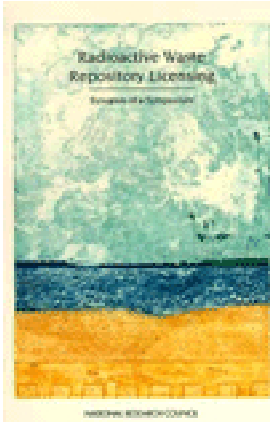

Radioactive Waste Repository Licensing: Synopsis of a Symposium

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

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Radioactive Waste Repository Licensing

Synopsis of a Symposium sponsored by the Board on Radioactive Waste Management

Commission on Geosciences, Environment, and Resources
National Research Council

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Preface

The Board on Radioactive Waste Management (BRWM) of the National Research Council convened a symposium on Radioactive Waste Repository Licensing in September 1990 while the U.S. Environmental Protection Agency (EPA) was in the process of reviewing "Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Waste" (the Standard). EPA was planning to reissue the Standard, the basis for U.S. Nuclear Regulatory Commission (USNRC) repository licensing regulations, in early 1991.

The BRWM had recently issued a position paper that raised questions about the philosophy and methodology of the U.S. high-level radioactive waste (HLRW) program. The BRWM wanted to hear views on regulation and licensing issues from a broad spectrum of the radioactive waste community in a neutral forum. The entities that comprise the radioactive waste community — government agencies, public interest groups, research groups, international organizations, and advisory bodies — were invited to the symposium to examine the status of radioactive waste repository licensing requirements.

The synopsis following this preface identifies the issues discussed at the symposium. It is intended to present neither conclusions nor recommendations but, rather, scientific and policy concerns expressed by the HLRW community. The papers from the 25 symposium presenters are not included because the speakers were invited on the basis that they not be required to submit texts of their presentations. Accordingly, a complete set of presenters papers does not exist.

The BRWM is grateful for the exceptionally active participation of the symposium audience and especially wishes to thank all the speakers for their contributions.

FRANK L. PARKER, CHAIRMAN
BOARD ON RADIOACTIVE WASTE MANAGEMENT

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Radioactive Waste Repository Licensing

Introduction

There is a worldwide scientific consensus that deep geological disposal — the approach being followed in the United States — is the best option for the disposal of high-level radioactive waste (HLRW). Despite this consensus, many in the radioactive waste community are concerned that current federal regulations, by virtue of the prescriptive nature of the Standard's assurance requirements and the expected contentious licensing process, may ultimately prevent identification and licensing of a site technically suitable for a repository in the United States. Others in this community believe that current regulations are workable if the proper site is chosen.

Since 1955 the National Research Council, the research arm of the National Academy of Sciences (NAS/NRC), has been advising the U.S. government on technical matters related to the management of radioactive waste, especially through its Board on Radioactive Waste Management (BRWM or the Board), a permanent committee of the NAS/NRC. After careful study, the Board concluded in a recent position statement ("Rethinking High-Level Radioactive Waste Disposal," National Academy Press, Washington, D.C., 1990; Appendix A in this volume) that the U.S. program for deep geological disposal of HLRW is unlikely to succeed if it continues on its current course because the present U.S. Department of Energy (DOE) approach, in which every step is mandated in detail in advance, is poorly matched to the technical task at hand.

The BRWM believes that, based on public concern over safety and the implementing and regulatory agencies' perceived need for public credibility, a high degree of inflexibility with respect to both technical and schedule specifications has been built into the U.S. Environmental Protection Agency (EPA) Standard and the U.S. Nuclear Regulatory Commission (USNRC) regulation. In "Rethinking High-Level Radioactive Waste Disposal" the

Board warned that the HLRW program might well fail to site and license a repository because the various federal agencies involved had, according to the Board, set unnecessarily high and technically insupportable hurdles to regulatory compliance. The Board viewed the policies of the federal agencies as promising to anticipate every potential problem and/or as assuming that science will soon provide the appropriate answers. The Board encouraged the involved federal agencies to see that the choice is not between an "ideal" underground facility and a less than perfect one, but rather between disposal underground with reasonable assurance of safety versus on-site storage at each nuclear power plant where there is greater chance of disturbance. The inherent variability of the geologic environment, the Board suggested, necessitates allowing flexibility and iteration in the design, construction, and scheduling of a repository. The Board also urged the federal agencies to facilitate greater participation in policymaking by interested parties and to involve them substantively in the planning and construction of a repository.

Because of the widespread scientific concern about these issues and interest in regulatory revisions planned by the EPA as a result of the court remand of 40 CFR Part 191 ("Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Wastes" — Appendix B), the BRWM held a symposium on September 17–18, 1990, in Washington, D.C. to examine the status of repository licensing requirements and related issues in the United States and elsewhere, and to consider approaches to the reconciliation of divergent viewpoints. Approximately 300 people, including representatives of federal and state regulatory agencies, Congress, national and international organizations, national laboratories, industry, public interest groups, and members of the public, attended the symposium.

At the symposium, the EPA, the State of Nevada, and the Natural Resources Defense Council (NRDC) asserted that the scientific basis for the Standard and the release criteria was strong. Other participants expressed concerns that aspects of the current draft of the Standard were not technically supported. They maintained that better quality scientific data would support a less prescriptive standard and allow for flexibility through a performance standard, rather than through the current subsystem performance criteria. They favored an iterative approach that could take into account new information acquired through the characterization and construction processes. These participants favored also the dose-to-man or population dose criteria, rather than current release criteria, as more valid regulatory criteria because they relate to health effects. EPA and the USNRC staff preferred to retain a multiple barrier approach to repository design and construction in order to resolve uncertainty about expected performance. Inasmuch as plausible human intrusion scenarios based upon worst-case assumptions may pose difficult challenges for assuring repository safety over 10,000 years — a period longer than all of recorded history — some participants wanted the issue of human intrusion to be considered separately from the performance standard.

Many participants expressed concern about the feasibility of implementing probabilistic standards as compared to deterministic standards; they believed that there was insufficient information on the distribution functions of many of the parameters. There was concern that, by itself, the uncertainty in some of the parameters could cause the results of a number of the modeled scenarios to exceed the Standard. The EPA, however, held that probabilistic standards are more appropriate for dealing with the long time frame of 10,000 years over which the prospective repository must demonstrate safety.

The EPA maintained that the current release limits are supported by recent radiation research demonstrating increased estimates of health effects from low doses of radiation. The state of Nevada and the NRDC asserted that this new research called for lower release limits. The New Mexico Environmental Evaluation Group pointed out that the stringency of the Standard was the catalyst for the U.S. Department of Energy's (DOE's) consideration of engineering enhancements to the Waste Isolation Pilot Plant design. Other symposium participants advocated modifying the probabilistic assumptions in order to make the human exposure risk from HLRW more nearly commensurate with that of other hazardous wastes; they wanted the Standard to require only the stringency necessary to the protection of human health. They also pointed out that the more stringent the Standard, the more costly it is to demonstrate compliance. An additional risk identified was that if compliance could not be demonstrated at any facility, the existing and any future radioactive waste must remain forever in "temporary" storage.

There was a good deal of discussion about the fact that licensee compliance with either the Standard, 40 CFR Part 191, or the USNRC implementing regulation, 10 CFR Part 60, did not guarantee licensee compliance with both rulemakings. This standard-to-regulation connection was termed the "nexus" and prompted an examination of ameliorative options.

The symposium generated detailed discussion of the science involved in modeling and assessing a repository and of the difficulties associated with the licensing process. Subsequent to the symposium, the EPA has issued revised Working Drafts of 40 CFR Part 191. While the drafts incorporate some recommendations from the BRWM's 1990 position paper and from the symposium participants, other recommendations — including quantitative probabilistic criteria vs. qualitative or deterministic criteria, and level of stringency — were not addressed in Drafts #3 and #4 of 40 CFR Part 191. The drafts do not incorporate suggestions made at the symposium to consider the relationship between cost/benefit and stringency and to consider separately the human intrusion issue (although there is an allowance made for adoption of diverse human intrusion assumptions by the implementing agency).

Background

HIGH-LEVEL RADIOACTIVE WASTE IN GENERAL

The challenge of HLRW disposal in the United States is dominated by spent fuel from nuclear power plants. At present, about 17 percent (20 percent in the United States) of the world's electricity is generated by some 413 nuclear power plants (111 in the United States). The generation rate is as high as 75 percent in France and 50 percent in Sweden. Each 1,000-megawatt electrical nuclear power plant produces about 30 metric tons of spent fuel each year. In 1990 spent fuel temporarily stored at ground level in pools or dry casks at the 111 nuclear power plant sites in the United States constituted about 21,500 metric tons of heavy metal (MTHM). By 2030, the last year of DOE's Mission Plan, spent fuel is expected to total 86,000 MTHM, provided that no reactor licenses are renewed and no new plants are operating. In addition to spent fuel, a HLRW repository would be licensed to contain some 10,000 metric tons of high-level solid and liquid defense wastes that have been stored pending permanent disposal since the inception of the U.S. nuclear program in the 1940s. (These wastes are present at such sites as Hanford, Idaho National Engineering Laboratory, and Savannah River.) At this time DOE is also looking carefully at the possibility of deep geologic disposal for Greater-Than-Class-C waste from processing of nuclear materials from the U.S. nuclear weapons program.

Most countries, including the United States, have concluded that the best means of long-term disposal of HLRW is deep geological emplacement, always including some form of engineered containment or encapsulation and generally with some limited retrieval capability, at least initially. The Nuclear Waste Policy Act of 1982 divides the responsibilities for regulation of HLRW disposal among three federal agencies: the EPA, to pro mulgate generally applicable standards to protect the environment from nuclide releases off site; the USNRC, to set technical requirements for specific implementation of the Standard and to license the facility; and DOE, to issue general guidelines for recommending and selecting sites, characterizing sites, and ultimately, constructing and operating a geologic repository.

