken to increase knowledge: studies on improving repository performance through modifying the waste form and changing the repository design; monitoring to determine whether there is a need to retrieve the waste for disposal elsewhere because the repository performance is not acceptable; and assessments of the desirability of retrieval because the waste has become valuable or another disposal alternative (site or technology) now appears preferable.

## ALTERNATIVES TO GEOLOGICAL REPOSITORIES AND SURFACE STORAGE

During the past three decades many national and international organizations have examined alternatives for long-term management of HLW and SNF (BNWL, 1974; OTA, 1982; SKB, 1992; IAEA, 1995c). The discussion below gives the concept underlying each alternative, its advantages, and its limitations.

### Partitioning and Transmutation

An approach that has been claimed to have the potential to change the future of geological disposal is partitioning and transmutation (P&T) of long-lived radionuclides to give wastes which have shorter half-lives and therefore do not present as serious a challenge to the isolation capacity of repositories. (NEA, 1999a, p. 29)

The P&T concept has an extensive history. Unlike the other options discussed below, P&T research is being investigated or pursued actively in a number of countries, including France, Japan, Russia, Sweden, and the United States. Most scientists believe that P&T might reduce the volume of long-lived HLW that would be sent to a repository, but that it will not remove the need for long-term HLW management (NRC, 1996b). Thus this option should be considered a supplement to, but not a substitute for, continued surface storage or geological disposition.

Any intense source of neutrons, such as a light-water reactor, a liquid metal reactor, a fast reactor (as in the U.S. Integral Fast Reactor [IFR]), or an accelerator-driven subcritical reactor, can accomplish transmutation of long-lived radionuclides. The physical requirements for neutron intensity and the energy requirements to achieve such intensity make it necessary to partition, or separate, the long-lived radionuclides to be transmuted from the uranium, the fuel rod cladding, and other components in SNF

and HLW. Partitioning is essentially the same as reprocessing spent fuel to recover plutonium and uranium, except that the goal includes separating long-lived fission products such as iodine-129 and technetium-99 as well as plutonium and other actinides. This step, which can lead to separated plutonium, is one reason for opposition to P&T.

Very high separation factors are required if the residue from partitioning is to be low enough in radioactivity to avoid being classified as long-lived waste requiring the same isolation as HLW. To achieve these very high separation factors, much more advanced and sophisticated reprocessing technologies than those available today are required. The reasons offered to support P&T are to make geological disposal safer and easier by reducing the volume of HLW, especially the long-lived radioactive constituents; to address plutonium management; and to extract valuable materials.

The National Research Council (NRC) report *Nuclear Wastes: Technologies for Separations and Transmutation* (NRC, 1996b), usually referred to as the STATS report, provided a comprehensive review of this approach as of the mid-1990s (see [Sidebar 7.2](#)). The STATS report concluded that removal of the actinides might allow four to five times as much waste to be emplaced in a given area of a repository and that removing the cesium and strontium could increase repository capacity by a factor of 10 to 40 (NRC, 1996b, p. 348). The STATS report also concluded, “The benefits of [P&T] (which is defined as enhanced reprocessing to recover essentially all radionuclides that would otherwise report to repository wastes) to [reduce] long-term repository risk can largely, if not totally, be achieved by employing basic reprocessing (i.e., recovery of about 99% of the uranium and plutonium in the spent fuel)” (NRC, 1996b, p. 349). Although it recommended further work on P&T, the STATS report is highly pessimistic that the need for a U.S. HLW repository can be eliminated: “It is to be emphasized that a [P&T] scenario in which the need for a repository is eliminated is considered to be highly unlikely if not absolutely impossible” (NRC, 1996b, p. 349).

In 1999, the U.S. Congress directed the Department of Energy to develop a “road map” for the accelerator transmutation of waste (ATW) (DOE, 1999a). This report highlights substantial technical issues, with the “key technical issues [being] (a) lifetimes of proposed materials and components, (b) reliability of components, (c) degree of partitioning and separations, and (d) quantification of long-lived radioactivity generated in operations, including spallation products” (DOE, 1999a, p. E-1). The report lays out a six-year, \$280 million R&D program to assess the technical viability of ATW.

The report concludes that “. . . ATW, if successful, on the first repository program, could reduce potential long-term radiation doses from repository wastes by a factor of about 10; however, a repository is still



required [for the United States] due to the presence of defense wastes, which are not readily treatable by accelerator transmutation of waste, and the long-lived radioactivity generated by ATW operations” (DOE, 1999a, pp. E-1, 2). “The inventory of fissionable materials from commercial spent fuel in the repository could be reduced by a factor of 1,000. . . . The 82,000 [metric tons] of chemically separated uranium could be suitable for nearsurface disposal at a low-level waste site or non-shielded storage for potential future use in advanced reactors” (DOE, 1999a, p. E-11). If a successful program can remove 99.9 percent of the actinides and 95 percent of the technetium-99 and iodine-129 from the spent fuel, then “. . . the dose rate from the repository . . . is lowered by about four orders of magnitude out to 8,000 years after repository closure” (DOE, 1999a, p. 5-3). The improvement is about a factor of five after 20,000 years (DOE, 1999a, p. 5-3).

Should the initial R&D program be successful, the roadmap gives an estimate of “total life-cycle cost to treat 87,000 tonnes (t) of commercial spent fuel: approximately \$280B [billion] (\$2B R&D, \$9B demonstration, and \$270B post-demonstration design, construction, operation, and decommissioning).” The time period for treating the commercial spent fuel is 117 years (DOE, 1999a, p. E-2).

#### SIDEBAR 7.2: THE STATS REPORT

The STATS report made the following recommendations for further research on P&T in connection with advanced nuclear reactors and for incorporating retrievability into repository design for Yucca Mountain (NRC, 1996b, p. 349).

- The Department of Energy should consider removal of actinides as one option in its broader systemic evaluation of the thermal strategy for Yucca Mountain.
- Pursuit of a HLW repository should be continued,
- The benefits of [P&T] should continue to be studied as part of the continuing evaluation of repository performance. This should include explicit consideration of the optimum recovery of various radionuclides.
- [P&T] technology should continue to be developed in an orderly manner, and by the turn of the [21<sup>st</sup>] century it should be brought to the point where preferred technologies could be selected and demonstration projects initiated if deemed appropriate. This development should be closely coordinated with development of the ALMR [Advanced liquid-metal reactor] and its attendant nuclear fuel cycle.
- The design of the repository should incorporate features that would allow spent fuel to be readily retrieved and reprocessed and the resulting HLW to be emplaced at a higher effective density.

The conclusion that P&T will not be sufficient to avoid the need for a repository was reaffirmed at the 1999 Irvine workshop by J. P. Shapira in his paper *Is Partitioning and Transmutation (P&T) an Alternative to Geological Disposal?*.



The ability of a P&T strategy to avoid any geological disposal lies in the possibility for [all] these wastes to be disposed in a shallow land burial disposal site (Shapira, 1999, p. 3).

. . . the DF [decontamination factor] needed to keep the total radiological capacity and the concentration limits for the waste packages low enough for a land disposal to be licensed, **seems beyond the present and conceivable P&T technologies** (Shapira, 1999, p. 9, emphasis added).

It appears to the committee that developments since the mid-1990s in P&T and ATW continue to support the position that partitioning and ATW require more R&D to determine whether their goals can be met. However, at least in some countries, even if the goals were to be met, a geological repository or ongoing surface storage appears to be needed eventually to handle some radioactive waste, including some from the partitioning and transmutation process.

### Extraterrestrial Disposal

Extraterrestrial disposal is conceptually straightforward—the waste material is simply given a one-way ride into outer space. Realistically, however, this option is not feasible due to scientific, technical, and economic factors. These include the energy required to boost payloads into space, the failure of launches and their consequences, and the tradeoffs between cost and safety (Rice and Priest, 1981).

Extraterrestrial disposal of HLW would require transport via spacecraft, with extreme attention to safety to avoid release of radioactive materials in the event of malfunction. Placing the waste in space near earth would not be sufficient. Orbits either around earth or around the sun in the inner solar system change over time periods that are short compared to the lifetime of waste components, so that a waste package placed in such orbits conceivably could return to earth. Most discussion of extraterrestrial disposal has therefore involved sending the HLW into the sun, which requires considerably more energy per pound than placing a payload into orbit, that is, larger rockets, and consequently, extremely high cost per pound of waste disposed. Although a technological approach has been described (Taylor, 1995), the formidable energy requirements for solar disposal imply that only the most dangerous waste components might warrant such expensive disposal. Accordingly, reprocessing or separation would be required, as in the case for P&T.

### Geological Alternatives to Mined Repositories: Subseabed and Deep-Borehole Options

Approaches for isolating radioactive waste on earth by means other than geological disposition in mined, engineered repositories are discussed briefly in this section. These are variations on the basic concept of

geological disposal, in that the waste would be sequestered far below the earth's surface or they involve disposition in remote locations. In general, these approaches have about the same advantages and disadvantages as the geological disposition and surface storage approaches discussed in this report, and they have additional technical or legal constraints as noted in each discussion.

*Emplacement in deep boreholes* drilled from the surface is an approach to geological disposition that avoids the mined repository. Disposal in shallow boreholes was a normal practice at the "Radon" low-level waste disposal sites of the former Soviet Union, and it is still practiced in many former Soviet countries (IAEA, 1995a). Deep-borehole disposal at depths much greater than feasible for mined repositories has been studied in Australia, Italy, Russia (Khakhaev et al., 1995), Sweden, and Switzerland. Retrieval and sealing the boreholes (because they may be numerous) are greater technical challenges than for mined repositories (Juhlin et al., 1998; SKB, 2000).

Since deep-borehole disposal is so similar to geological disposal in mined repositories, it involves the same societal issues and long-term technical uncertainties. For large amounts of waste, drilling many deep boreholes from the surface is probably more expensive than a single mined repository. However, this variation of geological disposal may be suitable for countries with small waste inventories.

*Seabed disposal* would result in waste emplaced tens or hundreds of meters deep in sediments or rock under the seabed, which itself is beneath several thousand meters of ocean. An international Seabed Working Group (SWG) conducted seabed disposal research under Nuclear Energy Agency auspices from about 1977 to 1987, and there is scientific support for this approach (NEA, 1988; Hollister and Nadis, 1998).

Two emplacement options are considered technically feasible. One option is dropping steel or titanium canisters of waste in missile-shaped penetrators from a ship. Field trials of about 100 penetrators showed that these free-falling devices would bury themselves up to 70 meters deep in seabed sediment. In the second option, waste-filled canisters would be lowered into predrilled boreholes. The requisite borehole drilling was demonstrated by the Deep Sea Drilling Project and Ocean Drilling Project of the U.S. National Science Foundation, although sealing the boreholes has not been demonstrated.

This approach has many technical advantages, including a very stable geological setting, dilution in the event of radioactivity release into a very large body of water, low cost to emplace the HLW, and very low probability of deliberate human intrusion. Retrieval might be possible, but only at a high cost. Such cost and the need for specialized retrieval equipment would discourage clandestine recovery attempts. However, research on seabed disposal has been discontinued as a matter of international policy.

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Further consideration would, at minimum, require amendments to international treaties involving use of the seabed.

*Small, uninhabited islands* have been suggested in the past as alternative locations for geological disposal. This alternative would combine the advantages of both deep-seabed disposal and land-based repositories. The repository would be built by conventional shaft and drifts, starting from the island surface, but the disposal drifts would be situated below the ocean, away from the island. The rock type, which could be selected for such an option, would be similar to any on-land disposal (e.g., clay, granite) and thus provide the same degree of confinement as a land-based option. However, a major difference would be that the risk of unintentional human intrusion would be greatly reduced, and furthermore, any long-term small releases from the repository, which could occur both for a land-based repository and for such an under-the-ocean repository, would be immediately diluted in ocean water. Artificial islands built for this purpose have also been considered.

*Direct injection* of liquid waste or slurries of liquid waste and grout<sup>3</sup> is essentially a form of geological disposal that uses neither a waste package (e.g., a metal waste container) nor a mined repository. It was practiced in several countries for a variety of wastes, but it has generally been phased out. Clearly it is not applicable to SNF or vitrified HLW, which are solids.

The United States practiced direct injection of low-level liquid waste grouts under high pressure into a shale formation beneath the Oak Ridge, Tennessee site in the early 1970s. This process was abandoned due to uncertainties about how the grout flowed within the fractured shale. In 1972, an NRC study found the option of disposing of HLW at the U.S. Savannah River Site directly into crystalline bedrock beneath the site to be technically feasible. However the report cautioned that public approval for this option would be problematic (NRC, 1972).

For many years, the former Soviet Union injected intermediate-level liquid waste into the subsurface at sites such as Krasnoyarsk, Tomsk, and Dimitrograd. In these cases, the waste appears to have been contained between geological strata as intended (Parker et al., 1999, 2000). However, the approach is being phased out because it is not considered to be in line with better practices that include solidifying and packaging the waste (IAEA, 1995a).

## CONCLUSIONS AND RECOMMENDATIONS REGARDING ALTERNATIVES

More advanced reprocessing, partitioning and transmutation technology, and disposal options such as deep seabed might be regarded

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<sup>3</sup> Grout is a cementitious material, for example, Portland cement that hardens into a solid material after being mixed with water.

favorably in future centuries. Science and technology will continue to advance, the availability of energy resources will change, and political institutions and public attitudes will evolve. Especially on a scale of centuries, the changes are nearly impossible to anticipate. Thus, options to benefit from advances should be kept open as far as possible. However, based on what is known today, several important conclusions can be drawn:

- There does not appear to be any promising alternative to geological disposal for permanent isolation of HLW that avoids a need for ongoing active management.
- The only two alternatives capable of assuring safety and security on the time scale of decades to a few centuries are geological disposition and continued surface storage.
- More analyses of the alternatives and deliberation on choices for implementating them are needed, rather than rigid commitment to a schedule or a previously established plan for geological disposal. For example, the NEA has recommended that:

. . . the pros and cons of extended surface storage and of partitioning and transmutation should be objectively debated, since these two strategies have a strong body of support today. (NEA, 1999a, p. 6.)

