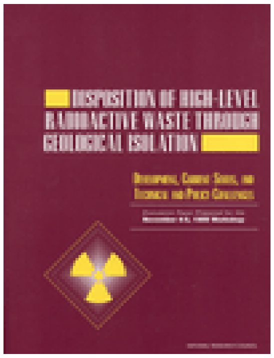

Disposition of High-Level Radioactive Waste Through Geological Isolation: Development, Current Status, and Technical and Policy Challenges

Board on Radioactive Waste Management, National Research Council

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Disposition of High-Level Radioactive Waste through Geological Isolation

Development, Current Status, and Technical and Policy Challenges

Discussion Paper Prepared for the Workshop to be Held at the Arnold and Mabel Beckman Center of the National Academies, Irvine, California on November 4–5, 1999

Steering Committee
Board on Radioactive Waste Management
Commission on Geosciences, Environment, and Resources
National Research Council

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Preface

During the next several years, decisions are expected to be made in several countries on the further development and implementation of the geological disposition option. The Board on Radioactive Waste Management (BRWM) of the U.S. National Academies believes that informed and reasoned discussion of relevant scientific, engineering and social issues can—and should—play a constructive role in the decision process by providing information to decision makers on relevant technical and policy issues. A BRWM-initiated project including a workshop at Irvine, California on November 4–5, 1999, and subsequent National Academies' report to be published in spring, 2000, are intended to provide such information to national policy makers both in the U.S. and abroad.

To inform national policies, it is essential that experts from the physical, geological, and engineering sciences, and experts from the policy and social science communities work together. Some national programs have involved social science and policy experts from the beginning, while other programs have only recently recognized the importance of this collaboration. An important goal of the November workshop is to facilitate dialogue between these communities, as well as to encourage the sharing of experiences from many national programs.

The workshop steering committee has prepared this discussion for participants at the workshop. It should elicit critical comments and help identify topics requiring in-depth discussion at the workshop. It is not intended as a statement of findings, conclusions, or recommendations. It is rather intended as a vehicle for stimulating dialogue among the workshop participants. Out of that dialogue will emerge the findings, conclusions, and recommendations of the National Academies' report.

Contents

Management of High-Level Waste: A Historical Overview of the Technical and Policy Challenges

The National Research Council (NRC) has provided scientific and technical analyses to inform policy decisions related to the disposal of nuclear waste since the 1950s. One of the NRC's earliest reports on this subject, *The Disposal of Radioactive Waste on Land* (NRC, 1957), was among the first technical analyses of the geological disposal option, and it marked the beginning of a four-decade effort by the U.S. government to identify a disposal site for commercial spent fuel and defense waste (collectively referred to here as high-level waste [HLW]), including the effort that is now underway at Yucca Mountain, Nevada. Repository programs are underway or planned in several other countries as well, most notably Belgium, Canada, Finland, France, Germany, Japan, Sweden, Switzerland, and the United Kingdom. Some of these programs deal with transuranic and long-lived low-level wastes as well as HLW.

In 1988, the Board on Radioactive Waste Management convened a study session with experts from the United States and abroad to discuss U.S. policies and programs for managing the nation's spent fuel and high-level waste. The board's follow-up report, *Rethinking High-Level Radioactive Waste Disposal* (NRC, 1990), provided a broad assessment of the technical and policy challenges for developing a repository for the disposition of HLW. The board noted in the report (p. 2) that

> “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.”

This 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, 1991). The views expressed were that geologic disposal can be done ethically and safely. It was also recognized that considerable technical work—in particular in the area of site characterization—remained to be done.

In pursuing geological disposal, national programs in several countries have encountered a number of challenges. These include understanding the nature and rates of geological processes, predicting long-term environmental change, predicting repository and waste package performance, and predicting long-term human behavior for the purposes of risk estimation. Those national programs that have made or are in the transition from research to repository development confronted a challenge that has both technical and sociological overtones: Simply put, many members of the public do not believe that geological isolation can be proven to be a safe, long-term waste disposal solution. They doubt the ability of experts to predict future changes or to make the right decisions to protect public health and are therefore reluctant to relinquish control of the waste, even though the continued management of this waste may be a burden on future generations. These public doubts and objections typically come to the fore when a disposal program moves into the task of identifying specific repository sites. General misgivings about safety suddenly crystallize into specific opposition.

Many national programs are seeking improved methods for addressing these challenges. Some countries have begun a phased approach to repository development while others have suspended their programs. In the United States, for example, the U.S. Department of Energy is considering a plan that would provide the capability to delay for centuries, or even indefinitely, the physical closure of a repository at Yucca Mountain, leaving the final decision on closure to 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 near 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 rock laboratory project at Sellafield. Spain has halted its siting program, and in Holland all work on specific disposal projects has been formally suspended for a hundred years.

In the midst of this general picture of forced or planned delays in repository programs, there are some counter examples. In the United States, the Waste Isolation Pilot Plant (WIPP) has gone into operation as the first deep repository designed for long-lived transuranic wastes. A community in Finland has agreed to host a repository and application has been made for a siting permit. The low-and intermediate-level waste program in Sweden is advancing.

WHAT IS HIGH-LEVEL NUCLEAR WASTE? A BRIEF HISTORY

In 1955, the U.S. Atomic Energy Commission requested that the National Academy of Sciences consider the possibilities of disposing of high-level radioactive waste in quantity within the continental limits of the United States. This request led to a conference at Princeton in 1955 and the subsequent report, *The Disposal of Radioactive Waste on Land* (NRC, 1957). The problem posed to the National Academy of Sciences at that time was primarily the disposal of fission products from the reactors used in weapons manufacture. These wastes were being stored at the Hanford, Washington, Oak Ridge, Tennessee, and Savannah River, South Carolina sites. The major concerns were Cs-137 and Sr-90. It was expected that the liquid or slurry waste could be disposed of directly, and containment was envisioned as necessary for a period of 600 years (about ten half-lives of these isotopes). The report recommended that geological formations such as salt deposits held promise for providing the needed isolation, because water would not be able to pass through these deposits and provide a pathway by which hazardous radioactive isotopes could come into contact with humans and other living things.

In the mid-1950s, the use of nuclear reactors for commercial power generation was just beginning. Most parties involved with nuclear power at that time envisioned that commercial power reactor fuel would be reprocessed to recover uranium and plutonium, using technology similar to that which had been used for the military reactors. The fuel for the first-generation light-water reactors was uranium enriched in the fissile U-235 isotope to about 3–4%, compared to the 0.7% (by weight) of this isotope in natural uranium deposits. High-grade uranium ore was scarce and enrichment using the gaseous diffusion technology was deemed expensive, so this low-enriched uranium fuel was considered expensive and limited as the basis for a large nuclear industry in the future. Many experts expected that breeder reactors producing plutonium from the non-fissile but plentiful (99.3% by weight) isotope U-238 would become the dominant technology as civilian use of nuclear power plants expanded during the next century. Reprocessing would be used to recover plutonium for recycling into light water reactor fuel and for breeder reactors when these were developed. Radioactive waste was expected to consist mainly of fission products, with Cs-137 and Sr-90 viewed as the most hazardous, as they were for the weapons program waste.

As the civilian nuclear power industry has developed over the past four decades, this picture has changed. The composition of high-level nuclear waste is now very different than what was considered in the 1957 National Research Council report. The main difference is that the United States and a number of other countries with nuclear programs now plan to dispose of spent nuclear reactor fuel as high-level radioactive waste, without reprocessing. This usage is called a “once-through” fuel cycle.

Reprocessing of civilian power reactor fuel is being carried out by other countries such as France and the United Kingdom, but the United States decided during the late 1970s not to support reprocessing of civilian reactor fuel. This decision was motivated by concerns that a large commerce in recovered plutonium could increase proliferation of nuclear weapons. However, economic factors have also favored a shift to once-through use of uranium fuel without reprocessing. Advances in techniques for locating high-grade uranium ore deposits have made uranium less expensive, and a large worldwide capacity has developed for uranium enrichment. The end of the Cold War led to additional availability of enriched uranium released from military programs. At the current time the availability of low-cost enriched uranium fuel makes once-though use of this fuel significantly less costly than recovery and recycling of plutonium for commercial power plant fuel. However, many parties continue to believe that recovering and stockpiling plutonium for future use is an appropriate strategy for meeting future energy needs.