In the 1987 amendments to the Nuclear Waste Policy Act, Congress designated the Yucca Mountain, Nevada, site as the single candidate location for a HLRW repository and directed DOE to conduct detailed site characterization. The Yucca Mountain site, by law, may store no more than 70,000 metric tons until a second repository is licensed.

The Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, was authorized as a research and development facility concerned with TRU waste disposal in December 1979 by DOE's National Security and Military Applications of Nuclear Energy Authorization Act of 1980 (P.L. 96–164).

THE EPA ENVIRONMENTAL STANDARD — 40 CFR PART 191

Promulgated by the EPA in September 1985, 40 CFR Part 191 establishes a set of generally applicable standards for the disposal of spent nuclear fuel, high-level and transuranic radioactive wastes. The Standard does not, by federal law, apply to WIPP, but is being implemented by DOE in accordance with an agreement with the State of New Mexico.

Subpart A of 40 CFR Part 191, "Environmental Standards for Management and Storage," covers temporary storage and long-term monitored retrievable storage (MRS). Subpart A establishes dose limits to the "public in the general environment" for exposure during waste management and storage. Subpart A was not included in the court remand of the standard, and the provisions of Subpart A were not discussed at the symposium.

As originally promulgated, Subpart B of 40 CFR Part 191, "Environmental Standards for Disposal," applies to disposal-related releases to the accessible environment, doses to the public, and contamination of groundwater. The release limits set forth in Subpart B were established based on generic analyses of the possible performance of hypothetical repositories. EPA's analyses suggest that such a level of performance would ensure that the risk to future generations does not exceed that of a corresponding amount of unmined uranium ore. The rationale of limiting health effects to that of unmined ore is contained in the preamble to the Standard, but there is no goal stated in the Standard itself.

The containment requirements in the Standard set total quantitative limits on release of radionuclides into the "accessible" environment during the first 10,000 years following disposal. The EPA derived these limits from a technology-based release standard by determining the amounts of radionuclides, singly or in combination, that would result in 1,000 or fewer cancer deaths during the 10,000-year period for each 100,000 MTHM in spent reactor fuel. Generic assumptions were made about the behavior of various types of repository sites, the pathways by which radionuclides might move through the environment (and be ingested or inhaled by people), and the habits of human populations over the next 10,000 years. Since many radionuclides might be released over time, a weighting procedure is provided to ensure that the calculated total of all effects under the release limits is below the objective of 1,000 cancer deaths in 10,000 years. Some symposium participants criticized the lack of a mechanism within the Standard for basing the distance to the accessible environment on the geologic or hydrologic variability of a specific site or geological medium.

The requirements of the Standard also provide two probabilistic distribution requirements: that the cumulative releases of radionuclides should have, first, less than a 1 in 10 chance of exceeding the specified limits and, second, less than a 1 in 1,000 chance of exceeding 10 times those limits. These probability distributions are to be used in performance assessments, to include all elements of uncertainty in the parameters. The assessments examine all credible possibilities for movement of radionuclides from the repository into the accessible environment. In conducting such analyses, DOE will rely heavily on computer modeling of the repository, taking into account the surrounding geological environment and all possible environmental transport pathways. The products of the various performance assessments will then be presented in a complementary cumulative distribution function (CCDF) format, overlaid on the probabilistic standards referred to above. This will indicate whether that particular set of performance assessments exceeds the Standard. With the understanding that absolute assurance is not feasible, the Standard requires only a "reasonable expectation" that compliance would be achieved.

The groundwater and individual protection requirements assume an undisturbed site, and are applicable for the first 1,000 years following disposal. One requirement specifies the maximum allowable annual radiation doses to individual members of the public. Other requirements pertinent to groundwater set dose limits for 1,000 years for any nearby irreplaceable sources of drinking water that supply communities (i.e., thousands of persons).

THE COURT REMAND

In July 1987 the U.S. Court of Appeals for the First Circuit vacated Subpart B of 40 CFR Part 191, remanding it to the EPA for further consideration and substantiation. Three reasons were cited by the court for the remand. The first was that EPA had not given adequate public notice in the proposed rule of the groundwater provisions adopted in the final rule. Sec ond, the court found the groundwater protection standard invalid because it was not reconcilable with the EPA standards that protect underground sources of drinking water according to the mandates of the Safe Drinking Water Act; the court directed the EPA to reconcile the inconsistency or to explain it. Third, the court found the 1,000-year duration of the individual and groundwater protection standard to be arbitrary and capricious, in part because the EPA had relied solely on general population, not individual, risks in setting it. EPA's reconsideration of these portions of the Standard could result in a revision of the Standard as a whole or merely the insertion of a better justification for the 1985 requirements.

THE USNRC REGULATION — 10 CFR PART 60

Promulgated by the USNRC in June 1983, 10 CFR Part 60, "Disposal of High-Level Radioactive Wastes in Geologic Repositories" (the Regulation), established procedures and technical criteria for licensing geologic repositories. Under an USNRC license, DOE is responsible for disposing of spent fuel and HLRW, and for implementing the Standard at the future HLRW repository.

The most controversial provisions of the Regulation are those that establish subsystem performance standards. The USNRC specifies quantitative criteria for each part of the subsystem: the minimum number of years (300 to 1,000) over which the waste package must provide substantial containment, the maximum release rate (1/100,000 or 0.001 percent of the yearly inventory of each radionuclide after the first 1,000 years of radioactive decay), and the minimum groundwater travel time (1,000 years to the accessible environment). The controversy over these criteria involves the stringency of the limits, the cost-effectiveness of their implementation, and the amount of reliance placed on a site's geology.

The Symposium

REACTIONS TO "RETHINKING HIGH-LEVEL RADIOACTIVE WASTE DISPOSAL"

"Rethinking High-Level Radioactive Waste Disposal" is reprinted in Appendix A. In general, the report was commended for bringing vital and contended issues to the forefront of debate. Many at the symposium agreed with the report's flexibility recommendations and encouraged increasing the site specificity of the Standard. Representatives of environmental groups, EPA, and the State of Nevada argued that the Standard was not overly stringent, inflexible, or unworkable. DOE pointed out that the program is now much better run than it was at the time of the workshop from which the report was developed. There was strong opinion at the symposium on both sides of the question of the validity of probabilistic release criteria. Several participants lauded the call for increased and more substantive public participation in the development of the Standard and in the licensing process, supporting the need for informal working relationships in addition to formal advisory functions.

One participant pointed out that, although a successful program demands accord on a set of licensing regulations that are rational, reasonable, and firmly grounded in science, the issue at hand, at least for the present, is not licensing. WIPP, not being subject to USNRC licensing authority, is not yet able to start an experimental program due to a delay in land transfer from the U.S. Department of the Interior to DOE. Yucca Mountain is far from a license application as DOE commences investigation of the geology of the mountain. At this point, the Yucca Mountain Project faces many stumbling blocks before it can tackle the intricacies of the USNRC licensing requirements.

40 CFR PART 191

Much of the debate at the symposium focused on technical criticisms of the Standard. James Curtiss, a USNRC Commissioner, made the point that the Standard was based on what was technically feasible rather than on an overall health and safety goal. Lawrence Ramspott, of Lawrence Livermore National Laboratory, said that the rule was written in 1985, based on 1970s technology. He suggested that if the EPA is to retain a standard based on what is feasible, revisions should be made to take into account newer technology and newly available data. Ramspott noted several changes since the 1970s: at that time there was a lack of data on actual radioactive waste, effects of water chemistry, and unsaturated sites. Since then, tests have been made on spent fuel and glass containing radioactive waste, and much work has been done with groundwater from sites and rock-equilibrated groundwater in the presence of container materials under a variety of conditions, including both saturated and unsaturated zones. In addition, much work has been done with container materials, such as copper, which greatly diminish the degree to which a repository must depend on geologic behavior.

Other technical criticisms raised at the symposium were:

- The Standard should be stated in terms of annual limits on the radiation dose to individuals rather than as release limits over broad time periods.
- The containment requirements should be directed toward the protection of individuals rather than populations.
- The Standard poses requirements in terms of numeric probabilities, an approach that has never been used previously in a federal standard and that the responsible agencies have no experience in implementing.
- The required evaluation of the human intrusion scenario is inadequate because it relies on unsupportable societal predictions 10,000 years in the future, thus suggesting that accurate predictions can be made over the far term, and rendering geologically different sites virtually equivalent in risk.
- The Standard is unnecessarily stringent compared with similar standards for disposal of hazardous chemical waste, especially considering the level of unavoidable background radiation that exists, both naturally occurring and man-made.
- An opposing view of the Standard's stringency was also expressed; two speakers thought the Standard was unnecessarily lenient compared with similar standards for disposal of hazardous waste.
- In focusing on protecting future generations the Standard pays insufficient attention to current worker exposure.
- The Standard provides flexibility only at the discretion of EPA administrators. Such flexibility should be built into the Standard so

that DOE can design a facility to take advantage of the range of possibilities for demonstrating compliance.

- Where the Standard calls for "reasonable expectation" of meeting limits, "reasonable" should be defined, so that DOE and contractors know how to measure it and to determine when it has been achieved.

The Standard was also criticized for its lack of attention to cost-effectiveness. It states in several places that compliance should not impose an unreasonably difficult or expensive burden on those seeking to comply. However, speakers noted, when the EPA said that site characterization was not unduly expensive, the agency had not had any experience with conducting such a characterization. It is now known that straightforward characterization, even without extensive litigation, is complicated and resource consuming. For example, most available data in the early 1980s assumed congruent dissolution; it has now been shown that dissolution in groundwater is noncongruent due to differences in nuclide solubility. Determining the extent to which dissolution is not congruent will be time consuming and costly.