Accordingly, the committee arrived at the following recommendations:

- **All countries with responsibility for radioactive wastes should be developing a geological disposal option, either for a repository within their own country or for a repository outside their country to be developed jointly with other nations.** The questions of “when,” “how,” and “where” remain open.
- **Until HLW is emplaced underground as a way to achieve safety and security, countries must assure that adequately monitored surface storage facilities for HLW, including SNF, are available.** New surface storage facilities also involve questions of when, how, and where, and such facilities can be expected to engender public controversy (see [Chapter 5](#)).
- **Options should be developed and maintained, with commitments made in small steps.** As recommended by the NEA:

Wastes should not, as far as possible, be conditioned into a form which precludes taking advantage of future technological developments; sites should not be definitively nominated until options have been explored; designs should not be frozen too soon; commissioning, operation and closure of a repository should all be in small steps each of which allows commitments to be fully considered. (NEA, 1999a, p. 27)

- **The analysis and deliberation should look at incremental changes in how and when waste might be moved from reactors and other sources**

**into centralized storage and from storage to emplacement underground. The analysis must compare rigorously the leave-in-place option, for realistic time frames, with other alternatives.**

The choice is not whether to put HLW and SNF into a repository or leave them on the surface for the order of 10,000 years. Rather, the choice is where to put them in order to assure safety and security. Although storage is not the final answer, it is a near-term necessity, and it will remain a necessity for many decades. Development of a site and the technology for geological disposal is a process that has taken decades already, and it may take many more for some national programs. Underground emplacement of HLW with retrievability is an alternative to surface storage, and neither surface storage nor such geological disposition precludes shifting to another disposition approach later.

**The major choice for nuclear programs for coming decades is how to assure the safe and secure control of HLW and SNF—while at the same time developing an option for geological disposal so that an ongoing commitment to active management can, at some future time, be brought to an end.** It is important not to prejudice the final steps in committing to geological disposal. Commitment to geological disposal will require both a robust technical basis and public understanding and acceptance of this commitment. The robust technical basis and public support may take some decades to achieve. In the meantime, other options for HLW disposition, or even disposal, may become available and may be preferred.

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## 8

# Improving Decision Making and Implementation

This chapter provides suggestions for national decision makers and other authorities who are responsible for radioactive waste management programs. It presents a time frame for these programs and recognizes recent shifts in many national programs that emphasize the need for societal partnerships in decision making. Adaptive program management for dealing with unavoidable technical and societal uncertainties is recommended. The committee recognizes that decision making under uncertainty is not unique to radioactive waste management. Genetic engineering and climate change, for example, pose similar challenges.

### THE NEED FOR A CONSISTENT POLICY THAT ENDURES

The time required to construct a repository, emplace waste, and then seal and close the repository is at least 50 years, even under the most optimistic plans that have been put forth for the U.S. and other national programs (see [Chapter 4](#)). Some national programs envision a period of at least a century before accomplishing geological disposition of high-level radioactive waste (HLW).<sup>1</sup> Measured against the frequency of changes in government leadership in democratic societies, the time necessary for implementing HLW policy is extremely long. For a policy to remain in place over this period it must have broad and enduring public support.

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<sup>1</sup> The term high-level waste (HLW) is used as a matter of convenience to include waste from nuclear fuel reprocessing and other materials such as spent nuclear fuels that are declared as waste and require similar disposition measures as reprocessing waste.

The challenge to the leadership of nations with nuclear programs is to establish and maintain this public support.

If a nation chooses to store its HLW in surface facilities, it must maintain both the containment integrity and the restriction of access so that this waste is neither released into the environment nor diverted for purposes that pose danger to society. The development of a geological repository and the alternative of continuing surface storage both entail substantial costs, which must be met either by funds provided by users of nuclear technologies or by governments. After a geological repository is closed, costs are reduced to a low level, for example, for monitoring. Costs for active management for surface storage continue throughout the storage period.

### IMPROVING POLICY DECISIONS AND MANAGEMENT IMPLEMENTATION

Leaders in the governments of democratic societies have to deal with many controversial issues in which local and provincial interests and attitudes must be balanced against national goals. One can observe in many areas of the world strong conflicts among nations and ethnic groups, whose roots in public attitudes go back many centuries. Progress in resolving these conflicts has often required arduous negotiation, innovative leadership from within each of the parties and from outside mediators, and patient efforts to make progress in small steps.

Similar processes may be needed in the nuclear waste context of linked dread, distrust, and concerns about inequities (see [Chapter 5](#)). Progress will not come overnight, and continued controversy, criticism, and dissent should be expected. There is little experience with policy problems that require a deliberation process to be carried out on a time scale of a half-century. Knowledge is now accumulating on new methods for achieving public decisions (Renn et al., 1995). During the coming years, it will be a significant, ongoing challenge to alleviate pressures on waste managers to revert to a very short decision and evaluation cycle.

The committee perceives that the political leaderships of various nations have reformulated nuclear waste programs to emphasize the need for societal choice. Concerted efforts are occurring to design, adapt, test, and carry out new procedures for, and approaches to, decision making. Two broad types of shift are especially apparent.

The first type of shift seen today in many countries concerns the consideration given to needs, concerns, views, and judgments that lie outside the central waste management system. Examples include the following:

- Collaborative research with volunteer communities to obtain equitable implementation. For instance, a “volunteer principle,” in which one

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begins the siting process by eliciting expressions of interest from communities over a wide region or in the entire country, has been tried in France, Sweden, Finland, Canada, and other countries (Richardson, 1998).

- The creation of oversight and peer review committees of plural composition.
- The use of varied consultation and deliberation formats. For instance, in the United Kingdom, hearings by the House of Lords Select Committee on Science and Technology were followed by a consensus conference (Tombs, 1999).
- The ethical evolution toward maintaining flexibility for future generations (see discussion in [Chapter 5](#)).
- The widespread adoption and elaboration of the concept of reversibility, often absent from early program concepts and introduced by public demand. For instance, the European Union's concerted action program, CNE (National Commission for Evaluation) in France, and KASAM (National Council for Nuclear Waste) in Sweden have collected input on reversibility. Sweden has pushed the concept of reversibility to the point of submitting the entire repository to a pilot evaluation period.

The second type of shift involves clarification of institutional identity and the relative roles of stakeholders. Examples are the following:

- The sharing of decision power among nuclear authorities and national and local representations. For instance, France shifted emphasis from evaluating designated sites for repository suitability, to creating a “responsible, democratic, transparent” management process and placing HLW management choices in the hands of parliament (the 1991 Waste Act). Finland will seek parliamentary approval of a design concept and submit that concept to local examination as well. In Sweden, the Swedish Nuclear Fuel and Waste Management Company (SKB) has promised to make site investigations only in communities where such investigations are accepted.
- The remodeling of implementing agencies to increase trust. For instance, in 1991 France recreated ANDRA (National Radioactive Waste Management Agency) as a new agency independent of the Atomic Energy Commissariat and other waste producers. The 1998 Seaborn Committee Report to the government of Canada recommended establishment of a new management agency “at arms length from the utilities and AECL (Atomic Energy of Canada, Limited), with the sole purpose of managing and coordinating the full range of activities relating to the long-term management of nuclear fuel wastes . . . subject to . . . policy direction from the federal government, and to regular public review, preferably by parliament” (CEAA, 1998, p. 3). Plans are being made in the United Kingdom to hold a public consultation to address options for waste management, including how to make Nirex an independent organization (Observer, 2000).

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The substantial social and institutional experimentation in progress in many countries is likely to encourage more new initiatives. Advice given to decision makers in a previous National Research Council report remains relevant to these new initiatives (see [Sidebar 8.1](#)).

### **SIDEBAR 8.1: GUIDANCE FROM THE 1996 NATIONAL RESEARCH COUNCIL REPORT *UNDERSTANDING RISK***

The disposition of HLW and SNF is not only a problem of complex public perceptions and attitudes, but also a challenging technical task requiring sound scientific backing to assure the goals of safety and security. As described in [Chapter 6](#) of this report, performance assessment to assure adequate safety is a highly technical exercise involving modeling of the geological setting and engineered barriers. A crucial aspect of performance assessment is the explicit assessment and communication of uncertainties. The societal decisions on disposition of HLW must be made in the face of these uncertainties.

The 1996 National Research Council report *Understanding Risk: Informing Decisions in a Democratic Society* (NRC, 1996a) provides useful guidance for public policy situations in which policy must be guided by technical analysis of risks and uncertainties. Such analysis involves complex, value-laden judgments and a need for effective two-way dialogue between technical experts and interested and affected citizens. The guidance in that report suggests that nuclear waste programs should act as follows:

- *Inform the interested and affected parties among the public.* Facilitate responsible and accurate scientific summary information, especially new information indicating surprises, need for change, and increased cost. Disclose areas of uncertainty and disagreement among scientific experts. Maintain strict accountability. All steps within the decision-making process and implementation should be verified independently and presented publicly.
- *Respect differences in values and cultures.* Separate issues of value from questions of what is scientifically correct. A multiplicity of values and viewpoints is to be expected in democratic societies, and differences in national cultures may motivate different policies for different nations. Ethical and equitable behavior must prevail in discussion of policy alternatives, as well as in program activities.
- *Seek flexibility and maintain choices.* Avoid dependence on a single “solution.” Expect and encourage through research further evolution in scientific knowledge, in governmental policies, and in public concerns and attitudes.
- *Most importantly in the current context, seek progress in stages, rather than seeking overall solutions.* At each stage, deliberation about policy choices should frame the objectives for technical analysis, and the technical analysis should inform policy deliberations. This should be an iterative process, involving both the technical community and the interested and affected groups among the public. This iterative process of deliberation supported by technical analysis should be used to encourage consensus, and to gain agreement on the most important issues for further study, on rejection of alternatives that are clearly inferior, and in seeking compromises that most parties can support.

## SITING: A CRUCIAL ASPECT OF SOCIETAL DECISION MAKING

Accumulated experience throughout many countries and a growing body of social science research indicate pathways for improved siting strategies. A set of “siting guidelines” (Kunreuther et al., 1993) highlights the issues that a process of siting hazardous facilities should expect to encounter. These guidelines should not be regarded as an operational manual for siting or as any sort of “ultimate” answer to managing a siting process. The guidelines are intended simply as useful advice drawn from experience on siting hazardous facilities in a number of countries.

The guidelines address three key features of any siting process. The first set relates to *goals and objectives*: instituting a wide participatory process, seeking consent that the status quo is not acceptable, and working to develop trust. The second set concerns *appropriate outcomes*: choosing the best solution to the problem, guaranteeing that stringent safety standards will be met, fully addressing negative aspects of the project, making the community better off, and using contingent agreements. The third set relates to *appropriate process*: using a volunteer system (even one of competitive bidding), aiming for geographic fairness in burden sharing, setting realistic planning schedules, and keeping a range of options open at all times (Lesbirel and Shaw, 2000).

### Goals and Objectives

Very little progress can be made in the siting of any controversial or risky facility if the need for the facility is not apparent and agreed upon. In Germany, nomination of the Konrad mine as a disposal site was perceived not as a response to the need to manage low-level and decommissioning wastes, but rather as an outcome to the search for a follow-up use for the unprofitable iron mine. This perception became a handicap to subsequent licensing phases. Controversies over low-level radioactive waste facilities in a variety of countries, as another example, have forced dramatic reductions in waste generation so that not all the planned capacity was needed.

Once a clear need for the facility can be demonstrated, then substantial efforts are needed in advance of the site selection process to establish widespread public understanding on three questions: (1) Is the status quo acceptable? (2) Is the proposed facility needed? (3) Have alternative approaches been duly considered and rejected for appropriate cause? If many segments of the public are unconvinced that disposition in a repository is superior to lengthy storage above ground, repository siting will face a serious added obstacle. A social consensus on facility need, in short, is a major asset on which to build. Experience from Canada underlines this point (Peelle, 1994). In successful voluntary siting experiences of haz

ardous waste facilities in the provinces of Alberta and Manitoba, Canada, extensive discussions over the question of need were begun well in advance of initiating the siting process.

### **Appropriate Outcomes**

A second major issue has been called the “siting paradox.” When an agency seeks permission to investigate the technical feasibility of a proposed site, it is usually necessary first to obtain the assent of the local community and its various councils and representatives that the site has been selected fairly and the project is provisionally acceptable. At this preliminary stage, however, there is generally no analysis available to the public showing that the project would be safe if it were to be approved. Communities do not know, at the outset of an expensive and disruptive site approval process, if they will host a safe facility or no facility at all. Consequently, the criteria for early approval of a potential site as a candidate for a feasibility investigation often will depend heavily on whether the site decision process is (1) clearly spelled out from the start and (2) fair and transparent to both politicians and the public. If there is public confidence that the agency in charge of the work is credible or trustworthy, the decision to accord provisional acceptance of a site for detailed study is likely to be facilitated. If not, other guarantees are needed that the decision process will be respected *and* that the accumulating weight of investment in the site will not lead to its being retained even if it is found to be technically inadequate (RWMAC-ACSNI, 1995).

### **Appropriate Process**

Strategies of partnership, power sharing, collaboration, and negotiation allow a host community to proceed with a siting process that relies less on trust in some external authority than on the host community's own capabilities and evaluation. Specific mechanisms that may be helpful in such an approach include the following:

- community participation in all phases of the siting process,
- support for independent consultants,
- community review of facility design and safety systems,
- monitoring of facility performance,
- property value protection, and
- right to initiate appeals for facility shutdown if health and safety standards are violated.

Such actions to empower local communities in both siting and facility development may be keys to greater siting success. Different means may be used to develop these recommended features. The Environmental Impact

Assessment (EIA) requirement has been used, particularly in Scandinavia, as an opportunity to conduct *social* impact assessment (see [Sidebar 8.2](#)). The EIA process thereby becomes a means by which extra-technical aspects of risk can be discussed, documented, and taken into account (Äikäs, 1999). The five country examples that follow, showing the experience of different countries with siting, may be useful as illustrations.