Spent nuclear fuel contains substantial quantities of plutonium and other transuranic elements produced through multiple capture of neutrons by the fertile isotope of uranium, U-238. Over the past forty years the nuclear industry has increased the residence time and therefore the burn-up of low-enriched uranium fuel rods. This improvement in fuel burn-up reduces the cost of nuclear electricity generation, but it also results in spent fuel with greater concentrations of long-lived transuranic radioisotopes. Neutron capture and beta decay transform U-238 into Pu-239. Additional neutron captures transform Pu-239 into Pu-240 and Pu-241. Reactors optimized for manufacture of plutonium for nuclear explosives minimized the creation of Pu-240 and Pu-241 by irradiating U-238 target assemblies for a relatively short time. Pu-241 decays to Am-241, and Am-241 decays to Np-237, a very long-lived radioisotope that is more soluble in water than is plutonium.

Isotopes such as Np-237 and the very long-lived fission products such as Tc-99 and I-129 were not discussed in the 1957 report. The most recent performance assessments of the proposed U.S. repository at Yucca Mountain indicate that releases of Np-237 into slowly-moving groundwater could provide the largest doses of radiation to nearby humans, who might use such water for subsistence farming, at a time tens to hundreds of thousands of years in the future. Risk assessments made in the United Kingdom show that nuclides like Cl-36 and Tc-99 can contribute substantially to peak long-term doses from intermediate level waste.

The United States and Russia are now determining how to manage an inventory of plutonium from nuclear weapons that have become surplus as the result of disarmament agreements. One proposed method is disposal in a geological repository, perhaps after placing fission products in proximity to the plutonium (e.g., by immobilizing plutonium in vitrified high-level waste) to make it as theft resistant as spent nuclear fuel. Another proposal is to irradiate plutonium in the form of mixed-oxide fuel in commercial reactors, and to dispose of it along with other spent fuels (NRC, 1994).

The composition of high-level radioactive waste has therefore changed considerably from what was contemplated in the 1957 report. The composition could change further if surplus weapons plutonium from military programs is also to be considered as high-level waste to be placed in geologic repositories.

THE QUANTITY OF HIGH-LEVEL WASTE TO BE MANAGED

Quantities of spent fuel are usually described in terms of the heavy metal equivalent, where the heavy metal is uranium (or other actinides such as thorium or plutonium). The amount of commercial spent fuel in the United States in 1995 was 32,000 metric tons. By 2020 the amount is projected to be 77,100 tons. This projection for the quantity of spent fuel depends on the usage pattern of existing commercial reactors. It assumes no new reactor construction, no extension of existing plant operating licenses, and that all plants will run to the end of their current licenses (Ahearne, 1997). A similar estimate for the spent fuel from all reactors operating or under construction worldwide in 1995 is 447,000 metric tons (McCombie, 1997).

The quantity of high-level waste from military programs is more difficult to estimate, because of the diverse forms of the reprocessing waste and the quantities of fuel from naval reactors that use highly enriched uranium fuel. Measured in radioactivity units, the 1995 estimate of the U.S. military HLW is about 3% of that in U.S. commercial spent fuel (Ahearne, 1997).

ASSURING THE SAFETY OF A GEOLOGICAL REPOSITORY FOR HIGH-LEVEL WASTE

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). Assuring that any release 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 initially considered by many of those involved in development of geological repositories to be closely linked to the selection of rock type. The 1957 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 the report 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 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 geological settings as candidates for geological repositories. Many of these programs have included extensive research in an underground laboratory to investigate transport pathways by which radioisotopes from the waste might be able to migrate into the biosphere, and so come into contact with humans and other living organisms. In most cases, the concern has been with water as a transport pathway. Water is essentially ubiquitous in underground environments, and most radioisotopes can under certain conditions dissolve into groundwater. Transport via groundwater is the main concern for how safety might be compromised, since radioactive materials from the repository may then come into contact with humans or other living organisms in the biosphere. In a few cases there has been concern that radionuclides in gaseous form might escape to the atmosphere through fractures in the rock.

The flow of water (and more generally, fluids, including gases) has been a focal area in the geological sciences and geoengineering. Hydrology and geohydrology have taken on additional practical importance in recent decades. Making relatively precise predictions about the flow of groundwater and other fluids is difficult, even in relatively homogeneous media such as salt or clay. In rocks containing fracture systems such as granite or volcanic tuff, it is possible to determine only the general character of groundwater transport. However, more detailed knowledge of the rock and the fracture systems may be needed to predict the degree of connection between a source area and a target area of concern, and the quantity and timing of flow from the source to the target. Even for rock types in which the extent of fluid flow appears very low, it is difficult to assure conclusively that conditions that permit flow will not occur in the future.

As research has proceeded in national programs, in particular in those proposing fractured host rocks like granite or volcanic tuff, more emphasis has developed on the use of engineered barriers as an aid to assuring adequate waste isolation. Waste is placed inside a container that acts for a long time as a complete barrier to the flow of water (and gases). The container is often surrounded by an impervious clay-type buffer that restricts flow of groundwater to the waste and transport of released radionuclides from the waste. Assuring the integrity of this engineered barrier system for time periods that are greater than those known for any engineered structures is an important safety question.

Most national repository programs now plan to rely on both the geological setting and engineered barriers to achieve safety. This design philosophy is often described as “defense in depth,” or reliance on multiple barriers. Crucial aspects of the geological setting may be to maintain geochemical conditions that inhibit degradation and corrosion processes, to avoid geochemical conditions that facilitate the dissolution and transport of key radionuclides, and to avoid mechanical stresses that would compromise the engineered barriers.

A difficulty with both geological settings and engineered barriers is that safety cannot be demonstrated by direct observation, because of the very long time periods required. Changes in climate may bring about changes in water table levels and flow regimes, and in high-latitude countries such as Sweden and Finland loading of ice from renewed glaciation is considered. Earthquakes, volcanism, and a variety of other geological processes may affect the ability of the site to contain waste. Generally, these issues must be addressed by modeling what would happen under the altered circumstances.

While some metals such as copper have been known to resist significant corrosion for long time periods, most modern materials have not been shown to maintain their integrity over a long period of time. Borosilicate glass and certain types of metal alloys are expected to be highly corrosion resistant under the conditions in the geological repository, but their performance over very long periods cannot be demonstrated directly. A major concern with engineered barriers is whether the barriers might fail as the result of a defect in manufacturing, such as a poor weld that escaped detection. Thus, for engineered barriers, as well as for the capabilities of the geological setting to isolate the waste from fluid transport, indirect methods of proof are the best that science can offer. Models based on short-term observations in laboratories and short-duration field experiments as well as other considerations such as defense in depth and natural analogs must be the basis for assuring that a geologic repository can meet its safety objectives.

If the time scale of concern is set by the lifetime of actinide isotopes such as Pu-239 and Np-237, assurance of safety requires modeling of release and transport processes over time periods that are unprecedented in human experience. The National Research Council report on the *Technical Bases for Yucca Mountain Standards* (NRC, 1995) recommended that compliance with a standard for the release of radioactivity be determined at the *time* of peak risk, whenever that occurs. A challenge of great magnitude thus confronts both those parties seeking to construct a geological repository (i.e., the national program managers) and those parties responsible for evaluating the safety of proposed repositories (i.e., the national regulatory authorities, or other responsible organizations as designed by the national government). Indirect means must be used, because the time scales are so long that experimental methods cannot be used to confirm directly predictions of the repository system or even of its components. The models and methods being used involve state-of-the-art scientific and analytical procedures from a large array of scientific disciplines.

The 1990 NRC report, *Rethinking High-Level Radioactive Waste Disposal,* reaffirmed deep geological disposal as the best option for disposing of high-level radioactive waste. It called into question the direction of the U.S. program during the 1980s and noted that the prescriptive approach being taken was

> "…poorly matched to the technical task at hand. It assumes that the properties and future behavior of a geological repository can be determined and specified with a very high degree of certainty. In reality, however, the inherent variability of the geological environment will necessitate frequent changes in the specifications, with resultant delays, frustration, and loss of public confidence. The current program is not sufficiently flexible or exploratory to accommodate such changes." (NRC, 1990, p. vii).