Many speakers stressed the importance of taking a new look at the expense of implementing 40 CFR Part 191 and how it relates to the benefits. They perceive the Standard as demanding protection that goes beyond that required for public safety, incurring exponentially greater costs for each additional increment of protection. This inattention to cost stems from the fact that what could be achieved with 1970s technology was far less costly than what could be achieved in 1990, in part because extremely small amounts of radiation can now be detected. The desire to shield the public and the environment from even the lowest levels of radiation may lead to HLRW disposal costs that are out of proportion to what is spent to curtail greater environmental hazards from other hazardous wastes.

David Pentz, an environmental and geotechnical consultant, asserted that it is questionable whether the stringency of the Standard is indeed furthering the public safety to any measurable degree. Pentz and Thomas Cotton, an environmental consultant, noted that when EPA justified their level of stringency based on what was technically feasible at the time, they reached the conclusion that the cost of compliance would not be burdensome. However, some of the assumptions on which they based that conclusion have changed significantly; Pentz and Cotton suggested that it might be useful for EPA to reexamine their analysis and conclusions.

PROBABILISTIC RELEASE STANDARDS VS. INDIVIDUAL DOSE LIMITS

Much opposition was expressed to EPA's selection of probabilistic re lease limits for protection of the public over the extended time frame of 10,000 years following waste disposal. James Mercer, a hydrogeologist, voiced doubt about the scientific basis for predicting transport of radionuclides for such a long period of time. He noted that projections for only a 10-to 20-year time frame are difficult. This view was voiced also by symposium participant David Okrent, a reactor safety physicist and consultant to the Advisory Committee on Nuclear Waste, who served on a subcommittee of the Science Advisory Board (SAB, EPA's advisory Board) that reviewed the Standard. He criticized the EPA's use of that review to support the idea that 10,000-year projections can be made with reasonable confidence. In Okrent's opinion, the probabilistic group that worked on the report had "strong questions about one's ability to estimate risk out to 10,000 years." He said that the "reasonable confidence" statement used by the EPA to back the Standard was an unfortunate choice of language that made its way into the Executive Summary (Appendix E) of the SAB report.

At the symposium, several speakers pointed out that the International Commission on Radiological Protection and other groups, both national and international, had concluded that an annual dose limit to the individual was the best criterion by which to judge the long-term acceptability of solid waste disposal. A USNRC staff representative discussed the possibility of a deterministic basis for licensing geologic repositories that closely parallels common precedents for individual risk-based standards and regulations. An example would be a quantitative standard, such as the 4 millirem/year individual dose specified in the Drinking Water Standard. Such an approach has been found generally to avoid the potential for large individual doses possible under a population-based standard, to ease interpretation and determination of compliance, and thus to be less likely to lead to controversy. Another reason given to support annual dose limits to individuals is the difficulty of determining the relative merits of any specific site by using the EPA probabilistic release limits. Various groups found insufficient EPA's explanation of how the generic standards were derived from the upperbound population health risk goal; they requested that further clarification of the limits be provided and, if probabilistic release limits are to be retained, that these limits become secondary to a primary annual risk or dose-limit standard.

The Standard does, it was pointed out, recognize the value of dose limits in requiring that engineered controls be able to prevent significant individual doses in the near term (i.e., for the first 1,000 years after disposal). The Standard also provides annual limits on individual dose and on average groundwater contamination from undisturbed performance in that initial period. Demonstrating compliance with individual dose limitations beyond 1,000 years was considered to be very difficult, due to the complexities involved in estimating exposures.

The EPA and others consider probabilistic release limits over the long term to be preferable to annual dose/risk limits for several reasons. First, the performance of a repository must be judged over very long periods of time, during which determination of compliance by the physical processes of measurement or inspection cannot be assured. The EPA views probabilistic limits on total releases integrated over time as providing a meaningful, if not absolute, standard for evaluation that more readily accommodates consideration of disturbance of a repository at both the population and the individual level. If annual dose limits for individuals were to be used, contrary to present practice, they would have to be evaluated on an incremental, multigenerational basis, taking into account the probability of potential releases.

Second, EPA points out that probabilistic limits on total releases over time from a repository present a quantitative standard against which the criterion of success may be more readily measured. Use of individual annual dose limits over long time periods would complicate the analytical task, again probabilistically, by requiring predictions of environmental events, human behavior, and exposure pathways to people on a year-by-year, multigenerational basis. The potential for nonresolution of issues and for adversarial situations would thereby, according to the EPA, be enhanced. Curtiss expressed his concern about the continuing and contentious debate over the feasibility of implementing the probabilistic portion of the Standard, and argued that a clear and unambiguous approach to its implementation in a licensing review has not been identified. Support for probabilistic limits came from Robert Loux, representing the State of Nevada, who felt that if WIPP and Yucca Mountain cannot meet the licensing criteria, new sites should be chosen. He said that before the Standard is rejected as unworkable, it should be tried on a less complicated site than Yucca Mountain. Loux believes that many in the HLRW community wish to alter the Standard in order to render the WIPP and Yucca Mountain sites viable. Robert Neill, of the New Mexico Environmental Evaluation Group, noted that the very concept of geologic isolation presumes the ability to predict long-term geological integrity.

Robert Shaw, of the Electric Power Research Institute, recommended a compromise, retaining the probabilistic approach as an acceptable option for anticipated events. For unanticipated events, such as human intrusion, he recommended a separate release limit on an event-by-event basis for those processes sufficiently credible to warrant consideration.

STRINGENCY OF THE STANDARD

General concern was expressed at the symposium that the risks associated with disposal under the Standard, though acceptably small, might be unnecessarily small, especially when compared to similar limits for the disposal of other hazardous chemical wastes and compared to the much higher level of unavoidable, natural and man-made background radiation. For example, while the Standard would permit a HLRW repository to cause no more than an average one cancer death every 10 years, EPA estimates that existing concentrations of naturally occurring radon inside houses in the United States are causing one cancer death every 18 to 75 minutes.

Shaw observed that EPA's rationale for an acceptable level of risk from radioactive waste was based on the waste risk being a certain fraction of the fuel cycle risk and therefore being lower than or equal to the total risk from nuclear reactor operations. He contended that there is no scientific basis for judging the EPA's fraction to be a reasonable risk relative to other accepted societal risks. He views the EPA rationale as a judgment based on a nonscientific response to the idea of radiation and would replace it with a rationale based on well-supported societal safety goals.

The stringency that draws criticism is found in the quantitative levels set for radionuclide release and containment, and also in the high probabilistic confidence levels that are required by 40 CFR Part 191. The confidence levels of the containment requirements, 90 percent and 99.9 percent, are unprecedented in their high conservatism. According to Wendell Weart, of Sandia National Laboratories, the orders of magnitude of uncertainty introduced into the CCDFs by the probabilistic assumptions, together with the uncertainty inherent in modeling releases that result from human intrusion, undermine the ability of *any* site to meet the Standard's assurance requirements.

DOE and others worried that the existing Standard might be so restrictive that it slows, or precludes, the characterization of any repository site. Although John Bartlett, Director of DOE's Office of Civilian Radioactive Waste Management, warned that the stringency of the Standard is costing the HLRW program a lot of time, money, and public confidence, he insisted that DOE is not complaining about the Standard; DOE's role is to comply with the Standard (and the Regulation) and develop methods for evaluating compliance. A question was posed as to the degree to which the release limits and associated residual risks might be raised and still provide an acceptable level of protection.

On the other hand, some speakers suggested that the Standard is not too stringent with respect to acceptable levels of risk, and might even require tightening, in view of both increased estimates of health effects from low doses of radiation and improvements in waste containment theory and technology.

EPA explained at the symposium that public acceptance is an important factor in setting regulatory limits, and the agency is confident that the requirements are perceived by most people as adequately protecting human health and the environment. EPA and Nevada officials asserted that the Standard would be within reach if the repository were properly sited. Dan Reicher, of the Natural Resources Defense Council, suggested that if the existing licensing approach is abandoned the process might have to be started over with a new set of potential repository sites. He said that otherwise the public would perceive any effort to alter the regulatory process as an attempt to protect the current potential sites — WIPP and Yucca Mountain — from possible failure under the present Standard.

Others held the view that compliance with the current Standard would achieve a level of protection greatly exceeding that needed to protect human health and the environment. However, according to some participants, if the EPA were to adjust the Standard now, regardless of the rationale, the changes would seem to be politically, rather than scientifically, based. It might be thought that the requirements were being changed in order to ensure that the prospective Yucca Mountain repository would be licensable. Richard Guimond, the EPA representative, warned that if the EPA relaxed the Standard, public skepticism would grow and the program would face even greater problems. Cotton, however, submitted that it might be better to fix the Standard now, rather than later, when and if significant problems with compliance have developed. A later adjustment in the face of problems might cause even greater difficulties with public perceptions. He also suggested that, since the Standard and the Regulation were conceived at a time when many sites were being considered, and Congress has since changed the mission to one of approving or disapproving one candidate, it would be appropriate to reconsider the agency rules in view of the new mission.

FLEXIBILITY

Part of the problem of stringency for many of the participants lay in the specificity of the Regulation. It was argued by many that, without relaxing the requirements for the overall performance of the repository, design and planning could be made easier by restructuring the requirements of the Regulation. Some believed that if the USNRC were to rely *only* on the system performance requirement adopted from 40 CFR Part 191, rather than on the current subsystem requirements for a repository, the systems designers would have more freedom to engineer into the containers and waste forms a level of safety that could offset flaws or uncertainties in the geology of a site.

In 10 CFR Part 60, the USNRC allows for flexibility (by means of case-by-case exemptions) in implementation, but all the flexibility is left to the discretion of the USNRC. Speakers argued that the flexibility should be defined in the Regulation, in order to give the licensee the ability to design according to site characteristics, with the knowledge that approval of speci fications is not subject to the changing politics and regulatory conservatism of the regulating agency. Curtiss pointed out the difficulty of relying on the exemption procedure to address issues late in the process. The same argument was made for building flexibility into 40 CFR Part 191. Section 191.17 of the Standard permits alternative provisions, but any alternative must undergo extensive public consideration.