### **SIDEBAR 8.2: ENVIRONMENTAL IMPACT ASSESSMENT: ENCOURAGING PUBLIC PARTICIPATION IN SITING DECISIONS**

The Environmental Impact Assessment Directive (85/337/EEC, as amended by 97/11/EC of 3 March 1997) requires that facilities in the European Union designed for the storage or disposal of radioactive waste be assessed to determine their effects on the environment.<sup>2</sup> This assessment must be undertaken before development authorization is granted. Member states enjoy discretion in translating the Directive's provisions into national law and practice. The process of environmental impact assessment is defined as the identification, description, and assessment of the direct and indirect effects of a facility project on the following factors:

human beings, fauna and flora; soil, water, air, climate and the landscape; material assets and the cultural heritage; and the interaction between these factors. (Art. 3)

Information expected from the developer should include at a minimum:

a description of the project comprising information on the site, design and size of the project; a description of the measures envisaged in order to avoid, reduce and, if possible, remedy significant adverse effects; the data required to identify and assess the main effects which the project is likely to have on the environment; an outline of the main alternatives studied by the developer and an indication of the main reasons for his choice, taking into account the environmental effects; and a non-technical summary of the above information. (Art. 5(3))

Of interest is Article 6, specifying that the request for development consent, with the information above, must be made available to the public; the public must be consulted before consent is granted. Member states may in particular:

determine the public concerned; specify the places where the information can be consulted; specify the way in which the public may be informed, for

<sup>2</sup> The committee's description of the European EIA Directive is based on O'Sullivan et al. (1999). That reference presents a study undertaken for the European Commission Directorate DGXI on the role, scope, and definition of EIA requirements for radioactive waste management facilities in member states and in adjacent countries of East and Central Europe. The study was managed by U.K. Nirex Ltd with participation by the University of Wales, ENRESA (Spanish National Waste Management Company), ONDRAF/NIRAS (Belgian National Agency for the Management of Radioactive Waste and Fissile Materials), and SKB (Swedish Nuclear Fuel and Waste Management Company).

example, by bill-posting within a certain radius, publication in local newspapers, organization of exhibitions with plans, drawings, tables, graphs, models; determine the manner in which the public is to be consulted, for example, by written submissions, by public enquiry; fix appropriate time limits for the various stages of the procedure in order to ensure that a decision is taken within a reasonable period. (Art. 6(3))

In practice, implementers may be charged with detailed development of certain of these provisions, such as designing and justifying a method for determining the "public concerned" or seeking effective methods of consultation. Other stakeholders (broadly defined) may also claim an active role and thereby become involved in concrete decision-making processes. Recent Scandinavian experience has inspired international interest in EIA as a potential "umbrella process" for stakeholder interactions (NEA, 2000b). The following table shows the EIA framework as it took shape in Oskarshamn, Sweden (Jensen et al., 1999).

<b>Phases in EIA</b>	<b>Actors</b>	<b>Activities</b>	<b>Product</b>
<i>Phase 1</i> Pre-study	All stakeholders (implementer, regulators, county municipality, and the public)	Meeting with EIA forum (a group of representatives from each stakeholder). Local meetings, hearings, etc.	Advice on the Environmental Impact Statement
<i>Phase 2</i> a) Implementer's work b) Continued EIA	Implementer All stakeholders	Project work Seminars, hearings, etc.	License application Understanding
<i>Phase 3</i> Final phase of EIA ` First phase of licensing	Regulator's interacting with municipality	Review and decide Hearings	Improved license application

Designed to allow discussions among stakeholders, the framework allows them at the same time to maintain independence. A key ingredient is that the procedures are flexible enough to accommodate new needs as they appear during the process. EIA is described as a means of "stretching," or ensuring that the implementer's environment is sufficiently demanding. The implementer must develop the capacity to respond in a satisfactory way to the hard questions posed by partners; in the process, the project ideally becomes more robust.

Lidskog (1997) reviewed the evaluation of various EIA uses showing that the licensing applicant's perspective can dominate the EIA. He highlights the need to open the EIA to alternative definitions of conceivable impacts and their relevance. The challenge of creating effective dialogue among stakeholders is thus not *eliminated* by the EIA. However, stakeholders seeking dialogue can see their task facilitated and clarified by an EIA framework.

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## Sweden

In Sweden, local communities have veto power over decisions affecting local planning in general, especially facilities that have the potential to affect the environment. Situations are also foreseen in which the government can overrule the local veto on grounds of national interest. Facilities for radioactive waste disposal are mentioned in this context, and the circumstances under which the government would use this power have been much debated. On the basis of interaction with various segments of the public in the early feasibility studies for siting, the Swedish implementing organization, SKB, has clearly stated that it will make investigations and build a repository only in a community where there is local acceptance or tolerance for it, thereby respecting the spirit of the community veto power. As discussed in [Chapter 5](#), local officials and members of the public have taken an increasingly active role in evaluating program plans and setting conditions. In addition, Sweden has set forth specific plans for a phased implementation procedure, with a part of the repository being backfilled, sealed, and monitored for decades before completing the rest.

The Oskarshamn experience in Sweden shows how an EIA process can be carried out as a fruitful and effective exchange by all parties in understanding the risks to the public posed by a nuclear waste storage facility. Elected representatives of the community were extremely active in developing the technical competence to evaluate program proposals and in ensuring that the implementer would be informed of local views and needs. When Oskarshamn (already a nuclear site) was named as the preferred site for a HLW encapsulation plant by SKB in 1992, the municipality announced two main prerequisites. First, municipal participation in discussions and investigations was to be paid for by the Nuclear Waste Fund; second, the primary concerned parties (SKB and the licensing authorities SKI [Swedish Nuclear Power Inspectorate] and SSI [National Institute of Radiation Protection]) would accept the formation of a forum for environmental impact assessment. A local “reference group” is a standard feature in large or controversial Swedish siting discussions. In Oskarshamn:

... it was felt that the natural reference group is the municipality council with 51 elected members. It was also decided that efforts should be made to engage the local population through public meetings, seminars and by engaging local study organisations. In 1995 SKB formally asked the municipality if it could accept a feasibility study for a deep repository. . . . The municipality took one year to [reply], in order first to find out more about the program and . . . to engage as many as possible in the debate and decision making process. (Ahagen et al., 1999, p. 372)

As competence to evaluate the program was built up through six multipartite working groups that have remained active, the implementer's



competence itself was “stretched” to respond in a satisfactory way to the questions posed by the community. This non-adversarial but determined dynamic, led by elected officials, is considered by the partners involved as contributing directly to a more robust set of management options, and a more tightly knit and informed community. This strong public involvement assures that a final consent or veto decision will be made on adequate grounds.

### France

Concerning siting efforts in France, three periods must be considered. Prior to 1990, all siting decisions were made by the government based on technical judgments on the merits of the site, and did not involve much participation of the public nor of local officials. Four sites were selected in this way and geological surveys at various levels were commenced. However, the implementer, ANDRA, experienced local opposition, and in some cases, violent demonstrations occurred. This led the French government, in 1989, to declare a moratorium on all site investigations. Parliament's science evaluation office (OPECST) was charged with investigating ways forward. Hearings by Christian Bataille, a member of parliament, resulted in the 1991 Waste Act, which specified that work would continue in parallel on a 15-year time scale on developing repository projects, studying waste treatment (including partitioning and transmutation), and clarifying further the issues associated with surface storage.

Christian Bataille was named mediator and charged with identifying potential candidate local communities that would look favorably upon the prospect of hosting a siting study for an underground research laboratory, and with conducting discussions with local officials at various levels (commune, department, region) where siting could be considered feasible. He had access to geological expertise within the French Geological Survey, and thus could choose for in-depth discussions only those volunteers in areas that looked *a priori* favorable for a siting study.

In 1994 with the agreement of the local communities, the mediator proposed four sites, out of an initial potential list of 30 sites, to the government. These sites were: La Chapelle-Baton, in the Vienne Département, in a granite formation overlain by a thick sedimentary cover; Marcoule, in the Gard Département, in a thick clay formation; and two sites subsequently merged into a single Eastern site at the boundary between the Départements of Meuse and Haute-Marne. This site, also in clay, was acceptable to both adjacent communities.

The geological reconnaissance programs went smoothly, and in 1996 ANDRA prepared three EIAs that were submitted to the local communities through an interactive public enquiry, to the local assemblies, to several review bodies (including the Commission Nationale d'Evaluation,

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created by the Waste Act), and to the government. In France, local authorities do not have power of veto. The final decision came on December 8, 1998, when the government decided to go ahead with the sinking of a shaft and the building of an underground research laboratory at one of the three sites (the Eastern site, at the village of Bure), and to drop the two other sites. Work is now in progress at the Eastern site where, by February 2001, the shaft had reached a depth of 50 meters.

The Marcoule site was abandoned because of local opposition, essentially from the wine growers, who argued that the siting of a waste facility would jeopardize the image of the local wine, Côtes du Rhône, independently of whether the site would be shown to be safe or not. The La Chapelle-Baton site was abandoned, not because of local opposition (on the contrary, local support existed at this site), but essentially because the Commission Nationale d'Evaluation expressed a number of scientific reservations about the intrinsic quality of the site.

The government also decided that a new site in a granite formation was to be selected. The 1991 Waste Act specifies that at least two sites must be examined prior to 2006. At that time, the parliament will examine the outcome of the research program pursued from 1991 to 2006 on the geologic disposal option, and also on the separation-transmutation option and the surface storage option.

Accordingly, the French Geological Survey and ANDRA carried out a survey of potential granitic sites in France, starting from existing literature and data without any local field work. From an initial list of about 200 potential sites, using various geologic criteria, the list was shortened to 15 new sites, distributed mostly over two areas, Brittany and Central France. This list was handed over to the government in October 1999 but was not released to the public. Rather than using a member of parliament to seek approval from potential local communities, the government appointed three high-ranking civil servants, none of whom had any prior links with the nuclear establishment, to conduct local discussion in some of the 15 selected areas. These officials prepared informative documents for their presentations in the local communities.

The official visits to the 15 sites and their local communities were about to start when, in January 2000, the map showing all 15 sites leaked out of the government and was posted on the internet by an opposing non-governmental organization. The result was that all of the 15 selected sites were antagonized to find themselves selected without knowing it, and starting any kind of discussion subsequently proved very difficult for the three officials. They encountered strong local opposition and demonstrations, some of which were violent. The government decided to stop the process, and none of the proposed 15 sites was selected. It is presently unknown what the next move will be, since a second site must be identified if the terms of the 1991 law are to be fulfilled.

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## Canada

Siting efforts for a low-level waste (LLW) facility in the Canadian province of Ontario were based on “voluntary participation of local communities in a collaborative, joint decision-making manner” (MEMR, 1990) including “structural and process guarantees that local participation [was] and remain[ed] voluntary” (Peele, 1994, p. 205). The process came close to completion but was ultimately unsuccessful, in part due to “uncertainty about government resolve to continue the process as designed” (Peele, 1994, p. 205). For example, the federal government refused to accept the community agreement in principle negotiated by a task force and the community (Richardson, 1998). Comparative evaluation of a number of such efforts involving both LLW and hazardous waste indicated that it is “very difficult for large bureaucracies to surmount internal constraints and technically oriented norms and goals to meet requirements (of voluntary siting programs) for responsiveness and adequate implementation” (Peele, 1994, p. 210).

## Belgium

Between 1990 and 1993, the government agency responsible for waste management in Belgium, ONDRAF/NIRAS, conducted a survey of the Belgian territory to identify zones where a near-surface repository for low-level short-lived wastes might possibly be installed. The survey was based on technical and scientific criteria, of which the most important was geologically favorable conditions. Ninety-eight such zones were identified, and the results were made available in a report. However, that report was rejected unanimously by all municipalities concerned. Given the deadlock, the government decided that further studies should concentrate on the existing nuclear zones: power reactors, fuel cycle industries, and major research facilities.

ONDRAF/NIRAS opted for a new approach that would involve local authorities, two universities, and local populations in site selection and planning of such a repository through the creation of local partnerships. Two such partnerships are already operational for the Mol-Dessel zone to consider technical, safety-related, social, economic, and environmental aspects. The final assessment and responsibility, primarily for aspects related to long-term safety, are the exclusive prerogative of ONDRAF/NIRAS. Conclusions of this exercise should be available no later than 2002.

## Finland

Of all countries, Finland probably has had the most success in moving toward siting a deep repository with maximum community involve

ment and public confidence. From studies at a number of potential sites, the choice was narrowed to two sites that already have nuclear facilities, with an emphasis on demonstrating that the geological conditions at these sites were no less suitable than at others. The EIA process was seized on as a means for in-depth consideration of public concerns and needs. Thereafter, competition even broke out between the two communities seeking to host the Finnish spent fuel repository. The balance achieved in Finland between geological and societal criteria for site choice deserves further study.

### Summary

The examples above present convergent evidence that public involvement, starting early and lasting throughout the process, may be an essential factor in bringing efforts forward. Evaluation of siting activities on the above-mentioned siting guidelines suggests that

the more involved the public is in the process, the more likely that they will accept a facility if it meets other concerns. . . . A participatory procedure by definition satisfies the factors that appear to be most important in increasing the chance that a facility will be successfully sited. (Kunreuther et al., 1993, pp. 313–314)

This orientation is shared by the World Health Organization (Sloan, 1993) in guidance favoring a voluntary process, including early community involvement in decision making, as the first choice for site selection. That recommendation is based on three key points: (1) equity, (2) economic efficiency, and (3) the likelihood of successfully completing the process.

Finally, the National Research Council (NRC), in its report *Understanding Risk* (NRC, 1996a) argues that an essential aspect of risk characterization, along with appropriate incorporation of science, is broad participation by the interested and affected parties. Its discussion of siting efforts focuses on deliberation, including public involvement. Following Fiorino (1990), the NRC presents “three compelling rationales for broad participation in risk decisions” (p. 23), classified as normative, substantive, and instrumental:

The normative rationale derives from the principle that government should obtain the consent of the governed. Related to this principle is the idea that citizens have rights to participate meaningfully in public decision making and to be informed about the bases for government decisions. . . . The substantive rationale is that relevant wisdom is not limited to scientific specialists and public officials and that participation by diverse groups and individuals will provide essential information and insights about a risk situation. . . . Nonspecialists may also help

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design decision processes that allow for explicit examination, consideration, and weighing of social, ethical, and political values that cannot be addressed solely by analytic techniques, but also require broadly participatory deliberation. The instrumental rationale for broad public participation is that it may decrease conflict and increase acceptance of or trust in decisions by government agencies. (NRC, 1996a, pp. 23–24)

### LEARNING WHILE DOING—AND KEEPING OPTIONS OPEN

Radioactive waste management, as originally conceived in many countries, was construed as a technical and logistical task—financing, scheduling, and engineering a technical disposition system or searching for and selecting a technically qualified repository site. Thus far, technological solutions largely have been predicated on the minimization of error and improving the science and engineering involved. Because the time scales over which a repository must perform satisfactorily preclude learning by trial and error, managers often have seen their sole responsibility as designing and operating a repository that is, as far as possible, error-free and predictable. Research on “high-reliability” organizations indicates, however, that such sociotechnical systems evolve over a considerable period of time, typically with numerous early failures and reversals (LaPorte, 1999).