There has thus been considerable evolution in the conceptualization of the high-level waste problem from 1957 to 1990 and to today. In 1957 the isotopes Sr-90 and Cs-137, having intermediate half-lives and presenting a clear radiation hazard, were seen as requiring "no element of doubt" in the containment of HLW for about 600 years. Prescriptive approaches for geological disposal continued into the 1990's, although the period of time for which the waste was perceived as hazardous increased some 100-to 1000-fold.

During the 1990s, experience in many national programs has 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. The design and the assurance of safety for geological repositories must be a carefully considered exercise in making decisions in the face of scientific uncertainty. Current scientific and technical knowledge might be interpreted as leading to pessimism that every "element of doubt" regarding safety of HLW can be eliminated. But extensive analysis of uncertainties may allow the doubts to be resolved. Francis Bacon, a founder of the scientific method, said 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." (Bacon, 1605).

Today it is understood that the design and the assurance of safety for geological repositories must be a carefully considered exercise in making decisions in the face of scientific uncertainty.

ACHIEVING PUBLIC ACCEPTANCE OF HIGH-LEVEL WASTE REPOSITORIES.

The magnitude of the technical challenges in designing and constructing a geological repository for HLW and assuring its safety is perhaps comparable to that of other large-scale and potentially hazardous engineered systems, such as the development of coal mines, bridges, or a new generation of commercial aircraft. A radioactive waste repository may face special challenges since it may be perceived as involving involuntary risks to members of the general public. Best technical efforts are made to model the system, to assure an appropriate amount of conservatism in the design, and then to improve the design as experience is acquired.

There are many areas in our highly technological society at the end of the 20th century where the public is willing to leave the assurance of safety to the technical experts. Both empirical experience and social science research on public attitudes suggest that this is not the case with radioactive waste disposal. There are a number of interrelated reasons that might be advanced for why public acceptance poses such a formidable challenge. First, the time scales for damage are long, much longer than for many other safety issues. It might be hypothesized that people might not care about adverse impacts that could occur in the far distant future. However, there is much research indicating that nuclear facilities and in particular, nuclear waste repositories, are viewed by many among the public with great concern (Weart, 1988; Flynn et al., 1995; Easterling and Kunreuther, 1995). Furthermore, research shows that underlying that concern is very strong negative imagery (Weart, 1988; Flynn et al., 1995), and the representation that damage from radioactive waste to human health, to ways of life, and to the environment may be widespread and severe.

There are many indications that publics neither understand nor trust the expert community on radioactive waste issues. For the non-specialist, the array of applicable scientific data and proposed methods is so complex as to be virtually incomprehensible. One critic of the U.S. program describes it as follows:

> “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).

This lack of trust in experts and public concerns caused by the proliferation of conflicting expert opinions is not a phenomenon peculiar to radioactive waste disposal. Today, similar attitudes are perceivable in other controversial areas such as genetic modification of foodstuffs.

Many social and policy scientists believe that the U.S. geological repository program and many other national programs are overbalanced in terms of too much emphasis on technological research, and too little emphasis on institutional innovation and supporting social science research. Again citing the same U.S. Critic,

> "While everyone can appreciate that complex, highly sophisticated engineering is required to safely store nuclear materials for thousands of years, few have appreciated the political requirements necessary to design and implement such a solution. 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).

Finally, there is the problem of perceived inequity. HLW is concentrated, so that the waste produced over many decades in a large nuclear industry may fit into one site, with a surface area on the order of a few square miles. While many citizens may enjoy the benefits of nuclear electricity, a far smaller number will be located near the single disposal site, deliberately placed in a relatively unpopulated area. Those who live immediately adjacent to the site may enjoy employment or other benefits from the proximity of the repository. Their neighbors, further away, may feel they have the stigma of living near an undesirable facility with no offsetting benefit. Social scientists have termed this response pattern a "doughnut effect" (Easterling and Kunreuther, 1995). It is easy for these "neighbors" to perceive that they were not treated fairly, especially if they did not participate directly in the choice of the disposal site.

This issue of fairness across current populations is referred to as intragenerational equity. The issue of fairness towards future inhabitants, intergenerational equity, is also important in waste disposal. Current generations benefit from nuclear technologies, which produce wastes. Should these generations attempt to reduce future burdens by disposing of wastes now, even if small potential releases are predicted for the far future?

As noted in the first section of this paper, many national HLW programs have made or are considering changes to deal with the myriad issues raised by the need for public acceptance. A review for the U.S. Secretary of Energy noted the gravity of the problem in the United States (DOE, 1993). Studies in connection with programs in Canada, France, Japan, Spain, and the United Kingdom have reached similar conclusions on the importance of public understanding and acceptance for geological repositories (Bataille, 1993; Aoyama, 1999). In a democratic society, public acceptance is an essential part of the political decision process. Excellence in geological science and engineering may be necessary, but not sufficient, to assure that a geological repository program will be successful.

Social scientists have identified a number of principles that apply to gaining public acceptance of national programs. First, participation in the decision process leading to a geological repository should be open, and to the extent possible given the complexity of the science, the process should be transparent. One method for accomplishing this goal is extensive review of the repository program by independent scientific experts. A second principle is that of staged decision making: the selection of the technologies and the site, the specific design, construction, emplacement of waste, and closure of the repository should be established as a sequence of steps, each taken after careful study and regulatory approval with public participation. Commitment to a site and to technology choices then occurs slowly. In the event of perceived weakness, the process can be slowed down and modifications made to repository design. In a more extreme case, the site selection process can be restarted.

ALTERNATIVES TO A GEOLOGICAL REPOSITORY

A considerable amount of study has been given over many years to alternatives to geological HLW disposal. Among those that have received the most consideration are disposal in the seabed and in outer space, transmuting long-lived isotopes, and continued storage (DOE, 1980).

Disposal of HLW in the deep seabed has been proposed by oceanographic experts and carefully evaluated by the international scientific community (Hollister and Nadis, 1998). This alternative offers excellent prospects for isolation of the waste in areas of the ocean floor that have been highly stable on a time scale of hundreds of millions of years. The major problem for this alternative is achieving the international political consensus needed to place waste in a location not under the sovereignty of a single nation.

Sending HLW into the sun also has been considered. While the required technological capability is not yet available, it is foreseeable within the next century. The space transport system would need to provide adequate protection so that in the event of a failure, waste would not be dispersed onto the Earth. The high cost of such transport would imply a need to separate HLW into components, and only the most long-lived and hazardous materials (e.g., plutonium, neptunium) might merit this alternative (Taylor, 1995).

Transmutation of plutonium, other actinides, and long-lived fission products can be accomplished with further irradiation in nuclear reactors or in accelerator-driven subcritical reactors. This class of alternatives has been studied by the National Research Council (NRC, 1996). The 1996 NRC report “found no evidence that applications of advanced separations and transmutation technologies have sufficient benefit to delay the development of the first permanent repository for commercial spent fuel” (NRC, 1996, p. 2). Several countries are continuing investigations on partitioning and transmutation technologies and whether they could be deployed on the scale needed to make a significant reduction in the inventory of spent fuel (NEA, 1998). Reprocessing of spent fuel is an essential aspect of these technologies.

As described previously, reprocessing rather than “once-through” use of nuclear fuel was the original concept for the commercial nuclear power industry at the time of the 1957 NRC study on nuclear waste. However, transmutation for waste management purposes would involve more extensive recycling and destruction of plutonium and other transuranic actinides than contemplated in a “closed” fuel cycle optimized for generation of electricity. In addition, the potential improvement in repository performance from transmutation of these materials in commercial spent fuel will be limited by the amount of such materials that will be present in high-level waste from defense nuclear activities.