Reicher noted that an important drawback of iterative, flexible standards is that all too often, where rigorous compliance standards and detailed licensing requirements are not imposed on large, costly projects, corners are more likely to be cut in the name of program objectives or schedules. Frank Parker, then Chairman of the BRWM, maintained that sound, definitive standards need not preclude flexibility in the method by which a repository meets compliance.

THE LACK OF A TECHNICAL CONNECTION BETWEEN THE STANDARD AND THE REGULATION

Regulations are generally designed to assure achievement of a corresponding goal, such as health protection or worker safety. Some symposium participants repeatedly criticized the fact that compliance with the Regulation does not necessarily achieve compliance with the Standard. At the symposium, Curtiss emphasized the significance of the discrepancy between the EPA release limits and the USNRC subsystem criteria specifying geological and container limits. The USNRC's methodology is deterministic, specifying quantitative criteria for multiple barrier performance, while the EPA's Standard is probabilistic, based on CCDFs for containment limits. Because of this discrepancy, those seeking repository licenses are currently faced with complying with disparate requirements simultaneously.

The linkage between the Regulation and the Standard it is intended to implement was termed the "technical nexus" by Curtiss. He emphasized the need for an unambiguous technical nexus because responsibility for implementing the HLRW program is divided between the EPA, which sets generally applicable standards, and the USNRC, which establishes the implementing regulations. As yet, CurTiss noted, the USNRC has been unable to identify a clear and unambiguous approach to implementing the Standard in licensing review. He believes that the lack of a nexus stems in part from the different approaches required by deterministic and probabilistic methods. The fact that the Regulation was promulgated while the EPA was still drafting the Standard is also a factor. (EPA's final rule states that the Regulation incorporates the limits that the EPA was promulgating in the Standard and that the Regulation was designed in concert with EPA's ongoing development of the Standard. In addition, the EPA stated in its promul gation of 40 CFR Part 191 that it expected the USNRC to revise 10 CFR Part 60 to bring it into full consistency with the Standard.)

A resolution of these disparate approaches could be effected by either or both agencies. Curtiss suggested that the USNRC could restructure the subsystem performance criteria of the Regulation, during resolution of the court remand, to establish such a nexus. But first the EPA must document the basis for the Standard, in accordance with the remand. The EPA could go further, in Curtiss's opinion, by reevaluating and revising the Standard to establish requirements that are realistic, technically justified, and defensible with respect to possible litigation. This task would best be accomplished now when the involved agencies can make technical adjustments reflecting clearer objectives and improved technical knowledge. If done later, the necessary modifications, relaxations, or stringencies may be interpreted incorrectly as excessive weakening or strengthening of public safety requirements. At the symposium both the EPA and the USNRC expressed a willingness to communicate about working toward the nexus, but the EPA did not want to waver from its reliance on the probabilistic Standard, and the USNRC is unlikely to abandon its deterministic subsystem requirements.

Negotiated rulemaking was mentioned by several speakers as a process that might work well to see the USNRC and the EPA through some evolutionary change, provided that all parties believed they could achieve an outcome better than the status quo. As a result of the exchange at the symposium, the feasibility of negotiated rulemaking was examined by RESOLVE, a dispute resolution program of the Conservation Foundation. RESOLVE conducted preliminary interviews with EPA, USNRC, DOE, the Edison Electric Institute, the Electric Power Research Institute, and the Natural Resources Defense Council. Although EPA was eager to enter into negotiated rulemaking, RESOLVE could not recommend that they take that action. Reasons that various of these entities rejected the idea of negotiated rulemaking include: too many issues under dispute were too technical to be negotiated; communication between EPA and USNRC is already excellent; such a procedure would merely delay repromulgation unnecessarily; and because the rulemaking has been underway for fifteen years, there is little fundamental dispute over what the major policy and technical issues are.

HIGH LEVEL RADIOACTIVE WASTE MANAGEMENT ABROAD

Representatives of Canadian, Swedish, and Swiss HLRW management programs described their countries' efforts at repository siting as less pressured for results than the U.S. program. Charles McCombie, of the Swiss radioactive waste disposal cooperative Nagra, said that Switzerland's first goal is technical consensus based on analytical assessment. The Swiss program differs from the U.S. program in that uncertainties do not have to disappear before a decision is made. European programs are more flexible than the U.S. program because repository schedules are tentative, not fixed by law, and the licensing is based on evaluation of safety assessments rather than on strict predetermined quantitative performance requirements. McCombie noted that there is less pressure to license a repository because European countries have accepted that storing the HLRW for 20 to 40 years before isolation in a permanent repository is essential; intermediate storage is planned either on site or in MRS-like facilities.

One participant pointed out that both European and Asian countries have made national decisions to rely on nuclear power, and the goal of the licensing processes is to support that decision in a way that is safe and environmentally sound. Every effort is made by the state and the licensing authority to rectify problems so that approval is obtained. The fundamental difference lies in the criteria for success: in the United States, an agency is successful regardless of whether a repository is licensed; abroad, an agency's success depends on the completion of licensing. Therefore, they avoid situations like that in the United States, where the two regulating agencies (EPA and USNRC) and the implementing agency (DOE) operate independently. The European representatives acknowledged that their countries will likely have the same problems as the United States in convincing the public to accept a repository, but public opposition is building more slowly.

Another major difference among the programs is that the United States is the only country using a population risk concept and radionuclide release limits instead of limits on individual doses or risks to members of the public.

NEED FOR AN OVERALL PUBLIC HEALTH AND SAFETY GOAL

Underlying the issues of a probabilistic standard vs. deterministic regulation and of stringency is the broader question of whether the involved federal regulatory agencies and the general public can be assured of adequate protection to health without a public health and safety goal that takes into account the pathways to man. (Such a goal is distinct from the intent, stated in the Supplementary Information that prefaces the Standard, of restricting the amount of risk to future generations to the risk that would be inherent in an equivalent amount of unmined ore.) Such a goal, for example, is set qualitatively for nuclear power plants by the USNRC and is supported by probabilistic quantitative objectives to assure achievement of the primary goal. The lack of a safety goal for repositories is reflected in the nuclear waste community's focus on release limits rather than safety estimates. According to McCombie, the United States lacks a common appreciation of the need for transparency of safety standards. He advocated emulation of the Canadian radioactive waste program, which facilitates public understanding, and advised colleagues in the United States to de-emphasize the licensing aspect of the repository and put the stress on safety.

At the symposium, many suggestions were made that a health and safety goal be applied to repository facility licensing in terms of standards, regulatory approaches, risk/benefit balances, and operational requirements. In the absence of a generally accepted public health and safety goal for the Standard governing geologic repositories, major concerns to be resolved include whether the regulatory agencies, in striving for health and environmental protection, can require the applicant to do less than the maximum that is technically feasible, and whether standards/regulations for disposal of HLRW should be promulgated to balance safety/risk and cost.

Appendix A

Rethinking High-Level Radioactive Waste Disposal

Rethinking High-Level Radioactive Waste Disposal
A Position Statement of the Board on Radioactive Waste Management

Commission on Geosciences, Environment, and Resources
National Research Council
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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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ABSTRACT

There is a worldwide scientific consensus that deep geological disposal, the approach being followed in the United States, is the best option for disposing of high-level radioactive waste (HLW). There is no scientific or technical reason to think that a satisfactory geological repository cannot be built. Nevertheless, the U.S. program, as conceived and implemented over the past decade, is unlikely to succeed.

For reasons rooted in the public's concern over safety and in the implementing and regulatory agencies' need for political credibility, the U.S. waste disposal program is characterized by a high degree of inflexibility with respect to both schedule and technical specifications. The current approach, in which every step is mandated in detail in advance, does have several advantages:

- it facilitates rigorous oversight and technical auditing;
- its goals and standards are clear;
- it is designed to create a sense of confidence in the planning and operation of the repository; and
- if carried out according to specifications, it is robust in the face of administrative or legal challenge.

This approach is 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.

The Board on Radioactive Waste Management is particularly concerned that geological models, and indeed scientific knowledge generally, have been inappropriately applied. Computer modeling techniques and geophysical analysis can and should have a key role in the assessment of long-term repository isolation. In the face of public concerns about safety, however, geophysical models are being asked to predict the detailed structure and behavior of sites over thousands of years. The Board believes that this is scientifically unsound and will lead to bad engineering practice.

The United States appears to be the only country to have taken the approach of writing detailed regulations before all of the dam are in. As a result, the U.S. program is bound by requirements that may be impossible to meet. The Board believes, however, that enough has been learned to formulate an approach that can succeed. This alternative approach emphasizes flexibility:

time to assess performance and a willingness to respond to problems as they are found, remediation if things do not turn out as planned, and revision of the design and regulations if they are found to impede progress toward the health goal already defined as safe disposal. To succeed, however, this alternative approach will require significant changes in laws and regulations, as well as in program management.

SUMMARY

Since 1955, the National Research Council (NRC) has been advising the U.S. government on technical matters related to the management of radioactive waste. Today, this advice is provided by the Board on Radioactive Waste Management (BRWM or "the Board"), a permanent committee of the NRC. The conclusions presented in this position statement are the result of several years of discussions within the Board, whose members possess decades of professional experience in relevant scientific and technical fields.

In July 1988, the Board convened a week-long study session in Santa Barbara, California, where experts from the United States and abroad joined BRWM in intensive discussions of current U.S. policies and programs for high-level radioactive waste (HLW) management. The group divided its deliberations into four categories: (1) the limitations of analysis; (2) moral and value issues; (3) modeling and its validity; and (4) strategic planning. A summary of the findings of these discussions, from which this position statement hasy been developed, follows the Summary.