The management approach should not be one of command and control, but rather one that emphasizes learning and keeping options open. One promising approach described in the environmental management literature is adaptive management, which is “living with the unexpected” (Holling, 1978). This approach applies the concept of experimentation to the design and implementation of environmental policies or sociotechnical projects (Cook et al., 1990; Lee, 1993). The approach is aimed at coping with uncertainty; learning from, and responding rapidly to, errors and surprises; and progressively identifying and investigating promising new alternatives. On the political side, it seeks to keep conflicts within reasonable bounds by promoting openness and flexibility to adapt. Additional research is needed to identify appropriate institutional structures and management processes to facilitate learning while doing and keeping options open for HLW programs.

A management system for HLW disposition will begin by openly addressing knowledge gaps and uncertainties. Suggesting that the managers of the waste disposition system know everything they need to know in doing something the first time is counterproductive. Openly acknowledging limitations in the facts and theories supporting models of the system will contribute to a readiness to restructure the problem if necessary. A more attentive and elaborate developmental approach to the repository program, staged in stepwise fashion, will give managers time to

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learn whether or not the predictions and expectations they rely upon are reasonable. Such a more deliberate repository development program will operate under flexible deadlines and continual program reinvention to secure success. Schedule-driven deadlines, as the *Rethinking High-Level Radioactive Waste Disposal* (NRC, 1990) report argues (see [Sidebar 8.3](#)), serve only to increase the probability of error and to undermine the integrity of science used in support of assessment.

### **SIDEBAR 8.3 GUIDANCE FROM THE 1990 NATIONAL RESEARCH COUNCIL *RETHINKING HIGH-LEVEL RADIOACTIVE WASTE DISPOSAL* REPORT**

In its 1990 report, the Board on Radioactive Waste Management of the National Research Council summarized the issues constraining the choice of management systems and approaches for geological disposal projects (NRC, 1990):

- . . . [T]here are certain irreducible uncertainties about future risk [from HLW]. An essential part of any successful management plan is how to operate with large residual uncertainties, and how to maintain full public accountability as information about the risks changes with experience. This is not an impossible task: public policy is made every day under these conditions, and private firms undertake all sorts of activities in the face of uncertainty. (p. 15)
- Those involved in HLW management must also avoid the trap of promising to reduce uncertainties to levels that are unattainable. . . . When unforeseen events occur, for example, the public can raise questions about the validity of the technical approach, as well as the competence of the risk analysis that was used to justify it. Conversely, when foreseen events occur, they lead to questions about why they were not prevented. The technical credibility of the project team suffers in either case, but it probably suffers more when the organization has understated the risk or uncertainty. (p. 17)
- It is a practical consequence of the complexity of high-level radioactive waste (HLW) disposal, together with the fact that no one has ever operated a repository, that performance assessment is, in the end, a matter of technical judgment. The traditional approach in such cases, where an important social decision hinges on uncertain scientific data and projections, is to inform the political decision through a consensus of the appropriate technical community. Such consensus is difficult to reach in this case, however, given the political controversy, conflicting value systems, and overlapping technical specialties involved in assessing repository performance. (pp. 13–14)
- [A] “perfect knowledge” approach is unrealistic given the inherent uncertainties of this unprecedented undertaking [HLW management], and it runs the risk of encountering “show-stopping” problems and delays that could lead to a further deterioration of public and scientific trust. (p. 2)
- The primary goal of the program is to provide safe disposal; a secondary goal is to provide it without any gross unfairness. As a result, the mechanisms of negotiation, persuasion, and compensation are fundamental parts of any program to manage and dispose of radioactive waste—not mere procedural hoops through which program managers must jump. (p. 6)

Redundancy in analysis, design, and operations is an important element in a flexible management strategy. The practice, for example, of having independent planning and evaluation groups inside and outside the organization working on the same question can prevent an insulated “in-group” from ignoring information and independent judgments by well-qualified outsiders. A single, overly centralized locus for dynamic modeling is particularly important to avoid; redundancy is especially desirable for understanding *and communicating* the changing information on risks and uncertainties. Multiple learning centers—well-funded research units under independent organizations, including the host area for the repository, that engage in basic research, data collection, and monitoring—can contribute to a more flexible waste management organization with a greater capacity to overcome mistakes while building confidence among interested and affected parties. Alternative repository sites and/ or alternative plans for staging and timing of emplacement, as well as monitoring, are needed. Societal discussion should be engaged on resource allocation for components of a waste management program. Many elements of such a management strategy probably can be undertaken without significant additional net cost and arguably could contribute to net efficiency in terms of confidence building.

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## 9

# International Cooperation

In the field of radioactive waste management, international cooperation has from the earliest days played an important role. In fact, the entire nuclear fuel cycle has always been international, with a relatively small number of countries providing uranium, enrichment services, fuel fabrication, reprocessing, and other services to a wide range of customer countries. As proper management of the back end of the fuel cycle—in particular disposal of wastes—became increasingly acknowledged to be a problematic issue, cooperation was expanded. Although the responsibility for proper waste management resides with each country that generates it, there are opportunities and challenges for cooperation among countries. This chapter describes the most important areas of international cooperation, the work of international organizations, and opportunities for greater cooperation.

### **RADIOACTIVE WASTE MANAGEMENT ISSUES TRANSCEND NATIONAL BOUNDARIES**

The key goals of assuring that nuclear safeguards are maintained and of demonstrating long-term safety both demand international approaches in waste management (see [Sidebar 9.1](#)). Accordingly, there are established procedures and mechanisms for keeping appropriate oversight and control of international activities—particularly in the transportation and safe-guards areas. Long-term management of the wastes must be considered in an international context simply because the time scales in question exceed those for which the stability of any national border can be guaran

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teed. The International Atomic Energy Agency (IAEA) *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management* (IAEA, 1997a) explicitly supports international cooperation and acknowledges that shared facilities can be beneficial. As of January 2001, 42 countries had signed and 23 had ratified, accepted, or approved this legally binding convention.

### **SIDEBAR 9.1: INTERNATIONAL CONSENSUS ON THE OBJECTIVE AND PRINCIPLES OF RADIOACTIVE WASTE MANAGEMENT**

The objective of radioactive waste management is to deal with radioactive waste in a manner that protects human health and the environment now and in the future without imposing undue burdens on future generations. To meet this objective, the following internationally agreed principles are detailed in the IAEA Safety Fundamentals (IAEA, 1995b), together with supporting text:

**Principle 1: Protection of human health**

Radioactive waste shall be managed in such a way as to secure an acceptable level of protection for human health.

**Principle 2: Protection of the environment**

Radioactive waste shall be managed in such a way as to provide an acceptable level of protection of the environment.

**Principle 3: Protection beyond national borders**

Radioactive waste shall be managed in such a way as to assure that possible effects on human health and the environment beyond national borders will be taken into account.

**Principle 4: Protection of future generations**

Radioactive waste shall be managed in such a way that predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today.

**Principle 5: Burdens on future generations**

Radioactive waste shall be managed in such a way that will not impose undue burdens on future generations.

**Principle 6: National framework**

Radioactive waste shall be managed within an appropriate national legal framework including clear allocation of responsibilities and provision for independent regulatory functions.

**Principle 7: Control of radioactive waste generation**

Generation of radioactive waste shall be kept to the minimum practicable.

**Principle 8: Radioactive waste generation and management interdependencies**

Interdependencies among all steps in radioactive waste generation and management shall be appropriately taken into account.

**Principle 9: Safety of facilities**

The safety of facilities for radioactive waste management shall be appropriately assured during their lifetime.

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Cooperation across the world is not restricted to national waste management programs or to implementer or regulator organizations. There are also close contacts among non-governmental organizations (NGOs) and environmental groups in different countries. In fact, some of the large NGOs are themselves international organizations. Currently, the cooperation across national boundaries between groups holding similar views on controversial waste management issues (whether for or against) often seems more intensive than the interactions within a country between groups with differing opinions.

The result of close and fast transnational communication between all parties involved in waste management is that issues become common. Scientific and technical concepts and controversies are shared, as are societal attitudes and concerns. Problems will not always be weighted equally in different countries, challenges will not be assigned identical priorities, and solutions will certainly not be directly transferable. However, the international character of radioactive waste management must be recognized and taken into account in developing national concepts and strategies.

In this chapter, the different mechanisms for collaboration between national programs are examined, with examples being drawn from experiences shared over the last 10–20 years. The advantages to be gained by cooperation are examined—as are the potential problems. Included in the discussion is a description of the types of activities fostered by international organizations, together with the committee's views on the possibilities for increasing their value. The issue of regional or international repositories in which one host country disposes of wastes from other nations is discussed. The chapter ends with a review of lessons learned from the past on the value of cooperation between countries and with suggestions for potential improvements.

## **SHARING KNOWLEDGE, EXPERIENCE, AND COSTS BETWEEN COUNTRIES**

This section provides an overview of international collaborations, including those directly among countries and those fostered by international organizations.

### **Waste Management Information Is Freely Available**

There has been a long tradition of open publishing in the waste management field. The national waste management organizations in many countries have extensive report series, which are freely available to all interested parties. Obvious examples are U.S. organizations such as the Department of Energy (DOE), Nuclear Regulatory Commission (USNRC), and

Environmental Protection Agency (EPA), but other countries such as Sweden, Switzerland, Canada, and Finland also have extensive lists of low-cost or free publications. Some countries, such as the United Kingdom, originally had more restricted access to technical reports and data, but these countries have also developed open publications over time. Weapons states obviously have restricted access to radioactive waste information—but this also has changed with the United States and Russia, in particular, making the cleanup and waste management tasks that the defense programs have left behind increasingly transparent (DOE, 1997, 1998a).

In recent times, the explosive growth of internet communications has also given access to huge amounts of information at all levels. Not only do waste management implementers, regulators, and others maintain web sites, but intensive use also is made of this tool by NGOs and environmental groups. The convenient cross-linking to numbers of other sites also affords the public opportunities for weighing the views of different parties against one another.

In addition to all of the information in national publications, international organizations such as the IAEA, Nuclear Energy Agency (NEA) and the European Commission (EC) also publish open reports. For a country starting out in the waste management field there is the potential to gain much time and to save costs by making use of the published material. Interpersonal exchange of information is also easy. The calendar is full of conferences at which contacts can be made, and virtually all waste management organizations and facilities are open for visits from colleagues or from the public. Furthermore, the number of qualified waste management experts around the world is not large, and these experts comprise an active and highly visible community. Availability of information on the programs of other countries is, thus, not a problem in this field.

### **International Organizations Provide a Framework for Collaboration**

A step beyond exchanging information is joint development or documentation of a knowledge database. Vehicles for this are provided by international agencies, which organize standing committees, working groups, and workshops for these purposes. The IAEA includes numerous countries—many without nuclear power—so that the focus is different from that of the NEA, which is more limited and more homogeneous in its membership, or the EC, which has still fewer members. All of these organizations have a useful role in arriving at and documenting consensus views on key issues.

The IAEA Safety Series documents are recognized internationally, and its legal conventions (such as the recent *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management*,

IAEA, 1997a) are binding commitments on signatory states. Within the waste management community itself, the NEA also has placed great emphasis on arriving at and documenting consensus views. The clearest examples here are the collective opinions organized through the NEA, but signed onto also by the IAEA and the EC (NEA, 1985, 1991b, 1995a). These have put on record the consensus of implementers, regulators, and national laboratories in member countries that geological disposal is ethical and can be accomplished safely.

A more proactive role is played by international organizations when they organize groups who try to develop new initiatives or ideas. These groups are sometimes very formalized, examples being the Radioactive Waste Management Committee (RWMC) or the Performance Assessment Advisory Group (PAAG) of the NEA or the Waste Safety Advisory Committee (WASSAC) of the IAEA. Sometimes they are less formal (e.g., the Natural Analogue Working Group of the EC [Côme and Chapman, 1986a, 1986b, 1989, 1991]) or the Principles and Criteria Subgroup at the IAEA). In addition, influential activities are undertaken by the International Commission on Radiation Protection (ICRP), which develops, independently of national governments, guidelines on radiation protection that are then adopted into most bodies of national legislation.

Organizing joint projects is more difficult for international organizations than is providing advice. There are often funding problems, because countries are reluctant to reallocate funds from national projects to internationally controlled projects where they have less control. Of the agencies mentioned, only the EC controls sufficient funds to run a major research and development program. The EC supports collaborative projects between agencies in the European countries by providing up to 50 percent of the funding for these projects. The present budget is equal to about 60 million U.S. dollars for the period 1998 through 2002. The result of these restrictions is that very few significant active investigation programs operate directly under the auspices of international organizations. When they appear to do so (e.g., NEA patronage of the international Stripa project doing underground research in Sweden) the role of the international organization is often more as a figurehead. Direct hands-on running of projects tends to occur more in ad hoc groupings of partners, as described in the following section.

A further criticism that has been leveled at the official international waste management organizations is that they are not sufficiently open to NGOs and other groups. This occurs mainly because participation in official working groups and committees is usually through nomination by governments. Even at major international conferences and workshops, attendance by those outside official waste management organizations is rare. In both the IAEA and the NEA, initiatives are under way to broaden participation.

## Joint Projects Are the Most Effective Vehicles for Collaboration

Almost all countries with significant waste programs have signed bilateral or multilateral cooperation agreements with a range of other countries. These encourage information exchanges but also provide a framework for direct collaboration on projects. There are numerous reasons why collaborative work between two or more countries can be advantageous for all participants:

- all costs from R&D work through to major construction can be shared and thus reduced for individual participants;
- the pool of expertise is widened, there can be more effective peer reviewing of the results, and world-class knowledge can be tapped;
- suitable facilities for technical work (especially with radioactive substances) may not be available everywhere;
- suitable locations for field work may not be available everywhere for technical or political reasons; and
- many of the scientific issues facing waste management experts (especially in the early years) were generic in nature so that solutions have been transferable.