An alternative to geological disposal, especially for the next century, is continued storage in surface facilities. This approach is not a true alternative, rather, it allows postponing the implementation of a permanent solution. Storage methods might be pool storage or dry cask storage at the site of the nuclear reactor where the fuel was irradiated, or dedicated facilities might be constructed at other locations. The concept of such “monitored retrievable storage” has been extensively studied in the United States and other countries. Sweden, Finland, Germany, and Switzerland have commissioned central storage facilities for spent fuel from electric utilities. The technologies for pool and dry cask storage are established and available, and most experts do not see assuring the safety of such storage is a problem on the time scale of a hundred years. The cost of ongoing surface storage becomes very high if such storage facilities have to last for hundreds of centuries, requiring them to be rebuilt on a regular basis. There are also significant risks inherent in the assumption that society will continue to manage such stores.

DISPOSAL VS. DISPOSITION

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 of ultimate disposal, on future generations. One statement of this view is as follows:

> “those who generate the wastes should take responsibility, and provide the resources, for the management of these materials in a way which will not impose undue burdens on future generations.” (NEA, 1995, p. 13).

At a time when many considered that assurance of the safety of geological repositories would be easily accomplished and demonstrated, this objective was widely accepted. As difficulties have emerged both with making the technical case for repository safety and with bringing the public to view proposals as acceptable, the feasibility of this objective has been increasingly questioned. The argument is predicated on acceptance that a sealed repository represents less of a future burden than controlled wastes for which one is still free to choose a disposal option. Many parties within the international HLW community are now reconsidering the merits of a strategy of ongoing monitoring and possible retrieval, as opposed to a program that involves closure of a repository and 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, the response of the geological site and of the engineered barriers to the waste may lead to adjustments in the containment system. Second, provisions for ongoing monitoring may be viewed by publics 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 plutonium in spent fuel.

The counter arguments are that safe disposal is already now feasible and that delaying closure for long times presents a greater hazard. For example, operational expertise and funding in the future are not guaranteed. Retrieval from a closed geological repository remains in principle possible for very long times.

In planning this workshop we have chosen to use the word “disposition” (an arrangement or plan for disposing) instead of “disposal” (emplacement without intent to retrieve) to describe the desired objectives of national programs. Disposition allows opportunities for ongoing management of HLW in a geological repository, as opposed to conceiving a repository only as a facility that will be filled with waste and then sealed. It may be appropriate to consider strategies for extending the time between emplacement of waste and closure of a repository, and to regard an underground repository in a deep geological formation as a monitored, retrievable HLW storage facility, until sufficient confidence in its safety can be developed and the repository closed.

SAFETY AGAINST HUMAN INTRUSION

In this discussion paper we have waited until this point to introduce what some regard as the most challenging aspect of the planning of a geological repository: assuring safety against the future actions of human society. This is, in fact, a problem with any material requiring long-term isolation. While the problems of assuring adequate isolation of HLW against intrusion and transport of radionuclides by groundwater are formidable, geological and climatic processes are relatively well understood compared to what may happen to human society on a time scale of hundreds to thousands of years. For the reasonable assurance of safety, consideration must be given to what humans might do that could compromise the integrity of the repository and release radioactivity that could damage human health or the well-being of other living species.

Human intrusion into a repository and consequent release of radioactivity could happen inadvertently. It should 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. These may include groundwater; oil, gas, or other energy sources (including geothermal); fertilizers for agriculture; minerals and other raw materials for manufacture; and gems for personal adornment. It is difficult to anticipate just what a future society might seek from materials underground. It is also 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 if such a warning would be necessary.

The NRC report on Yucca Mountain standards (NRC, 1995) and many regulatory agencies have taken the position that it is appropriate to evaluate safety in terms of the consequences of an inadvertent intrusion using current drilling technology. Examining the radioactive release from drilling a hole that intersected one container of HLW gives insight into how serious an intrusion event might be, even if the details of future intrusion with unknown technology are difficult to foresee. It is not possible to determine the frequency with which future human intrusion could occur, although in picking the repository site there are advantages to avoiding locations that have obvious potential for energy resources or valuable minerals.

In 1995, NEA published a consensus position that deliberate intrusion should not be covered in repository safety analysis (NEA, 1995). Most of the repositories being contemplated for current national programs could easily be opened by a future generation using today's mining technology. In some cases, mining technology used hundreds or even thousands of years ago might be adequate. The energy value of components in spent fuel, or materials in the engineered barriers, or a variety of other reasons might motivate a future society to dig into a repository, despite the hazard from the radioactivity, which will slowly diminish as the HLW ages.

The most serious threat from deliberate intrusion may be the recovery of materials to make nuclear explosives. In this case, the visibility of such intrusion may be important. An advantage of seabed disposal is that retrieval of HLW from beneath several miles of ocean could only be accomplished with large, specialized surface vessels whose purposes could easily be ascertained via satellite surveillance. Reopening of a geological repository on land might be carried out in such a way that it could only be detected through on-site inspection. Relatively few and very remote repository sites offering easier surveillance possibilities may discourage unauthorized intrusion.

The risk of intrusion, including both inadvertent intrusion and deliberate intrusion, such as an effort by terrorists to release radioactivity or to steal waste material, is a concern for both waste storage and underground disposal. An advantage of both centralization and of placing waste storage underground is that access can be more easily controlled.

THE EVOLVING BALANCE BETWEEN INTERNATIONAL AND NATIONAL EFFORTS

Most of the planning of HLW management has been though 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 (spent fuel if once-through or the waste residue if reprocessing is used) 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 yet approved a design and commenced construction, although the United States has started operation of a geologic repository for long-lived transuranic waste (WIPP). 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 (IAEA) and the European Union (EU) 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. Some countries, especially small and densely populated nations, face considerable difficulty in locating a suitable site for a geological repository. There have been purely commercial proposals in the past for disposal in China or on Pacific islands. One proposal for an international repository is now being developed that could offer a site in a large, essentially uninhabited region of Australia with highly stable geology. Many small countries could be eager customers for an international HLW repository, should such a facility be developed that would allow countries to place HLW outside their own borders under credible international supervision and standards. The end of the Cold War and the financial difficulties in the former Soviet Bloc have left some of these nations with legacies of nuclear materials but little funding to manage these materials. Assuring the safety of materials that could be used for nuclear explosives is particularly important. A proposal has been made to locate a facility in Russia that could provide secure storage for spent fuel from Asian nations and also for nuclear materials from the Russian military program. Other proposals may emerge for cooperation or consolidation of national programs into international activities.

An Overview of the Workshop Agenda

The workshop will focus on the generic issues of geological repositories for disposition of HLW, with illustrations from the experiences of national programs. The objective of the workshop is to provide new insights for the future directions of the geological disposal option. Such insights and other new information will be presented in a National Academies' report to be issued in spring, 2000. To encourage creative thinking, the workshop will emphasize informed and focused discussions by all participants during special sessions that will be described in the next pages of this workshop overview. Only four plenary papers will be presented.

PLENARY SESSIONS

Plenary speakers will include Frank Parker, Distinguished Professor of Water Resources Engineering at Vanderbilt University, and chairman of the National Research Council's Board on Radioactive Waste Management at the time that it produced the Council's 1990 *Rethinking High-Level Radioactive Waste Disposal* report (NRC, 1990). Dr. Parker will speak on geological repository development in the United States since *Rethinking*. Charles McCombie, Consultant and former Scientific and Technical Director, Swiss Cooperative for Radioactive Waste Disposal (NAGRA), will speak on international development of the geological disposition option during the past 10 years. Paul Slovic, President, Decision Research, and Professor of Psychology at the University of Oregon, will speak on public perceptions, trust, stigma, and the problems of achieving public acceptance of geological disposition. These plenary talks will be followed by invited comments from leaders and former leaders of national programs in the United States, France, and Sweden, and a distinguished sociologist from the United Kingdom. In the final session of the workshop, Francis Tombs, member of the U.K. House of Lords and chairman of the U.K. House of Lords enquiry into the management of nuclear wastes, will summarize how insights from the workshop can benefit national programs.

While there will be some opportunity for questions and answers with the plenary speakers and discussants, the main opportunity for participation by workshop attendees will be in the discussion sessions, which are described below.

ARRANGEMENTS AND TOPICS FOR DISCUSSION SESSIONS

In planning the workshop, considering the range and amount of information to be covered and logistical realities, he workshop steering committee agreed upon seven topical discussion sessions. These seven sessions will be held concurrently so that the expected 200 participants can be divided into discussion groups of about 30. In their essential content, the seven sessions will be repeated three times, thus, workshop attendees can participate in three of the seven.