Current U.S. Policy and Program

In the Nuclear Waste Policy Act of 1982 (NWPA), Congress assigned responsibility to the Department of Energy (DOE) for designing and eventually operating a deep geological repository for high-level radioactive waste. The repository must be licensed by the U.S. Nuclear Regulatory Commission (USNRC) and must meet radionuclide release limits, based on a generic repository, that would result in less than 1000 deaths in 10,000 years as specified in a Standard established by the Environmental Protection Agency (EPA) (40 CFR 191).

The U.S. program is unique among those of all nations in its rigid schedule, in its insistence on defining in advance the technical requirements for every part of the multibarrier system, and in its major emphasis on the geological component of the barrier as detailed in 10 CFR 60. Because one is predicting the fate of the HLW into the distant future, the undertaking is necessarily full of uncertainties. In this sense the government's HLW program and its regulation may be a "scientific trap" for DOE and the U.S. public alike, encouraging the public to expect absolute certainty about the safety of the repository for 10,000 years and encouraging DOE program managers to pretend that they can provide it.

For historical and institutional reasons, DOE managers tend to feel compelled to do things perfectly the first time, rather than to make changes in concept and design as unexpected geological features are encountered and as scientific understanding develops. This "perfect knowledge" approach is unrealistic, given the inherent uncertainties of this unprecedented undertaking, and it runs the risk of encountering "show-stopping" problems and delays that could lead to a further deterioration of public and scientific trust. Today, because of the regulatory requirements and the way the program is being carried out, U.S. policy has not led to satisfactory progress on the problem of radioactive waste disposal.

Scientific Consensus on Geological Isolation

There is a strong worldwide consensus that the best, safest long-term option for dealing with HLW is geological isolation. High-level waste should be put into specially designed and engineered facilities underground, where the local geology and groundwater conditions have been chosen to ensure isolation of the waste for tens of thousands of years or longer, and where waste materials will migrate very slowly if they come into contact with the rock.

Although the scientific community has high confidence that the general strategy of geological isolation is the best one to pursue, the challenges are formidable. In essence, geological isolation amounts to building a mine in which "ore" will be put back into the ground rather than taken out. Mining, however, has been and remains fundamentally an exploratory activity: because our ability to predict rock conditions in advance is limited, miners often encounter surprises. Over the years, mining engineers have developed methods to deal with the vagaries of geological environments, so that mineral extraction and construction can continue safely even when the conditions encountered are different from those anticipated.

It is at this point that geological isolation of radioactive waste differs in an important sense from mining. In the United States, radioactive waste management is a tightly regulated activity, surrounded by laws and regulations, criteria and standards. Some of these rules call for detailed predictions of the behavior of the rock for the tens of thousands of years that the radioactive materials are to be isolated.

Preparing quantitative predictions so far into the future stretches the limits of our understanding of geology, groundwater chemistry and movement, and their interactions with the emplaced material (radioactive waste package, backfill, sealants, and so forth). Although the basic scientific principles are well known, quantitative estimates (no matter how they are obtained) must rely on many assumptions. As a consequence, the resulting estimates are uncertain to some degree, and they will remain uncertain no matter how much additional information is gathered.

Treatment of Uncertainty

The character and implications of these uncertainties must be clearly understood by political leaders, program managers, and the concerned public. Engineers and scientists, no matter how experienced or well trained, are unable to anticipate all of the potential problems that might arise in trying to site, build, and operate a repository. Nor can science "prove" (in any absolute sense) that a repository will be "safe" as defined by EPA standards and USNRC regulations. This is so for two reasons.

First, proof in the conventional sense cannot be available until we have experience with the behavior of an engineered repository system—precisely what we are trying to predict. The existence of uncertainties has prompted efforts to improve the technical analysis, but there will always remain some residual uncertainty. It is important to recognize, however, that uncertainty does not necessarily mean that the risks are significant. What it does mean is that a range of results are possible, and a successful management plan must accommodate residual uncertainties and still provide reasonable assurance of safety.

Second, safety is in part a social judgment, not just a technical one. How safe is safe enough? Is it safer to leave the waste where it is, mostly at reactor sites, or to put it in an underground repository? In either case safety cannot be 100 percent guaranteed. Technical analyses can provide background for answering such questions, but ultimately the answers depend on choices made by the citizens of a democratic society. The EPA has not based its standards (which must allow for these choices by the citizenry) on social judgments derived from realistic consideration of these alternatives. Both of these important limitations of the analysis have been understated.

The federal government must provide full public accountability as information about the risks changes with experience. This is not an impossible task: government and business make decisions every day under similar conditions of uncertainty. But a policy that promises to anticipate every conceivable problem, or assumes that science will shortly provide all the answers, is bound to fail.

The public has been told too often that absolute guarantees can be provided, but most citizens watching the human frailties of their governments and technologists know better. A realistic—and attainable—goal is to assure the public that the likelihood of serious unforeseen events (serious enough to cause catastrophic failure in the long term) is minimal, and that the consequences of such events will be limited. These assurances rest on the credible application of general principles, rather than a reliance on detailed predictions.

Modeling of Geological Processes

The current U.S. approach to developing a geological repository (with a mandated 10,000-year lifetime) for radioactive waste is based on a regulatory philosophy that was developed from the licensing of nuclear power plants (which have a nominal 40-year lifetime). The geological medium, however, cannot be specified in advance to the degree possible for manmade components, such as valves or electronic instruments, nor can it be tested over its projected lifetime as can many man-made components. Commercial mining and underground construction both operate on the sound principle of "design (and improve the design) as you go." The inherent variability of the geological environment necessitates changes in specifications as experience increases. If that reality is not acknowledged, there will be unforeseen delays, rising costs, frustration among field personnel, and loss of public confidence in the site and in the program.

Models of the repository system are useful, indeed indispensable. The computerized mathematical models that describe the geological structure and hydrological behavior of the rock are needed to manage the complex calculations that are necessary to evaluate a proposed site. Models are vital for two purposes: (1) to understand the history and present characteristics of the site; and (2) to predict its possible future behavior. Putting the available data into a coherent conceptual framework should focus attention on the kinds of uncertainty that persist. For example, the modeling of groundwater flow through fractured rock lies at the heart of understanding whether and how a repository in hard rock will perform its essential task of isolating radioactive materials. The studies done over the past two decades have led to the realization that the phenomena are more complicated than had been thought. Rather than decreasing our uncertainty, this line of research has increased the number of ways in which we know that we are uncertain. This does not mean that science has failed: we have learned a great deal about these phenomena. But it is a commonplace of human experience that increased knowledge can lead to greater humility about one's ability to fully understand the phenomena involved.

Uncertainty is treated inappropriately in the simulation models used to describe the characteristics of the waste repository. As the quantity of information about natural geological settings grows, so too does our appreciation of their variability and unpredictability. This distinction has often been ignored. Indeed, the very existence of large databases and sophisticated computer models suggests, erroneously, that it is appropriate to design a geological repository as if it were a nuclear power plant or jet airliner, both of which have predictable attributes over their short lifetimes. That assumption of accurate predictability will continue to produce frustration and failure. Under the present program models are being asked to provide answers to questions that they were not designed to address. One scientifically sound objective of geological modeling is to learn, over time, how to achieve reasonable assurance about the long-term isolation of radioactive waste. That objective is profoundly different from predicting quantitatively the long-term behavior of a repository. Yet, in the face of public concerns about the safety of HLW disposal, it is the latter use to which models have been put.

The Board believes that this use of geological information and analytical tools—to pretend to be able to make very accurate predictions of long-term site behavior—is scientifically unsound. Its conclusion is based on detailed reviews of the methods used by the DOE and the regulatory agencies in implementing the NWPA.

Well-known geophysical principles can be used to estimate or to set bounds on the behavior of a site, so that its likely suitability as a waste repository can be evaluated. But it is inappropriate to stretch the still-incomplete understanding of a site into a quantitative projection of whether a repository will be safe if constructed and operated there. Only after a detailed and costly examination of the site itself can an informed judgment be reached, and even then there will still be uncertainties.

Many of the uncertainties associated with a candidate repository site will be technically interesting but irrelevant to overall repository performance. Further, the issues that are analytically tractable are not necessarily the most important. The key task for performance modeling is to separate the significant uncertainties and risks from the trivial. Similarly, when there are technical disputes over characteristics and processes that affect calculations of waste transport, sensitivity analysis with alternative models and parameters can indicate where further analysis and data are required and where enough is known to move on to other concerns.

It may even turn out to be appropriate to delay permanent closure of a waste repository until adequate assurances concerning its long-term behavior can be obtained through continued in-site geological studies. 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.

As a rule, the values determined from models should only be used for comparative purposes. Confidence in the disposal techniques must come from a combination of remoteness, engineering design, mathematical modeling, performance assessment, natural analogues (see below), and the possibility of remedial action in the event of unforeseen events. There may be political pressure on implementing agencies to provide absolute guarantees, but a more realistic—and attainable—goal is to assure the public that the likelihood of unforeseen events is minimal, and that the magnitude of the consequences of such events is limited. Such an alternative approach, now being used in Canada and Sweden, promises to be far more successful in achieving a safe and practical waste disposal system.

Moral and Ethical Questions

Radioactive waste poses hazards that raise moral and ethical concerns. First, some of the radioactivity lasts for extremely long periods of time—the EPA standard for HLW calls for isolation of the waste for 10,000 years and more, a time longer than recorded human history. Second, the risks of high-level waste will be concentrated at a very few geological repositories. The neighbors of proposed waste repositories have understandably been alarmed at the prospect of hosting large quantities of a material that needs to be handled with great care. Ethical studies in this area underscore two points: (1) the central role of a fair process; and (2) the pervasive problem of promising more certainty than can be delivered.