These reasons have led to a long line of collaborative projects of a bilateral or multilateral type. Some of the best examples cover underground research laboratories (URLs) (Brewitz et al., 1999; McCombie and Kickmaier, 1999). These are expensive facilities; various countries (e.g., Spain, United Kingdom) have failed to achieve the public acceptance needed to site URLs; one country might like to study various potential host rocks (granite, salt, clay) without having to construct a test facility in each. Accordingly, many of the URLs of the “first generation” (i.e., sited as pure research facilities rather than precursors of repositories) have hosted major international programs. The prime example is Sweden, which has run both the Stripa and later the Äspö crystalline URLs with numerous partners. Similarly, wide participation is a feature of the Grimsel (crystalline) and Mont Terri (clay) laboratories in Switzerland, and several nations have also been active in the Mol facility (clay) in Belgium, the Asse mine (salt) in Germany, and the Canadian URL (crystalline) at Whiteshell. The first operational deep repository at the Waste Isolation Pilot Plant (WIPP) (salt) in the United States is also open for international cooperative experiments.

Joint project work between national programs has not, however, been restricted to URL studies. Engineered barrier investigations (e.g., on spent fuel, high-level waste (HLW) glasses, and bentonite backfills) have also been the subjects of collaborative projects. A further common field for multinational investigations has been natural analogues. These are usually geological abnormalities that display some of the features of interest

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to waste disposers and that have existed for very long times in nature. Examples are the natural uranium reactors at Oklo in Gabon in Africa, where fission products from a chain reaction have remained relatively immobile for millions of years (Walton and Cowan, 1975; Miller et al., 1994; EC, 1998; Smellie, 1998; Jensen and Ewing, 2001); the geochemical systems at Pocos de Caldas in Brazil, where the important influence of oxidation state on the mobility of nuclides was studied (Chapman et al., 1990); and the hyperalkaline springs in Vordau, Oman, or Maqarin, Jordan, which afford opportunities for learning about the possible impact of cementitious materials on the geochemistry in a deep repository (Miller et al., 1994; Linklater et al., 1996; Smellie, 1998). All of these objects have been the center of multinational projects, supported by the participants because they present a rare or unique opportunity for scientists to learn directly from observation of these natural abnormalities. Natural analogues have also been used in attempts to inform a wider public of approaches to understanding the potential very-long term behavior of repository systems (Nagra, 1994).

Multinational projects of the type described in this section commonly are funded and managed by partner organizations from various countries, all with an equal interest in the results and with comparable capabilities for technical and financial contributions. A different type of interaction between national programs has developed in recent years as the experience, skills, and prior investments of some countries have grown significantly beyond those of later entrants to the field.

### **The Role of Commercial Consulting as a Know-How Transfer Mechanism**

Some countries intensified their national waste management programs more than 20 years ago, sometimes due to political or societal pressures. These pressures constrained countries—sometimes small—to invest significant funding in building a strong scientific and technical basis. When other countries moved 10–20 years later to build stronger disposal programs (e.g., in East Asia, or Eastern Europe), there was a trend toward national agencies commencing commercial consulting practices. A pioneer here was SKB in Sweden, but this was followed soon by others. One example is the Casseopée organization in which European Union (EU) waste management organizations combine to offer consulting services, primarily to Eastern Europe. Another example is the Swiss Nagra, which collaborates intensively with Japanese organizations.

In addition to consulting by national waste management organizations, services are provided around the world by many commercial companies that work on waste management in different countries and hence contribute to the sharing of technology and know-how. This also leads to



increased business competition, especially as opportunities have been declining in other areas of the nuclear market while expenditures on waste management have remained high. The extent to which different countries rely on private industry, as opposed to national organizations, for planning and implementing waste management strategies varies widely.

In the context of the current discussion on the goals of waste management, this is of little importance. Whether the programs are led by governmental organizations or delegated to private enterprise, the prime goal of any nation must be to see that those in charge concentrate on solving the problems of safe and secure management and do not focus instead on prolonging and extending programs or organizations.

### **Some Problems Can Arise During Cooperation— But the Benefits Outweigh These**

All of the above forms of collaboration between countries involved in waste management are of potential benefit to participants. Nevertheless, disagreements and disputes may arise over goals or principles. They are more likely when a country feels that it is not getting sufficient value for the funding it contributes. The United States, for example, has in the past disputed the promotional role for nuclear energy of the NEA and the IAEA, and various countries have questioned the cost-effectiveness of both. Dissatisfaction also can arise due to the lengthened time scales often resulting from the slower pace of international organizations, which must seek consensus at every step. An example here is the frustration felt by many participating countries at the slow pace of developing an international thermodynamic database at the NEA. Further doubts have been raised concerning the inclination of many established working groups to become self-propagating, with a tendency to seek further problems to study rather than solutions to existing problems. By and large, however, the waste management community recognizes and appreciates the opportunities in its field for profiting from international collaboration.

The acknowledged value of sharing experience and technical ideas also has encouraged social scientists in different countries to seek common ground. Although national cultural differences obviously present more of a challenge in these areas, there have been international workshops on ethics (KASAM, 1988; NEA, 1994), retrievability (ANDRA, 1998; IAEA, 2000b), and public dialogue (e.g., NEA, 1996) in the past few years. The attitudes and concerns of the public concerning radioactive wastes appear to have much in common. It is certainly worth considering and comparing the possible ways to address these without assuming that solutions will be transferable from country to country.

The increasing cooperation and convergence of approaches in the technical and societal aspects of national programs contrasts with the

situation in the area of policy decisions. Currently, national policies appear to be more divergent than they were 10–20 years ago. At that time, there was a wider commitment to geological disposal on time scales that now seem relatively close. Many countries intended to have deep repositories operating early in this century. Today, the acceptability of the option is being questioned in countries like Canada and the United Kingdom. Some countries, e.g., the Netherlands, have introduced waiting times of around 100 years before moving to disposal, and most countries working towards disposal have moved back their target dates. It is not to be expected that policies will be identical in different cultures or national programs. It is confusing, however, if there is insufficient common understanding of the reasons for the diversity, whether these are technical, societal or cultural. Differences in choice of timing, host media, and facility design, for example, should be understandable by the public in various countries. Increased collaboration and exchanges of views at the policy level could help achieve this objective.

### **COLLABORATION THROUGH USE OF COMMON WASTE MANAGEMENT FACILITIES**

This section first discusses experience in shipping wastes across national boundaries to shared facilities. It then focuses on issues and proposals for establishing international HLW repositories.

#### **Transboundary Shipments for Treatment or Storage of Wastes Are Difficult**

Despite the widespread and growing recognition of the value of collaboration between national programs, any activities involving the transfer of actual wastes across national boundaries have tended to become more difficult in recent years. Earlier, wastes were shipped without political or public opposition. The reprocessing nations, France, the United Kingdom, and Russia, accepted spent fuel from foreign customers and expected to retain the wastes remaining after recovering the plutonium and unused uranium. Individual swaps of specific waste streams were organized if a better overall environmental solution resulted.

With time, however, acceptance dropped. France and the United Kingdom, not wishing to be branded “the dustbin of Europe,” introduced contract clauses specifying that waste must be returned to customers. Various countries introduced legislation banning import of radioactive wastes (e.g., France, Sweden, Finland, and Russia). This was done despite the fact that other toxic wastes can be, and are being, shipped (with proper controls) for treatment or even disposal in foreign countries.

The negative perception of the safety of radioactive waste transport (despite its heavy regulatory requirements) has caused further barriers to shipping to be established, in spite of a history of more than 50 years of safe, secure, and essentially unchallenged shipment of fuels and other radioactive materials to nuclear power plants around the world. For example, opposition has been expressed in Germany to the transport of spent fuel from nuclear power plants to central interim storage facilities and to the return of nationally owned waste from foreign reprocessors. In Switzerland and France, there has also been opposition to waste transport associated with reprocessing. The global distrust of moving radioactive waste across boundaries is widespread but may be reduced by new efforts to involve the public in decisions regarding transportation issues.

Some countries are not adequately equipped to handle or store the radioactive materials that they currently possess. The most tragic example of this concern is sealed irradiation sources, which have been misappropriated, leading to serious accidents in some countries, for example, Goiânia, Brazil (Pettersen, 1988). Some countries are simply running out of storage space for their spent fuel at reactor sites and have difficulties siting new facilities for storage or disposal. For example, Taiwan has no storage space at some reactors, no possibility of juggling between reactors, and little prospect of being able to site a central store. Japanese utilities will also run into problems if they do not get extra storage at reactors or at a central location. Germany will either have to accelerate licensing for on-site storage or else allow transports to the Gorleben or Ahaus facilities. This pressure has led to open discussions on approaches for storing such fuel at a foreign location, such as in Russia. These proposals are mentioned in the following sections, which concentrate, however, on the still more controversial issue of disposing of foreign wastes in a host country.

### **International Repositories—A Global Issue**

There is widespread acceptance of the fact that all countries are not independent in all aspects of the nuclear fuel cycle, and there is wide agreement that close cooperation in waste management technology is to be encouraged. When this cooperation extends to sharing joint storage or disposal facilities, however, opinions differ. The divergence of views concerns not so much the desirability of international repositories as it does their practical feasibility and timing.

It is apparent that not all countries utilizing nuclear power are well suited for storing or disposing of spent fuel. Some countries are limited in area, or have unfavorable geology, so siting repositories is especially challenging. Some small countries may not have the resources to take the proper measures on their own to assure adequate safety and security, or

they may not have enough HLW to make constructing and operating their own repositories economically feasible. In any case, many small repositories will not be an optimal approach from the point of view of either economics or safeguards. In this section, the issues to be considered when evaluating the advantages or disadvantages of international disposal facilities are laid out, as has been done in recent years by the IAEA in a series of papers and reports (IAEA, 1998). These issues concern safety, environmental, economic, ethical, and public acceptance aspects (Bonne et al., 1999; Pellaud et al., 1999; IAEA, 1989, 1997b).

### **Long-Term Safety**

In the area of safety, particularly, long-term safety, the difference between a multinational repository and a national project is not the level of safety to be sought. There is no reason to tighten the rigorous safety requirements set for national disposal facilities, and it is definitely not ethical to seek regions or countries where less stringent safety measures could be acceptable. In both multinational and national cases, one needs a disposal system that provides the same internationally agreed-on, high level of safety over very long times.

### **Nuclear Security**

Fissile materials from dismantling surplus weapons and also spent nuclear fuel must be safeguarded against misuse (IAEA, 1989; Linsley and Fattah, 1994). Continuing safeguards are a burden that must be borne by countries with stocks of spent fuel. This burden can be lessened by transferring the material to centralized international facilities at which particularly strict controls are to be expected. Centralized facilities also appeal to the international community because they can be easier to safe-guard than multiple, distributed smaller national facilities (Carter and Pigford, 1999).

### **Economic Issues**

Shared repositories are attractive from an economic point of view. Deep geological repositories have life-cycle costs amounting to billions of U.S. dollars. This is true even for small countries with low projected waste volumes. Shared facilities can avoid the high costs of repository programs falling on each country individually, can allow economies of scale that result in lower unit costs, and may be sited and designed so as to lower capital and operating costs (Hensing, 1996). A country that is willing to share its repository with other countries can expect significant economic benefits.

## Public Acceptability

This will be a major issue in the host country, but it also is important for the export nation. Only if the safety, security, environmental, and ethical aspects are clearly seen to be taken extremely seriously by all parties and if the economic and infrastructure benefits are very clear is it conceivable that public acceptance can be achieved. A serious host country will not allow itself to be “bought”; there must be also a clear perception that the host is undertaking a service that helps less advantaged countries (geologically or economically) to fulfil their responsibilities for their waste in an ethical manner. The increased transportation requirements for international repositories also will be a major public and political issue.

## Political Issues

Public acceptability is, of course, intimately linked with political acceptability. Although there are few or no stumbling blocks hindering international repositories on technical, economic, or institutional grounds, politically it has proven difficult for most countries to support international disposal. However, some countries have openly expressed interest in the export or import of radioactive wastes. Despite the doubts expressed by various national programs of the feasibility of international disposal, there is growing interest in the concept. For example, Italy, Slovenia, Switzerland, Taiwan, the Czech Republic, and the Netherlands have decided that exploring the feasibility of international projects can be a prudent approach on its own or in parallel to a strategy for the development of national disposal concepts.

The wariness of most countries towards consideration of acceptance of foreign wastes signals that the issue remains politically very sensitive. Some national disposal programs are legitimately concerned that their population will interpret a national facility as the first step towards acceptance of foreign wastes or that their national politicians might use the prospect of an emerging international solution as an argument to curtail national programs. The argument often put forward is that a few national facilities must first show the way and that this will ease the problems of implementing further national repositories or international facilities. Thus, international initiatives should make efforts not to harm national repository programs.

A change of political attitudes is not likely in the short term, unless or until public appreciation of the economic advantages or of the international benefits outweighs, at both a national and local level, public apprehension over the disposal of radioactive wastes. In the past two years, however, there has been a rapid opening of the debate on international

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repositories, and more countries (especially small nuclear nations) are expressing an open interest in the option.

### SIDEBAR 9.2 THE CONCEPT AND STATUS OF PROPOSALS FOR INTERNATIONAL REPOSITORIES

The key characteristic of repositories referred to as “international” is that they would accept radioactive wastes from several countries. The repository would be located in a willing host country. Other terms for such shared repositories are “multinational” and “regional.” They could include, for example, a national repository that accepts waste from other countries, an internationally owned private company operating within a host country, or a fully international facility owned and operated by a consortium of nations or even an international organization.