Attendees will have the opportunity at the beginning of the workshop to sign up for the sessions of their choice, and the organizers will try to accommodate their preferences. While the specific content presented in each of the repeated sessions may vary, the topic area will remain the same. The presenters and discussion leaders in each session will assume that those present have not attended a previous meeting of the same session. Attendees are strongly encouraged to share their views and provide their critical commentary on the material presented. More than half of each session will be devoted to discussion, after the planned presentations are made.

KEY ISSUES FOR THE WORKSHOP.

In initiating the workshop, the National Academies' Board on Radioactive Waste Management suggested that three broad topical areas be examined: technical development of the geological disposition option, its scientific and policy challenges, and strategies for implementation. Key issues associated with each area, and to be included in the workshop discussions, were later identified by the workshop steering committee. Workshop attendees are encouraged to consider how they can contribute new ideas and approaches to the following issues:

Technical Development of the Geological Disposition Option—The scientific basis for the geological disposition option, how that option is being implemented on a worldwide basis, and the potential technical suitability and institutional maturity of the geological option.

- What are the key roles of the engineered and geological barriers?
- How site dependent are these?
- Robustness—What does it mean? How can we achieve it?
- What are the open technical areas in understanding engineered and geological barriers?
- Which of these can be cleared up by more R&D? Which are “intractable”?
- Modeling—Can we validate (including use of analogs)? Are “demonstration” experiments technically useful or do they contribute only to public confidence building?
- (How) can we use performance assessment to guide work on site characterization and on engineered barrier system design?

Scientific and Policy Challenges for Disposition of Highly Radioactive Waste Through Geological Isolation—Understanding natural processes and environmental change; predicting long-term repository performance; predicting long-term human behavior; limits to technical knowability.

- How should the scientific community describe to itself and to publics what is, or can be, known (climate, geology, social systems) for very long periods? How much knowledge is enough? (That is, what criteria can be used to judge information needs?) How does this knowledge relate to the choice among disposition approaches?
- To what extent can proof or certitude be achieved? What are the limits to system safety assessment methodologies such as total system performance assessment (TSPA)?
- How do we address the human concerns over irreversibility? What is the attractiveness of storage, retrievability, and monitoring? How do we deal with the possibility that a better alternative than geological disposal might be "just around the corner"?
- Are there benefits to a stepwise repository development program and what must be demonstrated at each step (technically and to policy makers)?
- How do we best address human intrusion (probabilities, information transfer, mitigating actions, etc.)?
- What type of analyses can best help us tackle the "irreducible uncertainties" (probabilistic, bounding)?
- Is commitment of enormous resources, especially rare metals, in geological disposal really justified?

Strategies for Implementing the Geological Disposition Option—Separating the technical and policy bases for licensing decisions; phased disposition options; long-term monitoring and surveillance; addressing public concerns about fairness in the decision process and long-term safety; other strategies to inform and involve publics; alternative disposition approaches.

- Should we store wastes rather than dispose of them "rapidly" (ethical, economic, public acceptance arguments)? How does the "storage vs. rapid disposal" issue relate to the question of how to proceed with siting and licensing of repositories?
- Do separations and transmutation provide real alternatives in the technical sense? In what time frame?
- The regulator's dilemma: how to deal with the conflict between the rigor and transparency required for regulatory processes and the intrinsic uncertainties in any performance assessment or in any real scientific predictions? What is reasonable confidence? Are there useful comparisons to regulation in other areas?
- What must the technical community provide to elected officials to best inform them about radioactive waste management alternatives? What do program managers need to know from publics?

- What is the value of simple transparent safety arguments versus opaque TSPA results?
- What are the critical factors that lead to success (such as the U.S. WIPP, Swedish success with low and intermediate level nuclear waste repositories and transport facilities, progress in Finland)? What are the lessons to be learned from these?
- What is the role of international cooperation (consensus building, international safety standards, proposals for international repositories)?

DESCRIPTION OF THE DISCUSSION SESSIONS

The key issues will be approached from various perspectives in one or more of the workshop's seven discussion sessions. The seven discussion sessions that form the core of the workshop are listed as follows:

- Role of total system performance assessment in establishing the acceptability of geologic repositories: An interface between technology and policy;
- Timing and staging repository development: Maintaining technical and social balance in stepwise development from concept through implementation;
- The regulator's dilemma: Decision making in the presence of uncertainty;
- Public acceptance in the context of social distrust;
- Lessons learned from national programs: Tracing routes to success or setback;
- Is geological disposal required?; and
- Making progress through international cooperation.

Each session is described in the remainder of this paper.

Session 1:Role of Total System Performance Assessment in Establishing the Acceptability of Geologic Repositories: An Interface between Technology and Policy

Deep geologic disposal of nuclear waste relies on several key concepts. The waste, which may be harmful to humans for tens of thousands of years up to a million years, may be isolated with a number of barriers, each playing a specific role, for a specific time, in order to prevent premature dispersion of the waste in the environment. However, if or when a release from a repository occurs, the potential for harm to humans must be shown to be acceptably low, that is, within established regulatory parameters. The measure of the harm to humans is to be estimated by the doses that could be received in the future, based on today's understanding of pathways and effects of doses. When the release is not certain to occur, the risk (probability of occurrence and consequence) is usually considered rather than an assumed dose.

The acceptability of the geologic disposal option is to be established, for the technical community, the licensing community, the political community, and publics, by an analysis that would try to predict the future of the repository and the waste in three different but complementary ways:

How will the barrier system behave under the most likely conditions? These likely conditions need to be selected and justified based on present understanding of the natural system. The thrust of the prediction is on the "normal" evolution of a complex interacting system of a natural medium in which vast amounts of heat and of exogenous elements have been introduced. The basic physical and chemical laws that apply to the barrier system must be identified, the system modeled, the modeling validated, and the relevant parameters to be used for representing the behavior over thousands of years estimated from short-duration experiments. This clearly introduces uncertainties, which need to be identified and bounded.

What external events can alter the "normal" evolution of the repository? These can be the global evolution of the Earth (e.g., climate changes, sea level variations, or recurrent faulting) or events which are of a more random nature, like the fall of a meteorite or volcanic intrusion. Any of these events may be assessed a probability of occurring once in any given year. In general, those events with a probability of less than 10^{-8} per year are ignored. The impact of these events on the repository (immediate release or degraded barrier system) needs to be evaluated to estimate the resulting potential harm to humans.

What inadvertent human action occurring in the future, can alter the performance of the repository or lead to the direct release of radionuclides in the environment? These events may be considered with a probability of occurrence, and may depend on the properties of the site, such as the incentive for reconnaissance or exploitation of natural resources. Taking into account human intrusion is fundamental, but represents a special category of events, since the intrusion scenarios must be specified, and cannot be predicted based on scientific arguments.

Very long-term repository barrier behavior can never be predicted with certainty. TSPA is being used to estimate the repository behavior and give the uncertainty in that estimate. A repository concept must be evaluated as a whole, with each barrier assigned a series of assumed behaviors and properties, and of uncertainties. Only the result of the TSPA makes sense, there is no "general" role for any given barrier. Barriers depend not only on the site (e.g., rock properties at the repository level, dilution properties in the accessible environment) but also on the concept (e.g., Is one given barrier sufficient to outlive the thermal phase of the waste? Is the backfill in place to protect the canister, or to retard the leak of the radionuclides? Is the solubility limit of the waste form a barrier?). Furthermore, regulations may also require that the role of a given barrier be limited in time (e.g., that no credit be given to any engineered barrier after 10,000 or 100,000 years).

Session Structure

The session will be organized around the following presentations and discussions:

- Examples of a successful TSPA that led to licensing of the WIPP in the United States and of unsuccessful TSPAs. What went right and what went wrong?
- What should be the role of regulators during development of a TSPA?
- Is the TSPA credible to the public, or how can it be made more credible?