The need for a fair process is simply stated: people feel threatened by radioactive waste; and they deserve to be taken seriously in the decision-making process. The sense of threat is often ill informed, in a narrow technical sense; but when that occurs, it is the duty of technical experts and program managers to provide information and employ analyses that will be credible to the affected populations. Only with valid information that they believe can those affected parties negotiate equitable solutions. The primary goal of the program is to provide safe disposal; a secondary goal is to provide it without any gross unfairness. As a result, the mechanisms of negotiation, persuasion, and compensation are fundamental parts of any program to manage and dispose of radioactive waste—not mere procedural hoops through which program managers must jump.

The second ethical point is also important: the demand for accountability in our political system has fostered a tendency to promise a degree of certainty that cannot be realized. Pursuing that illusory certainty drives up costs without delivering the results promised or comparable benefits. The consequence is frustration and mistrust. For example, it is politically costly to admit that one has been surprised in exploring sites being considered for HLW repositories. Yet, this situation is self-defeating: surprises are bound to occur because a principal reason for exploration is to discover what is there.

Instead of pursuing an ever-receding mirage, it is sensible to pursue an empirical exploratory approach: one that emphasizes fairness in the process while seeking outcomes that the affected populations judge to be equitable in light of their own values. This is not an easy course, but it is necessary.

An Alternative Approach

There are scientific reasons to think that a satisfactory HLW repository can be built and licensed. But for the reasons described earlier, the current U.S. program seems unlikely to achieve that desirable goal. The Board proposes an alternative approach that is built on well-defined goals and objectives, utilizes established scientific principles, and can be achieved in stages with appropriate review by regulatory and oversight bodies and with demonstrated management capabilities. The Board suggests an institutional approach that is more flexible and experimental—in other words, a strategy that acknowledges the following premises:

- Surprises are inevitable in the course of investigating any proposed site, and things are bound to go wrong on a minor scale in the development of a repository.
- If the repository design can be changed in response to new information, minor problems can be fixed without affecting safety, and major problems, if any appear, can be remedied before damage is done to the environment or to public health.

This flexible approach can be summarized in three principles:

- Start with the simplest description of what is known, so that the largest and most significant uncertainties can be identified early in the program and given priority attention.
- Meet problems as they emerge, instead of trying to anticipate in advance all the complexities of a natural geological environment.
- Define the goal broadly in ultimate performance terms, rather than immediate requirements, so that increased knowledge can be incorporated in the design at a specific site.

In short, this approach uses a scientific approach and employs modeling tools to identify areas where more information is needed, rather than to justify decisions that have already been made on the basis of limited knowledge.

The principal virtue of this strategy is that it would use science in the proper fashion. It would be similar to the strategies now being followed in Canada and Sweden, where the exploration and construction of an underground test laboratory and a shallow underground low-level waste repository have followed a flexible path. At each step, information and understanding developed during the prior stages are combined with experience from other underground construction projects, in order to modify designs and procedures in light of the growing stock of knowledge. During operations and after closure of the facilities, the emphasis will be on monitoring and assuring the capability to remedy unforeseen problems. In that way, the possibility is minimized that unplanned or unexpected events will compromise the integrity of the facility.

This flexible approach has more in common with research and underground exploration than with conventional engineering practice. The idea is to draw on natural analogues, integrate new data into the expert judgments of geologists and engineers, and take advantage of favorable surprises or compensate for unfavorable ones.

Natural analogues—geological settings in which naturally occurring radioactive materials have been subjected to environmental forces for millions of years—demonstrate the action of transport processes like those that will affect the release of man-made radionuclides from a repository in a similar setting. Where there is scientific agreement that the analogy applies, this approach provides a check on performance assessment methodology and may be more meaningful than sophisticated numerical predictions to the lay public.

A second element is to use professional judgment of technical experts as an input to modeling in areas where there is uncertainty as to parameters, structures, or even future events. Such judgments, which may differ from those of DOE program managers, should be incorporated early in the process; a model created in this way might redirect the DOE program substantially.

The large number of underground construction projects that have been completed successfully around the world are evidence that this approach works well. Implicit in this approach, however, is the need to revise the program schedule, the repository design, and the performance criteria as more information is obtained. Putting such an approach into effect would require major changes in the way Congress, the regulatory agencies, and DOE conduct their business.

The Risk of Failing to Act

Given the history of radioactive waste management in the United States, a likely alternative is that the program will continue as at present. That would leave the nation's inventory of high-level waste, indefinitely, where it is now: mostly at reactor sites at or near the earth's surface. By the year 2000, spent fuel is expected to contain more than 3 × 1010 curies, while High Level Waste is expected to contain another 109 curies.* This alternative is safe in the short term—on-site storage systems are safe for at least 100

* Integrated Database for 1988: Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics: DOE/RW-0006 Revision 4, Sept. 1988.

years, according to present evidence.* The at-surface alternative may be irresponsible for the long run, however, due to the uncertainties associated with maintaining safe institutional control over HLW at or near the surface for centuries.

In judging disposal options, therefore, it is essential to bear in mind that the comparison is not so much between ideal systems and imperfect reality as it is between a geologic repository and at-surface storage. From that standpoint, both technical experts and the general public would be reassured by a conservative engineering approach toward long-term safety, combined with an institutional structure designed to permit flexibility and remediation.

* Waste Confidence Decision Review. 54 FR 39767 (Sept. 28, 1989)

INTRODUCTION

The Origins and Purpose of This Document

Since 1955, the National Research Council (NRC) has been advising the U.S. government on technical matters related to the management of radioactive waste. Today, such review and advice is rendered by the Board on Radioactive Waste Management (BRWM or "the Board"), a permanent committee of the National Research Council. Over the past quarter century, the BRWM and its predecessors have acted as observer, critic, and adviser to the federal agencies responsible for the management of radioactive waste. In 1955, the National Research Council's Committee on Earth Sciences, the forerunner of the BRWM, first examined the problem of high-level radioactive waste (HLW) and recommended the strategy of isolation in stable geological formations. That basic approach is the one still being pursued in the United States and throughout the world. In 1983, the Board published the report of its Waste Isolation Systems Panel, a technical document that supported the use of "performance assessment." This method, first employed by the Karnbranslesakerhet (KBS) in Sweden for judging the performance of high-level waste and its packaging in geological formations, makes it possible to evaluate the ability of a repository to contain waste for the very long term. Performance assessment has become the keystone of the policies and regulations guiding the planning of HLW disposal in the United States as well as other nations.

Thus far, however, the technical programs carried out by government and industry in the United States have not led to a socially satisfactory resolution of the problem of HLW management and disposal. There are two reasons for this failure.

The first is the controversy over nuclear energy and radioactive waste disposal as part of nuclear energy development. The Board takes no position on the use of nuclear energy. However, it notes that even if nuclear power in this country were discontinued tomorrow—a highly unlikely event—we would still need to dispose of nuclear waste from existing power plants and defense programs, and we would therefore still require a viable HLW disposal program.

The second reason that radioactive waste management remains in trouble is the way in which the programs have been designed and carried out. That problem is the subject of this report: the Board believes that important scientific and technical issues concerning HLW have been widely misunderstood; the result is a set of programs that will not achieve their stated goals. Neither the technical nor the social problems of the waste materials already in existence are being handled effectively. The Board believes that the safe and effective isolation of radioactive waste is feasible. Improvements to what is now being done are described below.

These conclusions are the result of several years of discussions within the Board and are based on the decades of scientific and professional experience represented among the members of the BRWM. In July 1988 the Board convened a week-long study session in Santa Barbara, California, where the Board was joined by experts from the United States and abroad. The group divided its deliberations into four categories: (1) the limitations of analysis; (2) moral and value issues; (3) modeling and its validity; and (4) strategic planning. These categories also determine the structure of this position statement, although in the analysis here, as in the real world, there is no easy separation among them.

Although this position statement is critical of present policies, it must be emphasized that the changes that need to be made are not restricted to the U.S. government. The nature of the risks and the government's responsibility to address them need to be presented and understood in terms different from those reflected in today's public policy. Doing so will not lead to less safety but to more. Yet achieving that result will require courage on the part of leaders in government and industry, as well as a willingness to rethink risks among the public at large and in the interest groups concerned with public policies for the management of risk.

These questions touch on far more than radioactive waste, and the rethinking they imply will be difficult to launch and to sustain. The Board believes, however, that this rethinking is essential and that radioactive waste management is a reasonable place to begin. This position statement is a step in that direction.

High-Level Waste in Context

At present, approximately 17 percent of the world's electricity is derived from about 400 nuclear power plants, although the percentage is as high as 70 percent in France and 50 percent in Sweden. The challenge of HLW disposal is dominated by the spent fuel from these nuclear power plants. Each 1,000-megawatt (MWE) nuclear power plant produces each year about 30 tons of spent fuel, which if reprocessed and vitrified could be reduced to between 4 and 11 cubic meters (m^3) of highly radioactive glass. Some countries, including the United States, have chosen to dispose of commercial spent fuel directly. Each power plant also produces some 400 m^3 of short-lived, low-level waste (LLW) each year. Fuel production would leave another 86,000 tons of mill tailings on the earth's surface for each reactor, per year.

Radioactive Waste Management Policy

Because HLW must be isolated from the living environment for 10,000 years or more, all nations faced with the task of radioactive waste disposal have chosen underground repositories as the basic technical approach. In the United States, the Department of Energy (DOE) has been given the task of designing and eventually operating such a repository. Before operations begin, however, DOE must demonstrate to the U.S. Nuclear Regulatory Commission (USNRC) that the repository will perform to standards established by the U.S. Environmental Protection Agency (EPA) that limit the release of radionuclides to specific levels for 10,000 years after disposal. Before the USNRC will grant a license to operate a repository, DOE must present convincing data and analysis to the USNRC showing that the proposed facility can meet specified release limits.