At the generic level, papers on the concept of international repositories have been published in recent years by the IAEA (IAEA, 1998) and by workers in South Africa (Bredell and Fuchs, 1996, 1997), Germany (Hensing, 1996), and Switzerland (McCombie, 1997, 1999c). Recently, the issue has been highlighted from the point of view of secure storage and disposal of fissile materials from weapons dismantling (Suzuki, 1998; CSIS, 2000). The current suggestions for international storage and disposal facilities include the following:

- **The Nonproliferation Trust (NPT):** a private U.S.-based organization focusing on storage and disposal in Russia of surplus materials from weapons dismantling (Cochran and Paine, 1998).
- **Proposal of M. Bunn, N. Numark, and T. Suzuki:** This group suggested an approach similar to the current version of NPT, including storage—in particular of Japanese fuel—in the far east of Russia, but involving also fabrication of mixed oxide (MOX) fuels (Munsberg, 2000).
- **Proposal of the Russian government ministry Minatom:** Although it would involve changing the current law that prohibits import of nuclear fuels, Minatom has proposed storing and eventually reprocessing spent nuclear fuel from Asian and European countries (Dobbs, 2000).
- **The Global Peace Initiative proposed by A. Suzuki:** <sup>1</sup> This has the same prime goal of preventing proliferation in the wake of disarmament but includes a wider range of potential storage and disposal countries (Suzuki, 2000a, 2000b).
- **The Pangea Project:** <sup>2</sup> an international organization proposing commercial repositories for conventional spent fuel, ex-weapons materials, and other long-lived wastes in specially chosen geological settings (McCombie, 1999b; Miller et al., 1999; Pentz, 1999).

## CONCLUSIONS

Based on the foregoing discussion, the committee offers the following conclusions on international cooperation and international repositories.

<sup>1</sup> Atsuyuki Suzuki is a member of this committee.

<sup>2</sup> Charles McCombie is a member of this committee and director of the Pangea Project.

## International Cooperation

After extensive presentations of national programs and discussions on international exchanges at the 1999 Irvine Workshop, the following conclusions were drawn about the role of cooperation between countries in radioactive waste management:

- Cooperation is universally agreed to be valuable or even essential. Efforts to strengthen interactions may be expected to increase in the future.
- In some areas, for example, transport across boundaries or security of fissile materials, cooperation is essential.
- Organizations such as the NEA and IAEA play important roles; there are overlaps in their areas of responsibility, but these are not great.
- Underground laboratories are key mechanisms for collaboration. The trend is now to longer-time-scale projects aimed at demonstrating disposal technology.
- Production of generic data (e.g., thermodynamic databases) is of wide interest, and more could be done.
- International peer review activities are seen to be important and could be expanded with a focus on confidence building.
- The value of collaborative projects is very case specific. The most positive examples have had clear aims, strong management, and high-quality, timely reporting.
- Smaller national programs can benefit most, and these generally utilize collaboration more efficiently. For both small and large countries, international work should be fully integrated within the national program and not treated as an add-on option.
- International technical cooperation will facilitate developing a consensus on international standards for the safety, security, and reliability of long-term storage facilities and geological repositories.
- It could be useful to review the roles of existing international organizations and assess the potential value of new coordination groups such as EDRAM (Environmental Disposal of Radioactive Materials), a group including nations with large geological disposal programs.
- International cooperation has been very heavily weighted toward the scientific and technical areas. Given the growing appreciation that major problems in waste management today lie in the sociological and public arenas (see [Chapter 5](#) and [Chapter 8](#)) as well in institutional design, it would be worthwhile to consider the role that cooperation across national boundaries could play here also.

## International Repositories

The following conclusions can be drawn on the potential role of international repositories in radioactive waste management:



- As agreed in international conventions, all countries are responsible for their own radioactive wastes. This does not exclude centralizing activities (such as waste conditioning) or facilities (for storage or disposal) in specific countries.
- No country should transfer radioactive wastes to another unless it is assured that the organizational and technical requirements for safe management of these wastes are adequate in the importing country. No potential host country can be compelled to accept foreign wastes from others.
- International repositories in willing host countries can have economic, environmental, safety, and security advantages. There are, nevertheless, very divergent views on the political feasibility of implementing such facilities in the near future. On the other hand, it is widely accepted that international or regional repositories must eventually become a reality.
- International initiatives should recognize the sensitivities of national programs and make efforts not to harm these programs. In particular, international siting programs should not be presented as a search for the safest sites or interpreted as disqualifying national sites. Conversely, national programs should not, for parochial reasons, encourage a negative view of international concepts. Taking strong positions against international proposals for short-term objectives may make matters difficult for small countries in the future and can work against global environmental and economic optimization.

In summary, international cooperation in radioactive waste management has two rather contradictory aspects. On one hand, the high public and political profile of all radioactive waste issues in most countries has encouraged intensive collaboration to try to solve common problems facing countries intent on fulfilling their responsibilities for managing their wastes. This is clearly demonstrated by numerous bi- and multilateral projects and by the strong support for the efforts of international organizations. On the other hand, the sensitivity of radioactive waste issues has slowed progress toward common solutions based on shared facilities for storage or disposal. The committee believes that technical cooperation has helped national programs move ahead, that collaboration could be intensified more in both the technical and the social sciences, and that both national and international storage and disposal facilities will be needed in the future.

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### INTERNET ADDRESSES

The internet addresses of organizations that were sources of many of the reports listed as references are given below. They will be useful for finding the listed reports as well as new information.

European Union <http://www.rwm-eu.org>

International Atomic Energy Agency <http://www.iaea.org>

Nuclear Energy Agency of the OECD <http://www.nea.fr>

- U.S. Department of Energy Office of Civilian Radioactive Waste Management <http://www.rw.doe.gov>  
U.S. Department of Energy Yucca Mountain Project <http://www.ymp.gov>  
U.S. National Academies Press <http://www.nap.edu>  
U.S. Nuclear Waste Technology Review Board <http://www.nwtrb.gov>

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## Appendix A

### Biographical Sketches of Committee Members

- D. Warner North**, *Chair*, is president of NorthWorks, Inc., a consulting firm specializing in management science and quantitative risk analysis, and consulting professor in the Department of Management Science and Engineering at Stanford University. Previously Dr. North worked for Decision Focus Incorporated and SRI International. He has carried out applications of decision and risk analysis on management of toxic substances in the environment, quarantine policy for the exploration of Mars, wildland fire protection, weather modification, nuclear waste disposal, and environmental impacts from energy technologies. He has served as a member and consultant to committees of the U.S. EPA Science Advisory Board, as a member of the Nuclear Waste Technical Review Board, and as a member of the Scientific Advisory Panel on toxic substances under Proposition 65 for the governor of California. He is a past president of the Society for Risk Analysis, and he has been a committee member for many previous National Research Council reports dealing with risk, including *Science and Judgment in Risk Assessment* (1994) and *Understanding Risk: Informing Decisions in a Democratic Society* (1996). Dr. North received his B.S. in physics from Yale University, and M.S. degrees in physics and mathematics and a Ph.D. degree in operations research from Stanford University.
- Charles McCombie**, *Vice-Chair*, is an independent strategic and technical advisor to various national and international waste management programs. Currently he is director of Pangea Resources International.



Formerly, he was scientific and technical director of Nagra, the Swiss Cooperative for the Disposal of Radioactive Waste. He has 30 years experience in the nuclear field, 20 of which are in radioactive waste management. His responsibilities have covered performance assessment, engineering and geological investigations and overall program direction. He was the Swiss coordinator of collaborative work with numerous national programs and also with the IAEA, NEA and EU. He has also held positions as a research scientist with the U.K. Atomic Energy Authority and with the Swiss Federal Institute for Reactor Research. He has served on a number of committees advising national and international organizations on radioactive waste management issues. He is currently a member of the American Nuclear Society, Swiss Nuclear Energy Society, International Radiation Protection Association, the Nuclear Advisory Committee of the Swiss Paul Scherrer Institute and the National Research Council's Board on Radioactive Waste Management. Dr. McCombie received a B.Sc. degree in natural philosophy (physics) from the University of Aberdeen, Scotland and a Ph.D. degree in physics (materials science) from the University of Bristol, England.

**John F. Ahearne** is the director of the Ethics Program at the Sigma XI Center for Sigma XI, The Scientific Research Society, a lecturer in public policy, an adjunct professor in civil and environmental engineering at Duke University, and an adjunct scholar at Resources for the Future. His professional interests are reactor safety, energy issues, resource allocation, and public policy management. He has served as commissioner and chairman of the U.S. Nuclear Regulatory Commission, systems analyst for the White House Energy Office, Deputy Assistant Secretary for Energy, and Principal Deputy Assistant Secretary for Defense. Dr. Ahearne currently serves on the Department of Energy's Environmental Management Advisory Board and Nuclear Energy Research Advisory Committee, and is chair of the National Research Council's Board on Radioactive Waste Management. In addition, Dr. Ahearne has been active in several National Research Council committees examining issues in risk assessment. He is a fellow of the American Physical Society, American Association for the Advancement of Science, and American Academy of Arts and Sciences and a member of Sigma XI, the Society for Risk Analysis, the American Nuclear Society, and the National Academy of Engineering. He received his B.S. and M.S. degrees from Cornell University and a Ph.D. in physics from Princeton University.

**Robert J. Budnitz** is president of Future Resources Associates, Inc., in Berkeley, California. Previously, he served as Deputy Director and

Director of the U.S. Nuclear Regulatory Commission's Office of Nuclear Regulatory Research, and he also held several management positions at the Lawrence Berkeley National Laboratory of the University of California. His professional interests are in environmental impacts, hazards, and safety analysis, particularly of the nuclear fuel cycle. He has been prominent in the field of nuclear reactor safety assessment and waste-repository performance assessment, including probabilistic risk assessment. Dr. Budnitz has served on numerous investigative and advisory panels of scientific societies, government agencies, and committees of the National Research Council. His most recent NRC committee service was with the BRWM Committee on Buried and Tank Wastes and the Committee on Technical Bases for Yucca Mountain Standards. He received a B.A. degree from Yale University and a Ph.D. degree in physics from Harvard University.

**Ghislain de Marsily** has been a professor of applied geology at the University of Paris VI since 1987 and is also professor at the Paris School of Mines. He has extensive background in hydrology, as applied to radioactive waste disposal and for his contribution to an earlier BRWM report *Rethinking High Level Radioactive Waste Disposal*. He was elected to the NAE as a foreign associate in 1999. Dr. de Marsily was head of the hydrogeology group at the Paris School of Mines from 1973 to 1987. He is a member of the advisory group of the French Nuclear Safety Authorities, and of the National Committee for Evaluation of Research in nuclear waste disposal. He has also served on advisory panels for geologic disposal at the European Commission, the Swedish Nuclear Power Inspectorate, the Swiss Paul Scherrer Institute, and for Sandia National Laboratories on the WIPP project. Dr. de Marsily graduated as a mining engineer from the Paris School of Mines in 1963 and received a Doctorate of Science in 1978 from the University of Paris.

**Lars O. Ericsson** is professor and head of the Department of Geology at Chalmers University of Technology, Göteborg, Sweden. Dr. Ericsson has experience in rock mechanics and engineering of waste repositories. He is a member of the Swedish National Committee of Geo-science organized by the Royal Swedish Academy of Sciences, and a member of the Swedish Committee for the International Hydrology Programme of UNESCO. He served as president of the Swedish Society of Engineering Geology, and as a representative on the coordinating group on site evaluation and design of experiments for radioactive waste disposal (SEDE-group) of the Nuclear Energy Agency of the European Organization for Economic Cooperation and Develop

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ment. Prof. Ericsson received his M.Sc. in civil engineering and his Ph.D. in engineering geology from Chalmers University.

**Peter Fritz** is the scientific director of the Centre for Environmental Research (UFZ) in Leipzig, Germany. Dr. Fritz has done extensive research on environmental isotopes, including studies in isotope hydrology, work on brines and gases in crystalline rocks, paleoclimatology, and methodological developments for radiocarbon dating of groundwaters. He has worked on nuclear waste disposal programs in Sweden (Stripa), Canada (Canadian Shield), and Germany (Konrad Mine). He is a fellow of the Geological Association of Canada, the Royal Society of Canada, and the Academy of Sciences Leopoldina in Germany. Dr. Fritz completed his undergraduate, Haupt-Diplom (M.Sc.) and doctorate degrees in geology at the University of Stuttgart. Much of his doctoral research was undertaken in 1962 at the University of Pisa where Professor Tongiorgi and Dr. R. Gonfiantini had established one of the world's first environmental isotope laboratories focusing on isotope hydrology. He was professor and chairman of the Department of Earth Sciences at the University of Waterloo in Canada, director of the Institut for Hydrology at the GST in München, Germany and holds an honorary professorship in geology at the University of Leipzig.

**Roger E. Kasperson** is executive director of the Stockholm Environment Institute in Sweden. He has taught previously at Clark University, the University of Connecticut, and Michigan State University. His expertise is in risk analysis, risk communication, global environmental change, and environmental policy. Dr. Kasperson is a Fellow of the American Association for Advancement of Science and the Society for Risk Analysis. He has served on various committees of the National Research Council. He also has served as President of the Society for Risk Analysis and has been honored by the Association of American Geographers for his hazards research. He chaired the International Geographical Union Commission on Critical Situations/Regions in Global Environmental Change, was a member of the Sub-committee on Risk Reduction Strategies of the U.S. EPA Science Advisory Board's report on *Reducing Risk*, and currently serves on the Executive Committee of EPA's Science Advisory Board. He received his Ph.D. degree from the University of Chicago.

**Nikolai Laverov** is vice president of the Russian Academy of Sciences. He has worked in and with the Russian government on a range of ecological problems, particularly nuclear waste disposal. Dr. Laverov has held a variety of administrative positions, including chief of the Scientific

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Research Organizations Administration, which oversees the work of the Ministry of Geology's subordinate institutes. In 1992, he was named co-chair of the Earth Science Joint Working Group, which is under the auspices of the U.S.-Russian Space Agreement. Dr. Laverov graduated from the M. I. Kalinin Nonferrous Metals and Gold Institute in Moscow in 1954 and earned a doctorate in geological-mineralogical sciences in 1958.

**Jane C.S. Long** is currently dean of the Mackay School of Mines at the University of Nevada, Reno. Prior to this position she was on the staff of the Lawrence Berkeley National Laboratory for 20 years. Dr. Long is an expert in fracture hydrology and rock mechanics and has worked on several U.S. and international underground repository research projects. She has led research departments in both energy technology and environmental remediation. She was chair of BESR's Rock Mechanics Committee, and chair of the Committee for Fluid Flow in Fractured Rock sponsored by USNC/RM. She also chaired the Sub-surface Science Committee for BRWM. Dr. Long received an Sc.B. in engineering from Brown University, an M.S. in geotechnical engineering and a Ph.D. in materials science and mineral engineering from the University of California, Berkeley.