Issues to be addressed will include those in the following categories:

Technical. Is there a general consensus on the TSPA approach outlined above? Is there an alternative? Is there a limit of knowledge, which will prevent any confidence in describing possible situations in 10,000; 100,000; or 1 million years? Can we bound this limit of knowledge by estimating uncertainties? Is there a danger of building over-confidence on phenomena that are poorly known by trying to estimate ranges of uncertainties?

Regulatory Aspects Influencing the Technical Issues. Regulatory policy is by necessity involved in the safety performance analysis, by specifying time limits for the safety assessment, by specifying the type of potential receptors in the future (e.g., the assumed distance to the nearest well downstream from the repository), and the type of evaluation measure (e.g., deterministic peak dose, expected dose for a ensemble of probability-weighted scenarios or samples in the probabilistic parameter space, different dose limits for different scenarios, risk limit). How do the technical uncertainties affect the policy decisions of the regulators?

Regulatory Treatment of Human Intrusion Scenarios. Since these scenarios must be specified, is there a general international consensus on what these scenarios are? How to treat them? Which importance to give them relative to the performance of the system for all other scenarios? Is it adequate to merge all scenarios by giving a probability to the human intrusion scenarios (e.g., the probability of a new well to be drilled in the future based on the present observed drilling rate in the area), or should they be considered separately?

Social/Political. Is TSPA an appropriate approach for informing publics and public officials of the long-term performance of a repository? Will the discussion, on the contrary, be forced into assessing the role of individual barriers, and will the technical community be asked to “guarantee” the integrity of each individual barrier over a given lifetime? What is the importance given by publics to the human intrusion scenarios? Can TSPA be conducted in a way that addresses the concerns of various publics?

Session 2:Timing and Staging Repository Development: Maintaining Technical and Social Balance in Stepwise Development from Concept through Implementation

The many different national approaches to implementing geological disposal demonstrate that there is no unique or “best” approach. What has become clear, however, is that the development of a facility for disposition of high-level radioactive waste requires decades for completion. Compared to most industrial projects this development period is extremely long.

During this long process, the project implementers (the responsible waste management organization), the regulators, political officials and publics must establish a working relationship, a “partnership.” Without reaching consensus among the partners, progress will be unlikely. Experience shows that decisions made by only one or two partners (e.g., industry and government) and not including publics, are not likely to succeed. Thus the timing and staging of events in the course of repository development will depend on a balance of technical and social factors. Progress will involve the balancing of options and views regarding:

- political and legal matters,
- scientific and technical issues,
- public acceptance of sites and procedures,
- the interest of the nuclear industry, and
- needs to disposition waste from national defense activities.

A fundamental issue to be addressed is the question of retrievability or reversibility. Whether or not it should be possible to retrieve the waste may be considered in a wide perspective and is related to the views on technological advances, irreducible uncertainties, scientific understanding in general, and nuclear waste as a presumptive resource. This issue includes ethical and economic aspects regarding the appropriateness of the underground option.

Legal permissions and other legal aspects are important. The organizational structures, legal framework and regulatory review process are expected to provide a well-defined, logical and “credible” decision-making path. It is also expected that the basic principles of radiological protection against potential exposures are elaborated and that the roles for the implementers, regulators, and publics are clearly defined. These help to establish confidence in the regulatory procedures by which the facility would be either licensed or rejected.

The site selection process will involve many factors. Public acceptance will be of very special relevance. The balance among economic interests (industry and government), public and political acceptance, technical investigations and development, and estimation of environmental and social impacts will be decisive for a successful siting process.

The geoscientific database is an essential part of the siting background material. Different kinds of analyses (constructability, performance, and safety) follow different investigation phases. One has to consider that different levels of knowledge will be reached in each successive investigation phase. To be able to indicate whether a geoscientific parameter is a suitable evaluation factor, or to be able to specify criteria, knowledge is needed concerning what precision can be expected in the parameter estimation after a given investigation stage. The precision in measuring essential parameters varies greatly from feasibility studies to site investigations and to detailed underground surveys.

In this context the question and role of underground research laboratories (URLs) arises. There might be a clear advantage in developing a URL into a final disposal or storage site. Usually the objectives of the URLs are only to verify physical and chemical processes in a general site specific scale or demonstrate essential activities in situ. In either instance, the URL offers an opportunity for involving publics and addressing their concerns.

The construction of a final repository or a storage site is largely a technical issue that can be divided up into different stages. Are there advantages in an experimental pre-disposal storage phase for say 10% of the fuel? Should evaluation of the constructability aspects precede the safety and performance evaluation or vice versa in the final investigation strategy?

Session Structure

The session will be organized around presentations and discussion of the experiences of selected countries in seeking to combine technical development and social concerns into a stepwise strategy for implementing geological disposal.

The following issues will be addressed in the context of timing and staging events that will best lead to establishment of a geological repository:

- What are the key decision points in repository development and what must be known at each, taking into account both the knowledge that will be available and the consequences of decisions at each stage of development?
- How can science and politics be merged in site selection?
- How can decisions about repository development be properly framed in terms of the realistically available alternatives?
- To what extent should technical issues (safety, performance, and construction) be integrated with the public acceptance issues? At what stages of development should this integration occur?
- How can publics best be involved in different stages of the decision process?
- To what extent does progress in reducing the uncertainties about geologic disposal depend on development and evaluation of specific designs tailored to specific sites?
- What are the pros and cons of underground research laboratories? Should they be used for research and demonstration only, or as the first step in site development?
- Should the disposition concept be evaluated through limited waste emplacements?
- For how long should maintenance, safeguarding, and monitoring of the facility be continued?
- For how long should the possibility to retrieve the waste be maintained?

Session 3:The Regulator's Dilemma: Decision Making in the Presence of Uncertainty

It is broadly accepted that attempts to project the performance of a deep-geological repository can never be very accurate over the multi-thousand-year time periods that are usually considered important. Even using the most advanced techniques for modeling repository behavior out to multi-thousand-year times, and in the hands of very skilled analysts, there will inevitably be major uncertainties in the numerical dose-commitment projections of such models. These uncertainties will always be large in part because the distant future cannot be predicted, but also because the amount of detail required of the models, in order to make such projections, is much greater than is usually obtainable at a given site. Most actual geological sites tend to be heterogeneous at small scales (scales of several meters or less), yet the projections of performance often depend on such details, which are typically unknowable or may be estimated only in a statistical sense. Also, even the engineering aspects of the repository, such as the long-term behavior of metallic canisters or of concrete tunnel-support structures, are difficult to model for time scales of thousands of years or more, time scales that are well beyond actual experience. Publics may be skeptical of the performance projections over many millennia of geological repositories, for the same reasons that underlie the technical difficulties with modeling.

The national authority that is charged with issuing a license or other legal permission for a repository (referred to as the “regulator” in this discussion) is put into a very difficult position by the realities mentioned above. The first job of the regulator is to establish a standard that will be the basis for granting or denying a license to the repository. Both the form of the standard, and the level of safety that the repository must meet or exceed, are difficult to establish in any event, but that difficulty is greatly magnified by the problems mentioned above: the problem that the technical projections are inevitably highly uncertain, and the problem that publics are often distrustful of the claims of technical experts. This requires the regulator to develop not only a standard of performance, but also a standard of proof that takes those unavoidable uncertainties into account.

How safe is safe enough? If the technical projections could be made with relatively high confidence, the answer to this question would be very different than must be the case when the projections have the technical uncertainties that they do have.

How much confidence must the regulator possess to issue a positive finding (a license to proceed)? Does the required level of confidence depend upon the step for which the license has been requested (construction, operating license, closure)? How should that level of confidence be embedded into legal language, and then used in a defensible regulatory decision?

The national regulatory agency will play a very important role in confronting and resolving the difficulties involved in making national decisions about repositories. But the main intrinsic positive resource that such an agency needs—the general trust of the public that it will “do the right thing”—may be lacking or lost unless the regulatory body can exercise all of its roles well.

These roles include at least the following, all of which must be juggled successfully:

- the standard-setting-rulemaking role vis-a-vis both the form of the standard and the issue of how safe is safe enough;
- the independent-technical-expert role in which the regulator must through its own expertise demonstrate its own competence on the technical matters under review;
- the application-review role in which a judgment must be made as to the adequacy of the license submittal; the listening-to-the-public role in which the public's (and the legislators') legitimate concerns must be dealt with; and finally,
- an adjudicatory role if and when its findings are challenged in court.