To develop such an assessment, it is necessary to examine all credible possibilities for the movement of radionuclides from the repository and into the accessible environment. In conducting these analyses, DOE has relied heavily on building computer models of the repository and surrounding geological environment, along with possible pathways of radionuclide transport. However, preparing quantitative predictions so far into the future pushes the boundaries of our understanding of geology, groundwater chemistry and movement, and their interactions with the emplaced material (radioactive waste package, backfill, sealants, and so on). Although the basic scientific principles are well known, quantitative estimates (no matter how they are obtained) must rely on many assumptions. The resulting estimates cover a range of outcomes.

While continued scientific investigations should reduce the uncertainty, absolute certainty cannot be achieved. Indeed, a major theme of this position statement is the need for public policy to benefit from, and change in response to, accumulating experience.

FINDINGS

The Limitations of Analysis

Overview

Engineers are unable to anticipate all of the potential problems that might arise in trying to site, build, and operate a repository. Nor can science prove that a repository will be absolutely "safe." This is so for two reasons. First, proof in the conventional sense cannot be available until we have experience with the behavior of an engineered repository system—precisely what we are trying to predict ahead of time. And second, safety is in part a social judgment, not just a technical one. While technical analyses can greatly illuminate the judgment of whether a repository is safe, technical analysis alone cannot substitute for decisions about the degree of risk that is acceptable. These decisions belong to the citizenry of a democratic society. Both of these important limitations of technical analysis have been understated, a lapse that feeds the concern and magnifies the public's distrust of nuclear waste management when these limitations are pointed out by the program's critics.

Uncertainty and Significant Risks

A principal source of concern over the U.S. program is the uncertainty in estimating the risks from a radioactive waste repository. Technical approaches are available to reduce or at least bound these uncertainties. Yet in focusing on ways to improve the analysis, public discussion has often overlooked a more important question: whether the uncertainty matters. This is, in principle, the domain of performance assessment, which draws together the different portions of the technical analysis so that one can see which parts of the waste confinement system may pose environmental hazards during or after the time when the repository receives waste.

Performance assessment of a repository system is necessarily a task for computer modeling. The waste management system, which starts at the reactor and continues into the distant future of a sealed repository, includes many different parts and processes that are described through different kinds of data (with different levels of quality), and different kinds of analysis (with different levels of accuracy). It is a practical consequence of the complexity of high-level radioactive waste (HLW) disposal, together with the fact that no one has ever operated a repository, that performance assessment is, in the end, a matter of technical judgment.

The traditional approach in such cases, where an important social decision hinges on uncertain scientific data and projections, is to inform the political decision through a consensus of the appropriate technical community. Such consensus is difficult to reach in this case, however, given the political controversy, conflicting value systems, and overlapping technical specialties involved in assessing repository performance. Indeed, the allowable residual risk associated with a permissible repository site is a political choice; EPA has taken the position that the implementation of their guidelines constitutes the exercise of this choice. Unfortunately, the number and magnitude of the uncertainties in the probabilistic approach may be expected to reintroduce political controversy. This was recognized by the High-Level Radioactive Waste Disposal Subcommittee of EPA's Science Advisory Board in their January 1984 report reviewing EPA Draft Standard 40 CFR 191. That subcommittee concluded there was

> insufficient basis for agreeing with the EPA staff that the proposed release criterion with its probabilistic corollary can be demonstrated to have been met with reasonable assurance, and that this could be argued definitively in a legal setting.

The subcommittee strongly affirmed the validity of EPA's probabilistic approach, but warned that

> if EPA cannot have high confidence in the adequacy and workability of a quantitative, probabilistic standard, [it should] use qualitative criteria, such as recommended by [the US]NRC.

Specifically, with regard to the first major topic of the Science Advisory Board's findings and recommendations, "Uncertainty and the Standard," the subcommittee recommended relaxing the nuclide release limits by a factor of 10, modifying the probabilistic release criteria so that

> analysis of repository performance shall demonstrate that there is less than a 50% chance of exceeding the Table 2 release limits, modified as is appropriate. Events whose median frequency is less than one in one-thousand in 10,000 years need not be considered,

and, finally

> that use of a quantitative probabilistic condition on the modified Table 2 release limits be made dependent on EPA's ability to provide convincing evidence that such a condition is practical to meet and will not lead to serious impediments, legal or otherwise, to the licensing of high-level-waste geologic repositories. If such evidence cannot be provided, we recommend that EPA adopt qualitative criteria, such as those suggested by the [US]NRC.[1]

Unfortunately none of these recommendations was adopted.

The USNRC staff, in commenting on the EPA Draft Standard, strongly questioned the workability of quantitative probabilistic requirements for the defined releases stating, in part

> numerical estimates of the probabilities or frequencies of some future events may not be meaningful. The [US]NRC considers that identification and evaluation of such events and processes will require considerable judgment and therefore will not be amenable to quantification by statistical analyses without the inclusion of very broad ranges of uncertainty. These uncertainty ranges will make it difficult, if not impossible, to combine the probabilities of such events with enough precision to make a meaningful contribution to a licensing proceeding.[2]

The problem is compounded when the adequacy of the performance assessment—to determine if the allowable residual risk is achieved—is judged by its political impact (i.e., the effect of reopening the discussion of what is allowable residual risk) as well as its technical accuracy.

The difficulty of evaluating performance assessments is compounded by the fact that there is no actual experience in the disposal of HLW on which to base estimates of the risk. Some risk scenarios include low-probability/high-consequence events. Others are based on explicit or implicit assumptions that cannot be plausibly proved or disproved—for example, the consequences of climatic changes that could increase rainfall and groundwater flows at a repository site. The data and methodologies for modeling of repository isolation performance are still under development.

The actual performance of a repository is difficult to predict for many reasons. Geologists often disagree about the interpretation of data in analyzing the history of a site or geological structure. Long-term predictions are even more uncertain. Releases may occur thousands of years in the future, and they are likely to be diffuse and hard to detect. The potential for (and effects of) human exposure will be further shaped by unpredictable changes in demographics and technology.

These uncertainties do not necessarily mean that the risks are significant, nor that the public should reject efforts to site the repository. Rather, they simply mean that there are certain irreducible uncertainties about future risk. An essential part of any successful management plan is how to operate with large residual uncertainties, and how to maintain full public accountability as information about the risks changes with experience. This is not an impossible task: public policy is made every day under these conditions, and private firms undertake all sorts of activities in the face of uncertainty.

What is clear, however, is that a management plan that promises that every problem has been anticipated, or assumes that science will provide all the answers, is almost certainly doomed to fail. There have been many cases where attempts to understate uncertainty have damaged an agency's credibility and subverted its mission. For this reason, experienced regulatory agencies like EPA now pay careful attention to describing the uncertainties associated with their risk assessments.

Perceptions of Risk

Studies have linked the high public perceptions of the risk from nuclear power plants to certain qualities of that risk, in particular to perceptions that the risks are catastrophic, new, uncertain, and involuntary (i.e., beyond individual control). Radioactive waste poses risks with many of the same technical characteristics: the principal health risks (chiefly cancer and genetic defects) originate in the hazards of ionizing radiation. The risks from radioactive waste also have some of the same social characteristics as risks from nuclear reactors: a long time may pass before the hazards become apparent, dangers may be imposed involuntarily on populations, and there is a perceived possibility of catastrophe. The last perception, in particular, is qualitatively incorrect for HLW, since radioactive waste materials have far lower energy levels in comparison to those of reactors, thereby limiting the risk associated with HLW to much lower levels in virtually all accident scenarios.

Given the complexity of the potential risks from HLW, most people will transfer the judgment of the safety of geologic disposal to the experts. The key question is which experts they will listen to. The answer depends on who seems more trustworthy: citizens may have little experience with radioactive waste, but they have considerable experience in evaluating people.

The perception of integrity and competence in risk managers depends not only on their personal attributes but also on the character of the policies they implement and the institutions they represent. The current decision process is structured in a way that does not promote trust in those who are implementing the waste management program. The current situation in Nevada, for example, demonstrates the importance of local input in the acceptance of risk. The political leadership of Nevada is fighting the proposed repository and portraying their State as a victim, reinforcing the perception on the part of the broader public that the program is beyond local control.

The Department of Energy (DOE) should recognize that communications about the program will be ineffective so long as Nevadans believe they have no voice in the process. To the extent that DOE can share power, however, the increased perception of local control is likely to improve acceptance of a repository. The funding of a technical review group whose members are selected by the State government would be one positive step in this direction. In order to encourage rigorous technical analysis, it should be required that the findings of this review group include a statement of the technical evidence and reasoning behind the conclusions, as is done now by the State of New Mexico's Environmental Evaluation Group for the Waste Isolation Pilot Plant.

Given the highly polarized reactions to radioactive waste disposal, it is reasonable to anticipate criticisms and challenges to the technical competence and integrity of the program and its participants. Critics of the program point to the perceived incentives to find the proposed site and technology suitable, the motivation to meet schedules and budgets, and the resulting incentive to disregard or play down troubling findings. Claims to predict accurately events like earthquakes and climatic change are guaranteed to be challenged. These concerns have been addressed through a regulatory review process that is carefully designed to reveal errors, optimistic assumptions, and omissions; but the perceived credibility of that process can be bolstered if state and local groups and individuals have an opportunity to participate, not only in the formal review process but also through informal working relationships with project staff.

Those involved in HLW management must also avoid the trap of promising to reduce uncertainties to levels that are unattainable. Uncertainties are certain to persist. Whether the uncertainties in geologic disposal are too great to allow proceeding can only be judged in comparison to the projected risks and uncertainties for the alternatives, such as delayed implementation of disposal or surface storage of spent fuel. As a rule, the values determined from models should only be used for comparative purposes. Confidence in the disposal techniques must come from a combination of remoteness, engineering design, mathematical modeling, performance assessment, natural analogues, and the possibility of remedial action in the event of unforeseen events. There may be public desire or political pressure on implementing agencies to provide absolute guarantees, but a more realistic —and attainable—goal is to assure that the likelihood of unforeseen events is minimal, and that the consequences of such events are of limited magnitude.