**Claire Mays** is a social psychologist with Institut Symlog, a private French research consultancy. Radioactive waste management, as seen from the perspective of risk communication in society, became a major area for Ms. Mays in 1990 with a European Commission study comparing public information practices in Great Britain and France. She and her institute have conducted comparative studies of risk perception using interview and survey methods, and on social and psychological impacts of the Chernobyl accident in the contaminated territories using focus groups. Ms. Mays has acted as an observer and rapporteur for the OECD Nuclear Energy Agency Forum on Stakeholder Confidence. She is editor of the *European Review of Applied Psychology*, a bilingual quarterly. She was elected secretary of the Society for Risk Analysis Europe (1999–2001) and is a member of the U.S. National Council on Radiation Protection and Measurement. Ms. Mays received her A.B. from Harvard and D.E.S.S. from the University of Paris.

**Atsuyuki Suzuki**, is professor of nuclear engineering at the University of Tokyo and member of the Board of Directors of the Institute for Applied Energy in Japan, Nuclear Safety Research Association of Japan, Council for Nuclear Fuel Cycle in Japan and Nuclear Material Control Center of Japan. His scientific interests are management of

nuclear fuel, plutonium and radioactive waste, nuclear fuel cycle safety, and public policy of science and technology. He has extensive experience in advising the Japanese government on nuclear issues. Dr. Suzuki serves as chairman for the Committee of Nuclear Safety Standards within the Nuclear Safety Commission of Japan, Nuclear Non-proliferation Committee of Japan Nuclear Cycle Development Institute, and Nuclear Fuel Cycle Safety Research Committee of Japan Atomic Energy Research Institute. Dr. Suzuki is a member of the Atomic Energy Society of Japan, the Society of Chemical Engineers, Japan and the American Nuclear Society. He has published more than 20 books and more than 200 papers. Dr. Suzuki received his B.S., M.S., and Ph.D. in nuclear engineering from the University of Tokyo.

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## **Appendix B**

### **Workshop Program**

#### **Disposition of High-Level Radioactive Waste Through Geological Isolation: Development, Current Status, and Technical and Policy Challenges**

**November 4–5, 1999**

**The Arnold and Mabel Beckman Center 100 Academy Drive, Irvine,  
California, USA**

#### **WORKSHOP FINAL AGENDA**

**Thursday, November 4, 1999**

**Plenary Session from 08:30–12:30**

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08:30 Call to order and opening remarks  
*Michael Kavanaugh*, Chairman, Board on Radioactive Waste Management  
*D. Warner North*, Workshop Chairman

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- 09:00 Keynote Addresses  
*Frank Parker*, Distinguished Professor of Water Resources Engineering, Vanderbilt University and Chairman of authoring committee “Rethinking High-Level Radioactive Waste Disposal” (National Research Council, 1990), will speak on geological repository development in the U.S. since issuance of “Rethinking.”  
*Charles McCombie*, Former Scientific and Technical Director, the Swiss National Cooperative for Radioactive Waste Disposal, now International Consultant, will speak on international development of the geological disposition option during the past 10 years.  
*Paul Slovic*, President, Decision Research, and Professor of Psychology, University of Oregon, will speak on perceived risk, trust, and the politics of nuclear waste management.
- 11:00 Perspectives on Keynote Addresses  
*Dan Dreyfus*, Former Director of the U. S. DOE Office of Civilian Radioactive Waste Management  
*Ray Kemp*, Honorary Visiting Professor of Risk Management and Communication, University of Surrey, U.K.  
*Yves Le Bars*, President of the National Agency for Radioactive Waste Management (ANDRA), France  
*Peter Nygård*, President of the Nuclear Fuel and Waste Management Company (SKB), Sweden
- 12:00 Format and Objectives of afternoon sessions  
*D. Warner North*, Workshop Chairman
- 12:30 LUNCH AT THE BECKMAN CENTER**
- 

### Afternoon Discussion Sessions from 2:00–5:00

Seven concurrent sessions organized as follows. Each session will be restricted to 30 participants to encourage open discussion, which will be initiated by invited presentations.

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**Session 1:** Role of total system performance assessment in establishing the acceptability of geologic repositories: An interface between technology and policy.

---

Organizers: *Jane Long* and *Ghislain de Marsily*

Presentations:

- Total system performance assessment for the U.S. Waste Isolation Pilot Plant, *Richard Anderson*
- What went wrong at Sellafield? *John Mather* and *John Holmes*



Panel: Limits to knowledge: Examples of unexpected radionuclide transport and implications for performance assessments, *Jane Long, Dave Prudic, Tom Wood, June Fabryka-Martin, Roy Gephart, Annie Kersting, Jesús Carrera, Frank Parker, Alex Pek*

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**Session 2:** Timing and staging repository development: Maintaining technical and social balance in stepwise development from concept through implementation.

---

Organizers: *Lars Ericsson and Peter Fritz*

Presentations:

- Timing and staging approaches in the United States program, *Ron Milner*
- The role of Äspö hard rock laboratory in the Swedish siting program, *Olle Olsson*
- Planning of site suitability determinations for Gorleben, *Manfred Wallner*
- Retrievability and reversibility issues in deep underground repositories, *Jan Vrijen*

Discussion: What are the key steps in repository development? How can technical and social challenges best be balanced and met at each step?

---

**Session 3:** The regulator's dilemma: Decision making in the presence of uncertainty.

---

Organizers: *Robert Budnitz and Atsuyuki Suzuki*

Presentations:

- The United States regulatory approach, *Robert Bernero*
- A European perspective on the regulator's dilemma, *Sören Norrby*

Discussion: How can a regulator meet the demands imposed by technical uncertainty, legal defensibility, transparency, formality, and public involvement?

---

**Session 4:** Public acceptance in the context of social distrust.

---

Organizers: *Roger Kasperson and Claire Mays*

Presentations:

- Public perceptions, *Peter Allen*
- Distrust and long-term institutional performance, *Todd LaPorte*
- Technology and values, *Armin Grunwald*
- Institutions, *William Freudenburg*

Discussion: Core issues in public acceptance and distrust.

---

**Session 5:** Lessons learned from national programs: Tracing routes to success or setback.

---

Organizers: *Roger Kasperson and Charles McCombie*

Presentations:

- Social issues, *Dan Metlay*
- United States programs, *Bob Neill* (WIPP), *Chris Whipple* and *Russ Dyer* (Yucca Mountain)
- United Kingdom programs, *John Holmes* and *Neil Chapman*
- French programs, *Yves Le Bars*

Discussion and questionnaire: What factors have helped or hindered these national programs?

*Neil Chapman* and *Tom Isaacs*

---

**Session 6:** Is geological disposal required?

---

Organizers: *John Ahearne* and *Nikolay Laverov*

Presentations:

- Problems in geological isolation, including matrices for HLW, *Nikolay Laverov*
- The separations technology and transmutation systems (STATS) report, *John Garrick*
- The accelerator transmutation of waste (ATW) roadmap, *Darleane Hoffman*
- Impact of the “leave in place” option, *Dee Walker*; comments, *Lake Barrett*

Discussion: General discussion.

---

**Session 7:** Making progress through international cooperation.

---

Organizers: *Charles McCombie* and *Ghislain de Marsily*

Presentations:

- Is international cooperation more trouble than it is worth? *Ian McKinley*
- What has the NEA done to improve international cooperation? *Claudio Pescatore*
- What has the IAEA done to improve international cooperation? *Arnold Bonne*
- Underground rock laboratories as a vehicle for international cooperation, *Bernard Neerdael*

Discussion: The scope and value of international cooperation, *Claudio Pescatore* and *Ian McKinley*

---

**5:30 RECEPTION AND BUFFET AT THE BECKMAN CENTER**

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**Evening Discussion Sessions from 7:00–9:00**

The seven discussion sessions, Round 2. Each will begin with a summary of views expressed in the afternoon session.

---

**Session 1:** Role of total system performance assessment in establishing the acceptability of geologic repositories: An interface between technology and policy.

---

Organizers: *Jane Long* and *Ghislain de Marsily*

Discussion: Role of regulators concerning total system performance analysis (TSPA), *Tom Peake* and *Johan Andersson*

---

**Session 2:** Timing and staging repository development: Maintaining technical and social balance in stepwise development from concept through implementation.

---

Organizers: *Lars Ericsson* and *Peter Fritz*

The Thursday afternoon session is repeated.

---

**Session 3:** The regulator's dilemma: Decision making in the presence of uncertainty.

---

Organizers: *Robert Budnitz* and *Atsuyuki Suzuki*

The Thursday afternoon session is repeated.

---

**Session 4:** Public acceptance in the context of social distrust.

---

Organizers: *Roger Kasperson* and *Claire Mays*

Presentations:

- Perceptions and trust in Sweden, *Olof Söderberg*
- Perceptions and trust in the United Kingdom, *John Holmes*
- Value issues in France and elsewhere, *Claire Mays*
- Perceptions and institutions in Japan, *Yasumasa Tanaka*

Discussion: How have public acceptance and distrust been addressed in national programs?

---

**Session 5:** Lessons learned from national programs: Tracing routes to success or setback.

---

Organizers: *Roger Kasperson* and *Charles McCombie*

Presentations:

- German programs, *Klaus Kühn*
- Japanese programs, *Masao Shiotsuki*
- Belgian programs, *Jean Paul Boyazis*

Discussion and questionnaire: What factors have helped or hindered these national programs? *Neil Chapman* and *Tom Isaacs*

---

**Session 6:** Is geological disposal required?

---

Organizers: *John Ahearne* and *Nikolay Laverov*

Presentations:

- Selected summaries by Thursday afternoon and Friday morning presenters.

Discussion: Is a repository needed now?

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**Session 7:** Making progress through international cooperation.

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No evening session.

**Friday, November 5, 1999**

**Morning Discussion Sessions from 08:30–11:30**

The seven discussion sessions, Round 3. Each will begin with a summary of views expressed in the previous meetings of the session.

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**Session 1:** Role of total system performance assessment in establishing the acceptability of geologic repositories: An interface between technology and policy.

---

Organizers: *Jane Long* and *Ghislain de Marsily*

Presentations:

- Credibility of TSPA for the public, *Michèle Rivasi* and *Andrew Stirling*
- Can we make a repository more credible by engineering measures? *Charles Fairhurst*

---

**Session 2:** Timing and staging repository development: Maintaining technical and social balance in stepwise development from concept through implementation

---

Organizers: *Lars Ericsson* and *Peter Fritz*

The Thursday afternoon session is repeated.

---

**Session 3:** The regulator's dilemma: Decision making in the presence of uncertainty.

---

Organizers: *Robert Budnitz* and *Atsuyuki Suzuki*

**The Thursday afternoon session is repeated.**

---

**Session 4:** Public acceptance in the context of social distrust.

---

Organizers: *Roger Kasperson* and *Claire Mays*

Discussion and comments: Moving forward in the future, *Douglas MacLean*, *Gene Rosa*, *Phil Richardson*

---

**Session 5:** Lessons learned from national programs: Tracing routes to success or setback.

---

Organizers: *Roger Kasperson* and *Charles McCombie*

Presentations:

- Swedish and Finnish programs, *Tönis Papp*
- Spanish programs, *Juan Luis Santiago*
- Swiss programs, *Piet Zuidema*

Discussion and questionnaire: What factors have helped or hindered these national programs? *Neil Chapman* and *Tom Isaacs*

---

**Session 6:** Is geological disposal required?

---

Organizers: *John Ahearne* and *Nikolay Laverov*

Presentations:

- Problems in geological isolation, including matrices for HLW, *Nikolay Laverov*
- Is partitioning and transmutation an alternative to geological disposition? *Jean-Paul Schapira*
- Post-closure safeguards monitoring for geological repositories, *Per Peterson*
- Disposal possibilities for nuclear wastes, *Paul Dejonghe*
- Human Intrusion: The Achilles heel of geological disposal? *Daniel Galson*
- Comments, *Jane Long*

Discussion: General discussion

---

**Session 7:** Making progress through international cooperation

---

Organizers: *Charles McCombie* and *Ghislain de Marsily*

Presentations:

- Seabed disposal—an international solution that foundered, *Richard Anderson*
- The non-proliferation proposal for collaboration between the United States and Russia, *Tom Cochran*
- An overview of past and present proposals for international storage or disposal, *Fred McGoldrick*
- The Pangea project for an international repository, *David Pentz* and *Ralph Stoll*

Discussion: International disposal concepts, *Ian KcKinley* and *Claudio Pescatore*

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**12:00 LUNCH AT THE BECKMAN CENTER**

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**Plenary Session from 1:30–5:00**

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- 1:30 Informing the Academies' report on geological disposition: Summaries by the chair and rapporteur of each discussion session
  - 3:30 *Francis Tombs*, Chairman, U.K. House of Lords Enquiry into the Management of Nuclear Wastes. Lord Tombs will speak on how insights from the workshop can benefit national programs.
  - 4:00 *D. Warner North*, Chairman's Closing Summary
  - 5:00 Adjourn the Workshop
-