The regulator may also have a role in decision stages that are not required in the formal licensing procedure. For example, is there a responsibility to assure an appropriate balance between the confidence that a safe repository can be achieved and the commitment (in money or resources) required to take the next step in developing the repository?

Session Structure

The session will be organized for discussion of this “regulator's dilemma.” Its several aspects all deserve illumination from the many different perspectives represented by the several different sectors to which the regulator must be responsive. The objective is to air and discuss the different approaches that have been taken in different countries that have tried to confront this dilemma. Both success stories and failure stories need to be covered, with an emphasis on lessons learned.

Issues to be discussed include the following:

- Given unavoidable technical uncertainty, how should a regulator approach the issue “how safe is safe enough”?
- What level of confidence must a regulator have before granting a license application?
- How can a regulator's level of confidence be written into a legally defensible action?
- How should a regulator deal with the uncertainties of human intrusion?
- What measures should a regulator take to ensure fairness to stakeholders of all persuasions?

Session 4:Public Acceptance in the Context of Social Distrust.

Most interested or concerned persons would probably agree that the public acceptance or rejection of the geological option is a central issue for radioactive waste management today. This issue of acceptance, however, is interpreted differently in various contexts. Implementers and decision makers may regard securing public acceptance as a necessary step, as a difficult obstacle, or as a worthy democratic imperative. Concerned citizens and residents may well seek, even demand, another role in waste management decisions than is implied by the notion of “coming to accept" pre-arranged plans. Social scientists might observe that all of these views imply differing definitions of "acceptance," or even of what is meant by "publics." These views imply, as well, various ways of understanding, measuring, and working toward acceptance.

Experiences in the different countries suggests that some prior institutional conceptions and processes of decision making may need to change in order to move toward a situation deemed "acceptable" by major interests. At this time, it is useful to step back and consider why radioactive waste management programs seem to encounter such a high level of societal conflict, controversy, and opposition, and why efforts to move ahead with even redesigned programs may fail. In fact, a large body of studies provides a substantial base of knowledge about four factors at the roots of today's conflicts. These include the following:

Public perceptions of risk. According to extensive cross-national data, publics see the risks of nuclear power and radioactive wastes as very high and are greatly concerned about the dangers. The sources of these perceptions include qualitative aspects of the risks, perceived links with weapons of destruction, and memories of Chernobyl and Three Mile Island. There is also evidence that these perceptions are quite ingrained and unlikely to be changed by provision of risk information or proffered assurances from developers or authority figures.

High social distrust. A high level of social distrust of the managers and institutions charged with the waste management task is documented across a number of countries, including some that on other issues show high deference to authority. This distrust is both specific to the radioactive waste area, and also a more general phenomenon in society. Evidence exists that once lost, trust is often very difficult to regain. Patterns of media coverage may reinforce (or at least do nothing to diminish) attitudes of distrust. Management strategies under conditions of high distrust may well need to be different than when higher levels of social trust prevail.

Value and ethical issues. Mixed in with the risk and trust situations are some difficult value issues, including intragenerational equity, intragenerational (geographical) equity, procedural equity (fairness in process), and responsibilities to risk-bearers. Such values are becoming more paramount in society. There are increased expectations in many societies for consultation and public participation to meet the "fairness" criterion.

Legacy of past mistakes. For decades some radioactive waste management measures have been inadequate, mistake-prone, and often poorly implemented. Many lessons have been learned, and over the last decade institutions, processes, and strategies have been altered to adapt to societal requirements as they are better understood. Nevertheless, a legacy of past mistakes remains with publics. Ordinary people may wonder if national management programs can now overcome past deficiencies and deliver high-quality process and results. What will convince skeptical publics that there has been a radical break with the past and that new approaches and programs will now be handled much better? What types of evidence are most likely to win confidence? This legacy factor encourages us to examine recent and future changes in institutions.

Session Structure

This session will be organized around the following series of questions for discussion:

- What are the core issues involved in public acceptance and distrust, and what do we know about them?
- How have these issues been addressed in various national programs? What approaches have been most satisfactory? Where have we gone wrong and why?
- How do we best move forward? What should our goals be in the area of “public acceptance”? What approaches or mid-course corrections offer the best chance of reaching those goals?

The sessions will open with framing papers to give data and insight on the four factors seen above to be at the root of today's conflict situations. The following topics will be addressed once from a research point of view and once in light of country cases. What do we know about public perceptions? Of what use can knowledge of perceptions be in radioactive waste management?

What patterns of trust and distrust are apparent across societies? Can trust be regained where it has been lost? How? How can program managers best proceed in a climate of distrust? Can trust be granted to institutions when the management task reaches very far into the long term? What institutions are best suited for such long-term tasks? What major value issues are involved in highlevel radioactive waste management? Are these unique to the field, or do they reflect issues facing all technologies in society? To what extent have they been successfully addressed in the various national programs? How might they be handled better in technical options and in sociopolitical processes?

What are the implications of the foregoing for types of technical approaches, institutional strategies, and processes for interacting with publics? Can comparisons from other fields of risk and technology be usefully made? What should the architects of radioactive waste management programs be aware of and aim for today?

Session 5:Lessons Learned from National Programs: Tracing Routes to Success or Setback

Countries seeking to implement the geological disposal option have gained much experience during the past decade. While the overall picture appears to be one of little progress and many setbacks, there have been notable successes. The purpose of the session is to solicit candid overviews on successes (and the contributing factors) together with setbacks (and what one should have done differently). The overviews should serve to initiate discussion on lessons learned on topics of common interest and on how transferable such experience is. Each of the sessions on this topic will be introduced by three or four brief invited overviews from national programs.

A questionnaire has been prepared eliciting from speakers and other participants their opinions on lessons learned from national programs. Although different national programs will be described in each of the three meetings of this session, the questionnaire will ensure that the broad issues to be addressed will be consistent. A synthesis of responses to the questionnaire will be presented in the workshop summary and considered in the resulting National Academies' report.

Topics of concern to this session will also be addressed in other thematic sessions during the workshop. This session, however, is oriented toward comparing and contrasting specific experiences from individual national programs. Attendees should be prepared to discuss, analyze, and learn from the experiences of others. The session organizers will make clear in advance which case studies will be covered in each of the three meetings of this session.

Session Structure

This session will be organized around presentations of national experiences. The experiences of different national programs will be highlighted at each of the three different meetings of this session. Speakers will address themselves to answering a set of questions about their programs. Following the program presentations, the speakers will be invited to join a panel and help develop the discussion.

During the discussions, participants will be expected to give their personal views on what they believe to have driven programs along or tripped them up. We propose to distribute the questionnaire during each session; any of the participants can complete all or part of the form. This will address the same set of questions that speakers will cover in their talks. For programs that are well represented by participants, the output of the questionnaires may represent an interesting peer group consensus (or simply highlight uncertainties and differences!).

Issues addressed in this session will include the following:

- degree of public acceptance of geologic disposal (current status and trends);
- alternative site selection strategies (technical, volunteering, etc.);
- reference disposal concept (e.g., weight of engineered vs. geologic barriers);
- importance given to alternatives like separation and transmutation;
- impact of regulations;
- regulator-implementer relationships;
- influence of organizational structures on progress made;
- interacting with publics; and
- most effective arguments of opponents.

QUESTIONNAIRE ON NATIONAL EXPERIENCE

1. How is POLICY developed and implemented?

- Are national responsibilities (e.g., policy, funding, implementation, regulation) clearly enough defined, fully appropriate and functioning well? What are the relative roles of federal, state and local governments and how has this affected progress? Does the issue of who runs the program affect its credibility?
- Is the repository development program well prescribed and understood by all stakeholders, or has it grown piecemeal as it went along?
- Are prescriptive, stepwise program milestones helpful, or too constraining?
- Has the issue of how a site has been selected influenced the acceptability of the process and, if so, how? How has politics vs. technical suitability affected siting?
- Have national party-political policies and events played an important role in the program?
- How does the way in which the program receives funds affect decision making and progress?