## Appendix C

### List of Attendees

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<p>Ahearne, John F.                      Sigma Xi, The Scientific Research Society                      Research Triangle Park NC USA                      Ahn, Joonhong                      UC-Berkeley                      Berkeley CA USA                      Allen, Peter T.                      EIHMS                      Guildford UK                      Anderson, Rip                      Sandia National Laboratories                      USA                      Andersson, Johan                      Golder Grundteknik                      Solna SWEDEN                      Andersson, Kjell                      Karinta-Konsult                      Taeby SWEDEN                      Andrew, Graham                      U.K. Safeguards Office                      London UK                      Andrews, Robert                      BRWM/National Academies                      Washington DC USA                      Appel, Gordon                      Illinois Dept of Nuclear Safety                      Springfield IL USA                      Apted, Mick                      Monitor Scientific                      Denver CO USA</p>	<p>Awal, Kazi Obaidul                      NSRCD, BAEC                      Dhaka BANGLADESH                      Barnard, Bill                      NWTRB                      Arlington VA USA                      Barrett, Lake                      DOE                      Washington DC USA                      Bell, Michael                      IAEA                      Vienna AUSTRIA                      Benson, Allen                      DOE/Yucca Mtn Site Characterization Office                      Las Vegas NV USA                      Benson, William E.                      National Academies/Retired                      Falls Church VA USA                      Bernero, Robert.                      Consultant                      Gaithersburg MD USA                      Bhattacharyya, Samit K                      Argonne National Lab                      Argonne IL USA                      Black, Paul                      Neptune &amp; Company, Inc.                      Los Alamos NM USA                      Boehmer, Nils H.                      Bellona Foundation                      Oslo NORWAY</p>
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Bonne, Arnold	Clark, Donald E.
IAEA	JAI Corporation
Vienna AUSTRIA	Richland WA USA
Boyazis, Jean Paul	Closs, K.D.
ONDRAF	Forschungszentrum Karlsruhe GmbH
Bruxelles BELGIUM	Karlsruhe GERMANY
Boyle, William J.	Cochran, Thomas B.
DOE/Yucca Mountain Site	National Resources Defense Council
Las Vegas NV USA	Washington DC USA
Brady, Barry	Cole, Belle
University of Western Australia	The PMR Group, Inc.
Perth WA AUSTRALIA	Los Angeles CA USA
Brauer, Volkmar	Cotton, Thomas A.
BGR	JK Research Associates, Inc.
Hannover GERMANY	Washington DC USA
Brennecke, Peter W.	Craig, Paul
BfS	NWTRB
Salzgitter GERMANY	Arlington VA USA
Brewitz, Wernt	Crowley, Kevin D.
GRS	BRWM/National Academies
Braunschweig GERMANY	Washington DC USA
Brocoum, Stephen	Davies, Peter
DOE/Yucca Mountain Site	Sandia National Laboratories
Las Vegas NV USA	Albuquerque NM USA
Brown, Steven	de Marsily, Ghislain
DETR	Laboratory of Applied Geology
Victoria UK	Paris FRANCE
Budnitz, Robert J.	Dejonghe, Paul
Future Resources Associates, Inc.	SCK-CEN
Berkeley CA USA	Mol BELGIUM
Bullen, Dan	Di Bella, Carlos W.
NWTRB	NWTRB
Arlington VA USA	Arlington VA USA
Calas, Georges	Dreyfus, Dan
University of Paris/LMCP	Consultant
Paris FRANCE	McLean VA USA
Campbell, Andrew	Dudley, Bill
USNRC	U.S. Geological Survey
Rockville MD USA	Lakewood CO USA
Carrera, Jesus	Duncan, Allan G.
ENRESA	Environment Agency-UK
Barcelona SPAIN	Abingdon Oxon UK
Chapman, Neil	Dyer, Russell
NAGRA	USDOE-Yucca Mountain Project
Wettingen AG SWITZERLAND	North Las Vegas NV USA
Chase, Jon R.	English, Mary R.
Numark Associates	The University of Tennessee
Washington DC USA	Knoxville TN USA
Chaturvedi, Lokesh	Ericsson, Lars O.
Environmental Evaluation Group	Chalmers University of Technology
Albuquerque NM USA	Gothenburg SWEDEN
Chou, C.K.	Eriksson, Leif
DOE/RW	GRAM, Inc.
Bethesda MD USA	Albuquerque NM USA

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Ewing, Rodney C.	Gottlieb, Peter
University of Michigan	TRW, OCRWM M&O
Ann Arbor MI USA	Las Vegas NV USA
Fabryka-Martin, June	Greeves, John T.
Los Alamos National Lab	US Nuclear Regulatory Commission
Los Alamos NM USA	Washington DC USA
Fairhurst, Charles	Grunwald, Armin
University of Minnesota	Institute of Tech. Assess.& Systems
S. St. Paul MN USA	Analysis
Faruquee, Abidur Reza	Karlsruhe GERMANY
Bangladesh Atomic Energy Commission	Halsey, Bill
Ramna Dhaka BANGLADESH	LLNL
Flueeler, Thomas	Livermore CA USA
Swiss Federal Institute of Technology	Hanks, Thomas
ETH	USGS
Hausen AG SWITZERLAND	Menlo Park CA USA
Flynn, James	Heath, Colin
Decision Research	TRW Environmental Safety Systems,
Eugene OR USA	Inc.
Frei, Mark	Washington DC USA
USDOE	Helt, James
Washington DC USA	ANL
Freudenburg, William	Argonne IL USA
University of Wisconsin	Hirusawa, Shigenobu
Madison WI USA	The Institute of Applied Energy
Frishman, Steve	Tokyo JAPAN
Nuclear Waste Project Office	Hoffman, Darleane
Carson City NV USA	Lawrence Berkeley Labs
Fritz, Peter	Oakland CA USA
UFZ Leipzig-Halle	Holmes, John
Leipzig GERMANY	NIREX
Fuchs, H.D.	Didcot Oxfords UK
GNS	Holtzscheiter, Earl William
Essen GERMANY	Savannah River Technology Center
Galson, Daniel	Aiken SC USA
Galson Sciences Ltd.	Hueckel, Tomasz
Oakham UK	Duke University
Garrick, John	Durham NC USA
PLG, Inc. (retired)	Isaacs, Thomas
Newport Beach CA USA	LLNL
Gavela, Ramon	Livermore CA USA
ENRESA	Ishida, Hisahiro
Madrid SPAIN	UC-Berkeley
Gephart, Roy E.	Berkeley CA USA
Battelle/PNNL	Issler, Hans
Richland WA USA	NAGRA
Gilbertson, Mark A.	Wettingen SWITZERLAND
DOE/OEM	Jackson, Ken
Washington DC USA	LLNL
Gilleland, John R.	Livermore CA USA
Archimedes Technology Group, Inc.	Johnson, Stephen G.
San Diego CA USA	Argonne National Lab-West
	Idaho Falls ID USA

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Kasperson, Roger E. Stockholm Environment Institute Worcester MA USA	LeBars, Yves ANDRA Chatenay Malabry FRANCE
Kavanaugh, Michael Malcolm-Pirnie Oakland CA USA	Leckie, James Stanford University Stanford CA USA
Kawamura, Hideki Obayoshi Corporation Minato-ku Tokyo JAPAN	Lehman, Linda Technical & Regulatory Evaluations Group Inc. Prior Lake MN USA
Kelly, John JK Research Associates, Inc. Breckenridge CO USA	Leroy, David Leroy Law Offices Boise ID USA
Kemp, Ray University of Surrey Melbourn Cambridge UK	Lessler, Richard EPA San Francisco CA USA
Kersting, Annie LLNL Livermore CA USA	Letourneau, Carmel Natural Resources Canada Ottawa Ontario CANADA
Kessler, John H. EPRI, Inc. Palo Alto CA USA	Logan, Stanley E. S.E. Logan & Associates, Inc. Santa Fe NM USA
Kiess, Thomas BRWM/National Academies USA	Long, Jane C.S. Mackay School of Mines Reno NV USA
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Kraft, Steven Nuclear Energy Institute Washington DC USA	Martens, Berndt-Rainer Federal Ministry for the Environmental Bonn GERMANY
Kuehn, Klaus GSF/TU Clausthal Clausthal-Zellerfeld GERMANY	Mather, John Royal Holloway University Surrey UK
Kuhn, Richard G. University of Guelph Guelph ON CANADA	Mays, Claire M. Institut Symlog Cachan FRANCE
LaPorte, Todd UC-Berkeley USA	McCombie, Charles International Consultant Gipf-Oberfrick SWITZERLAND
Larson, Kurt Sandia National Labs Albuquerque NM USA	McGoldrick, Fred Walpole MA USA
Laverov, Nikolay P. Russian Academy of Sciences Moscow RUSSIA	McKinley, Ian G. NAGRA Wettingen SWITZERLAND
Lawless, William F. SRS Citizens Advisory Board Augusta GA USA	

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Stanford CA USA	Institute
Meigs, Marilyn F.	Washington DC USA
BNFL Inc.	Olsson, Olle
Washington DC USA	SKB Aspolaboratoriet
Metlay, Daniel	Figehulm SWEDEN
NWTRB	Ouzounian, Gerald
Arlington VA USA	ANDRA
Miller, David L.	Chatenay-Malabry FRANCE
INEEL	Palciauskas, Victor V.
Idaho Falls ID USA	Walnut Creek CA USA
Mills, William	Palmer, Cindy
Oak Ridge Associated Universities	LLNL
(retired)	Livermore CA USA
Olney MD USA	Papp, Tonis
Milner, Ronald	SKB
USDOE	Stockholm SWEDEN
Washington DC USA	Parker, Frank
Mockler, Susan	Vanderbilt University
BRWM/National Academies	Nashville TN USA
Washington DC USA	Patchet, S.J.
Muraoka, Susumu	WIPP – Westinghouse
Japan Atomic Energy Research Institute	Carlsbad NM USA
Tokai JAPAN	Patrick, Wesley
Murphy, James	Center for Nuclear Waste Regulatory
DOE-Environmental Management	Analyses
Integration	San Antonio TX USA
Idaho Falls ID USA	Peake, Tom
Neerdael, Bernard	EPA
SCK CEN	Washington DC USA
MOL BELGIUM	Pek, A.A.
Neill, Robert H.	IGEM RAS
EEG	Moscow RUSSIA
Albuquerque NM USA	Pentz, David L.
Niewodniczanski, Jerzy W.	The Pentz Consulting Company
Nuclear Atomic Energy Agency	Bellevue WA USA
Warsaw POLAND	Pescatore, Claudio
Norrby, Sören	OECD/Nuclear Energy Agency
SKI	Issy Les Moulineaux FRANCE
Stockholm SWEDEN	Peterson, Per
North, D. Warner	UC-Berkeley
NorthWorks, Inc.	Berkeley CA USA
Belmont CA USA	Pickett, Susan E.
Nygards, Peter	Sociotechnics of Nuclear Energy
SKB	Bunkyo-ku Tokyo JAPAN
Stockholm SWEDEN	Prudic, Dave
O'Connor, Sally	USGS
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New Orleans LA USA	Reiter, Leon
	NWTRB
	Arlington VA USA

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WIPP-Westinghouse	Russian Academy of Sciences
Carlsbad NM USA	Moscow RUSSIA
Richardson, Phil	Shoemith, David W.
EnvirosQuant(I)Sci	USDOE Mined Geological Disposal Board
Ashby de la Zouch Leics UK	London Ontario CANADA
Rivasi, Michele	Simmons, Ardyth M.
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Hokkaido University	Science and Technology Agency
Sapporo JAPAN	Tokyo JAPAN
Schapira, Jean-Paul	Tanaka, Yasumasa
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Orsay FRANCE	Tokyo JAPAN
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North York Ontario CANADA	Denver CO USA
Shepard, Les E.	Tauxe, John
Sandia National Labs	Neptune & Company
Albuquerque NM USA	Los Alamos NM USA
Shiotsuki, Masao	
JNC	
Ibaraki JAPAN	

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Tombs, Francis House of Lords London UK	Wieland, Beat Swiss Federal Office of Energy Berne SWITZERLAND
Torikai, Seishi Pesco Co., Ltd. Tokyo JAPAN	Wikjord, Alfred Atomic Energy of Canada Ltd./ USDOE Las Vegas NV USA
Treichel, Judy Nevada Nuclear Waste Task Force Las Vegas NV USA	Wiley, John BRWM/National Academies Washington DC USA
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Wallner, Manfred BGR Hannover GERMANY	Yow, Jesse LLNL Livermore CA USA
Weart, Wendell D. Sandia National Laboratories Albuquerque NM USA	Zoback, Mary Lou USGS Menlo Park CA USA
Wenbin, Zhou East China Geological Institute Linchuan Jiangxi P.R. CHINA	Zuidema, Piet NAGRA Wettingen AG SWITZERLAND

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## Appendix D

### Acronyms

AECL	Atomic Energy of Canada Limited
ALMR	Advanced Liquid-Metal Reactor
ANDRA	French National Agency for Radioactive Waste Management
ATW	Accelerator Transmutation of Waste
BRWM	Board on Radioactive Waste Management
BSE	Bovine Spongiform Encephalopathy
Ci	Curie
CLAB	Central Interim Storage Facility for Spent Fuel (Sweden)
CNE	Commission National D'Evaluation (France)
DF	decontamination factor
DOE	U.S. Department of Energy
EC	European Commission
EDRAM	Working Group on Environmental Disposal of Radioactive Materials
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
ENRESA	Spanish National Waste Management Company
EPA	U.S. Environmental Protection Agency
EU	European Union
feps	features, events, and processes
HADES	High Activity Disposal Experimental Site (Belgium)
HEU	highly enriched uranium
HLW	High-Level Waste
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiation Protection
IFR	Integral Fast Reactor
ILW	Intermediate-Level Waste
INEEL	Idaho National Engineering and Environmental Laboratory (U.S.)
JNC	Japanese Nuclear Cycle Development Institute
KASAM	Swedish National Council for Nuclear Waste

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LLW	Low-Level Waste
mt	metric ton
Nagra	National Cooperative for the Disposal of Radioactive Waste (Switzerland)
NAS	U.S. National Academy of Sciences
NEA	Nuclear Energy Agency
NGO	nongovernmental organization
NIMBY	Not in my backyard
NRC	National Research Council
NPP	Nuclear Power Plant
NUMO	Nuclear Waste Management Organization of Japan
OECD	Organization for Economic Cooperation and Development
ONDRAF/NIRAS	National Agency for the Management of Radioactive Waste and Fissile Materials (Belgium)
P&T	partitioning and transmutation
PA	performance assessment
PAAG	Performance Assessment Advisory Group
PRACLAY	Preliminary Demonstration Test for Clay Disposal (Belgium)
RWMC	Radioactive Waste Management Committee
SFR	Final Repository for Radioactive Operations Waste (Sweden)
SKB	Swedish Nuclear Fuel and Waste Management Company
SKI	Swedish Nuclear Power Inspectorate
SNF	Spent Nuclear Fuel
SSI	National Institute of Radiation Protection (Sweden)
STATS	<i>Nuclear Wastes: Technologies for Separations and Transmutation</i> (NRC, 1996c report)
SWG	Seabed Working Group
URL	Under ground Research Laboratories
USNRC	U.S. Nuclear Regulatory Commission
WASSAC	Waste Safety Advisory Committee of the IAEA
WIPP	Waste Isolation Pilot Plant

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