2. Has TRANSPARENCY helped the program?

- Would you describe the repository development program as having been open and transparent?
- Would it still be acceptable to say that there are parts of the process that cannot be fully transparent without causing unwarranted concern (e.g., siting)?
- What has been the role and response of the scientific community and how has this helped/hurt?
- Have other national programs or participation in international projects helped, or have they had negligible real impact?

3. Have REGULATORY ISSUES affected the program?

- Has the structure and content of regulations been clear and helpful?
- Have implementer/regulator interactions been efficient, or could they be improved?
- Do you think that the regulatory system (and style of regulations) has helped to build public confidence and thus gain acceptance?

4. How has PUBLIC ACCEPTANCE been handled?

- What have been the major issues with gaining acceptance from the local community?
- Has there been strong, nation-wide opposition and, if so, has it been effective in changing or slowing the program?
- Has it been helpful in terms of progress to place a disposal program in a wider context, including long-term waste retrievability and the assessment of other waste management options?

5. What has been GOOD and could it have been BETTER?

- What are the single most successful and most unexpected aspects of the program in the last ten years?
- What would be the single most significant change in approach that you would make (or would, in retrospect, have made in the last decade) to help move the program forward?

Session 6:Is Geological Disposal Required?

All countries with nuclear power programs face the problem of disposing of some form of high-level, long-lived radioactive waste. Some countries have chosen to reprocess the spent fuel, removing the plutonium (and uranium) for reuse as mixed oxide fuel. However, this cycle does not eliminate all the long-lived products.

For at least thirty years, the planning in most countries was to develop some form of geologic repository in which the waste could be isolated permanently. This was planned for both once-through cycles, in which the spent fuel was disposed of directly (suitably packaged), and for the waste from reprocessing, usually planned to be immobilized in glass or ceramic. No country has yet successfully developed such a repository, although the United States has started operation of a repository for transuranic waste.

Which problems is geological isolation intended to solve? For which is it a unique solution? Perhaps it is time to re-examine other options. The default option has been to leave the spent fuel in place at a reactor site or the waste at a reprocessing plant. This is an unintended form of monitored surface storage; surface storage is an alternative long advocated by some analysts. To understand some of the arguments for a repository, the “leave-in-place option” or storage in other controlled and maintained facilities with different levels of active safety functions will be examined in this session.

The committee that developed the 1995 NRC report *Technical Bases for Yucca Mountain Standards* wrote:

> “We have not considered whether the development of a permanent repository should proceed at this time… . We were not asked and we did not attempt to address whether a repository is needed in the near future, nor did we compare the risks and benefits of proceeding with a repository now as opposed to those that might be realized by continued reliance on surface storage well into the next century.” (NRC, 1995, p. 21).

The Board on Radioactive Waste Management pointed out in *Rethinking High-Level Radioactive Waste Disposal* (NRC, 1990) that the process of geologic disposal involved decisions throughout the life of the project, and that those decisions should be made in the context of consideration of the alternatives:

> “Judgments of whether enough is known to proceed with placement of waste in a repository will be needed throughout the life of the project. But these judgments should be based on a comparison of available alternatives, rather than a simplistic debate over whether, given current uncertainties, a repository site is ‘safe.' Even while the detailed, long-term behavior of an underground repository is still being studied, it may be marginally safer to go ahead and store reactor waste there (in a way that permits retrieval if necessary), rather than leaving it at reactors.” (NRC, 1990, p. 5).

What is the time scale for the need for repositories? If plutonium with its very long half-life drives repository design and public concern, perhaps technology can be brought to bear. In particular, the NRC Committee on Separations and Transmutation reported:

> “Some of the proposed solutions have focused on separating the hazardous long-lived radioactive radioactive components of the waste and transmuting them by neutron bombardment to form nuclides that would be either stable or radioactive with a much shorter half-life.” (NRC, 1996, p. 1).

It is timely to review this report from today's perspective, since most of the work cited was completed in 1993. One of the technologies that has progressed significantly since that time, at least in interest in many countries, is accelerator transmutation.

Historically, a range of alternative disposal technologies has been examined. These include subseabed emplacement, deep boreholes, island disposal, and space disposal. The international consensus has been that geologic repositories offer the most promising permanent disposal technology. Have there been any important developments in any of these technologies that would warrant reexamination of this consensus?

Session Structure

This session will be organized around presentations of possible alternative means of HLW disposition. Attendees should be prepared to discuss the alternatives, their viability, and how they might alter our present approach to geological disposal.

Issues to be addressed in this session are the following:

- Why is a repository required? Options, including spent fuel storage at reactors and transmutation.
- Might a repository become a mine for weapons material, or for expensive materials used in the engineered barriers?
- Advantages and disadvantages for international sites, including questions of institutional monitoring and controls, safeguards, and impacts on a country trying to develop its own site if an international site will become available.
- From an international perspective, are there any consistent requirements for an acceptable repository?

Session 7:Making Progress through International Cooperation

International cooperation toward implementing the geological option has two dimensions. Firstly, there are international organizations that are charged with maintaining responsible oversight of peaceful uses of nuclear technology.

Secondly, individual countries themselves participate in bi- or multi-lateral agreements in areas of nuclear technology.

During the past decade, there has been a growing interest in international cooperation for repository siting. Is this because there are superior sites available in non-nuclear power countries, or because a coalition of countries can convince (or make it worthwhile) for another country to host a repository, or for some other reason? One may ask “Why should we go through the difficult process to disposition our own waste if we can wait for others to do it for us?” Do the environmental, ethical, and economic aspects require, or justify, international solutions?

For an international site, some problems are harder to solve, some easier. Who provides institutional control and to what standards? How is funding determined? Should a major goal be to support the continuation or growth of nuclear power or should a requirement for participation be a timetable for shutting down nuclear power (e.g., Sweden, Germany). Do proliferation concerns exclude some international locations or arrangements? For how long can institutional controls be relied upon for an international site?

International organizations such as the IAEA and NEA have sponsored many projects in the area of geological disposal, both aimed at the technical community and at presenting consensus opinions to enhance public acceptance (NEA, 1991, 1995, 1999).

Session Structure

This session will be organized around presentations by representatives of international organizations and discussions of the role of international cooperation. Presentations are planned on the work of the IAEA and the NEA, with opportunities given to examine the value of specific past projects and to suggest future needs. The role of these organizations, and others such as the EU, in assisting countries with and without nuclear power programs will be discussed. International work on seabed disposal will be described and the technical merits and political problems debated. On the subject of international repositories, the intention is not only to present past and present proposals, but also to examine the technical, ethical, economic and political issues involved. Contributions to the debate will be solicited also from national programs that perceive the concept or the timing of international disposal schemes to be problematic.

Issues to be addressed in this session are the following:

- Exchange of information. Can this be used to avoid duplicating errors, to reduce expenditures, etc.? Has it been so used?
- Collaborative study projects. This includes international code comparisons, like *Intraval, Decovalex, and Geoval.*
- Collaborative experimental projects (e.g., analog studies, URL programs). Which are the biggest successes? In which areas could more be done?
- Value of international organizations. Do organizations such as the IAEA, NEA, and the EU provide a useful service to member countries? Is the answer the same for major nuclear countries and small nations?

- Coherent policies or regulations. Are they desirable? Feasible?
- Public communication and acceptance. Can collaboration in this field be as useful as in technical areas and what can be learned across national cultures?
- Exchanges of wastes. How much has taken place? What are equivalence principles?
- International repositories. Can they succeed? Which schemes are out there? What are the effects on national programs? What are safeguards benefits?

CONCLUSION.

This discussion paper is intended as an introductory overview and preview for the attendees at the workshop. It is intended as a vehicle for beginning a dialogue among the workshop participants. Much has happened in the past decade regarding the development of geological HLW repositories, and it seems an excellent time for a revisiting and reformulation of the issues by the technical community as an input to the decision process for the national programs and for international cooperative efforts. The authors of this discussion paper look forward to interaction with the workshop participants. We hope that out of this dialogue will emerge a useful set of findings, conclusions, and recommendations for the subsequent National Academies' report that the Workshop Steering Committee is committed to produce.

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