Technical program managers may ask whether it is better for the public to know too much or not enough. When unforeseen events occur, for example, the public can raise questions about the validity of the technical approach, as well as the competence of the risk analysis that was used to justify it. Conversely, when foreseen events occur, they lead to questions about why they were not prevented. The technical credibility of the project team suffers in either case, but it probably suffers more when the organization has understated the risk or uncertainty.

Moral and Value Issues

Overview

The foregoing discussion suggests that, in the area of radioactive waste, ethical issues are as important as management and technical decisions. Interested parties approach the issues with different views about the right way to proceed, often due to differences in moral and value perspectives. As a result, an exploration of ethical issues can illuminate the fundamental policy debates in this field by showing the technical issues in their political and social context. Such an exploration also provides scientists with an opportunity to explore their own ethical responsibilities as they provide society with technical advice on controversial subjects. During its 1988 study session, the Board examined recent work on ethical questions in radioactive waste management conducted by scholars from a variety of disciplines.

These ethical concerns fall into two principal areas: (1) questions concerning the professional responsibility of scientists and engineers; and (2) questions concerning the appropriate uses of science in the decision-making process. Science and engineering are part of broader human activities, and as science enters the public arena, decisions can no longer be purely scientific; good science is not enough. Science has also become an important source of information and analysis for the public policy process, and scientists find themselves being called to account for, and to justify the results of, those decisions. Is this responsible, good, or desirable? How can the process be improved and the parties satisfied? Scientists have been sheltered from such questions in the past, but the increasing scale, sophistication, and pervasiveness of technical information require a corresponding increase in the sophistication with which these value judgments are made.

Three Issues of Equity

To see how questions of equity apply to radioactive waste management, consider first a study by Roger E. Kasperson and Samuel Ratick.[3] This project identified three sets of equity concerns, each of which raises questions of differential impact, public values, and moral accountability:

- ***Labor*.** Who does the work and who pays for it? Congress has determined that DOE will be responsible for the work and that the beneficiaries of nuclear power will pay for it through a surcharge on their electric rates.
- ***Legacy*.** What do we owe to future generations? Moral intuition tells us that our descendants deserve a world that we have tried to make better.[4] Posterity matters to us, independent of economic trade-offs; policy should therefore take that interest into account. The EPA regulation requiring evidence that radioactive waste releases will be limited for 10,000 years and more is an illustration of such a concern for the distant future.
- ***Locus*.** Who benefits, and who is exposed to risk? A repository is the final resting place for the waste from nuclear power plants that provide benefits spread over the whole nation for a short time; but it also concentrates risks and burdens along transportation routes and, for a much longer time, at the disposal site. A radioactive waste repository poses additional complications: it will be the first facility of its kind; the risks it poses are uncertain and, to the extent they exist at all, are likely to emerge over very long time spans; public fears are unusually high; and the history of federal action has raised

concerns about whether the interests of local populations will be treated equitably.

These ethical questions, when applied to radioactive waste management, demonstrate that once science enters the policymaking arena, good science is no longer enough, because technical decisions are no longer simply scientific. When the questions are no longer scientific, scientists alone cannot be expected to answer them. Sheldon Reaven suggests that the Nuclear Waste Policy Act (NWPA) creates a "scientific trap," in which citizens are encouraged to expect certainty from flawless science, and in which scientists and engineers are encouraged to believe or pretend that they can supply it.[5]

Sheila Jasanoff makes the same point: the political need for accountability in the United States pressures regulators to seek a "scientifically correct" answer, even when there is none.[6] The attempt is doomed to scientific and political failure. It is therefore critical to recognize the boundaries of scientific understanding as it can be applied to a societal problem.

Five Issues of Policy

These ethical considerations have been applied to the current HLW situation by an interdisciplinary team led by E. William Colglazier.[7] For each of five key policy issues, the study discusses the "fairness" and appropriateness of the procedures for making decisions, the distribution of costs and benefits, and the type of evidence that is considered sufficient and admissible. The study places special emphasis on the role of scientific evidence because of the large scientific uncertainties and the continuing controversy, even among experts, on what is known and not known. The study's observations include the following:

- ***The need for the repository.*** The core policy dispute concerns the choice between permanent disposal in a geologic repository and long-term monitored storage in an engineered facility (including at-reactor storage) at or near the surface. The controversy has been over the distribution of costs and benefits to current and future generations and to various stakeholder groups:

—Pro-nuclear groups feel that the federal government promoted nuclear power and therefore has a special responsibility (spelled out in contractual obligations) to accept spent fuel in a timely manner for permanent disposal.

—Many environmental groups, on the other hand, view radioactive waste as a special threat to people and the environment; they also favor permanent disposal in order to fulfill this generation's responsibility, and view interim storage as an unfair "legacy" to future generations.

—Some proponents of interim storage, however, argue that this generation should not make decisions that would be costly to correct in the future; new technological developments may occur over the next century that could change our view of how to handle nuclear waste.

In short, all stakeholder groups agree that this generation should fulfill its responsibility to future generations, but they disagree on how to turn this value principle into policy.

- ***Siting*.** In making politically difficult siting decisions, political leaders have two basic options: make the choice internally and impose it on a weak constituency; or set up and follow a selection process perceived as objective, scientifically credible, and procedurally fair. When NWPA was passed in 1982, the latter course appeared necessary for both technical and political reasons. However, critics soon claimed that DOE was being political rather than objective in its decisions, citing as evidence DOE's choice of first-round sites and its decision to defer the second round of site selection. This perception led to a stalemate: DOE lacked credibility, and credibility is essential to implement the siting approach set forth in the NWPA. This stalemate was broken by Congress with the 1987 NWPA amendments, which designated Yucca Mountain, Nevada (one of DOE's first-round choices), as the initial site to be characterized and, if acceptable, to be licensed.
- ***Intergovernmental sharing of power*.** Procedural values were also important in NWPA, which established rules for sharing power among the affected governmental entities. However, the states feel that federal agencies, and especially DOE, have generally chosen to try to meet milestones rather than slow down the process to live up to the spirit of "consultation and cooperation." DOE, for its part, feels that it has a mandate to move forward expeditiously; it has tried to accommodate the states, which (in DOE's view) seek delays to throw obstacles in the way of efficient implementation. Nevada, in particular, interprets the 1987 NWPA amendments as unfair on procedural (as well as distributional and evidential) grounds.
- ***Safety*.** The fundamental safety issue is the determination of a fair evidential process and standard of proof for showing that the repository is acceptably safe for the thousands of years over which the waste will remain dangerously radioactive. The United States has adopted a set of licensing criteria (e.g., groundwater flow time, package lifetime, waste release limits, and so on) that require considerable certainty. As is often the case with frontier science, however, knowing more may actually increase rather than decrease the uncertainties, at least in the near term. The evidential uncertainties in assessing repository safety may point to a more flexible and evolutionary approach (see below); but this conflicts with the concerns to keep to a fixed schedule, so as to limit costs, discharge obligations to future generations, and meet contractual commitments to utilities holding spent fuel.
- ***Impacts*.** The debate over the distributional impacts of the repository program include such issues as who should pay for the program, how the impacts can be fairly calculated, and what is fair compensation for negative

impacts. NWPA determined that the costs should be paid by the beneficiaries of nuclear-generated electricity through fees, initially, of one mill per kilowatt-hour. An evidential dispute concerns the potential "stigma effect," including lost jobs and lost tax revenues, due to nuclear waste; the social science methodologies for assessing this effect are still controversial. Another issue concerns the use of incentives and compensation: in the 1987 NWPA amendments, Congress authorized special payments for the host state, provided it forgoes its right to object. This runs the risk of being perceived by opponents as a bribe, offered in exchange for taking otherwise unacceptable risks. Congress also sought a procedural solution to these distributional impacts through creation of the Office of Special Negotiator, hoping that the negotiator might find an acceptable arrangement with the host state.

Consideration of these policy debates regarding the disposal of radioactive waste leads to three important conclusions:

- no interested party has an exclusive claim to be rational or to articulate the public interest;
- what is considered fair or unfair is subjective and can change over time;
- and with regard to repository safety, the issue is acceptability rather than certainty—acceptability being what is acceptable to society, given the evidential uncertainties, perceptions of risk, and contentious stakeholder debates.

These conclusions highlight the advantage of an empirical approach—one that examines fairness in process, outcomes, and evidence; one that reflects an understanding of the values as well as the interests of the stakeholders. Such an approach may lead to policies that have a greater chance of surviving over time because they are more widely perceived as fair.

Modeling and Its Validity

Overview

Models based on geological principles play a central role in the design and licensing of a waste repository. Because this is where science enters into the design and evaluation process, the Board discusses the appropriate use of models at some length, including the following topics: the purposes for which models are used; the relationship among modeling, treatment of uncertainties, and regulation; and supplements to the use of models in the current program.

The role of models in the design and licensing of the repository should properly be understood to be different from the use of models in designing airplanes or licensing nuclear reactors. There are major sources of uncertainty in quantitative geophysical modeling—even geohydrology, the best developed, can provide only approximate answers. Geoscientists will need more time to learn how to do more reliable predictive modeling of near-term events, and some events may prove to be chaotic—that is, impossible to predict in detail.

In particular, there is a critical need for (1) better communication between modelers and geological experts, in order to improve model prediction; and (2) a more open, quality-reinforcing process such as could be obtained through a peer-reviewed research program at universities and elsewhere. This would do much to improve technical and public confidence in models. DOE could support such an effort by allocating R&D funds, possibly through or in cooperation with the National Science Foundation, for model improvements.

In the meantime, however, models can be useful in identifying and evaluating significant contributors to risk and uncertainty. Models are not well suited to describe the risk and uncertainties to lay audiences, however. Natural analogues, if they can be found, are far more useful for this purpose (see below).

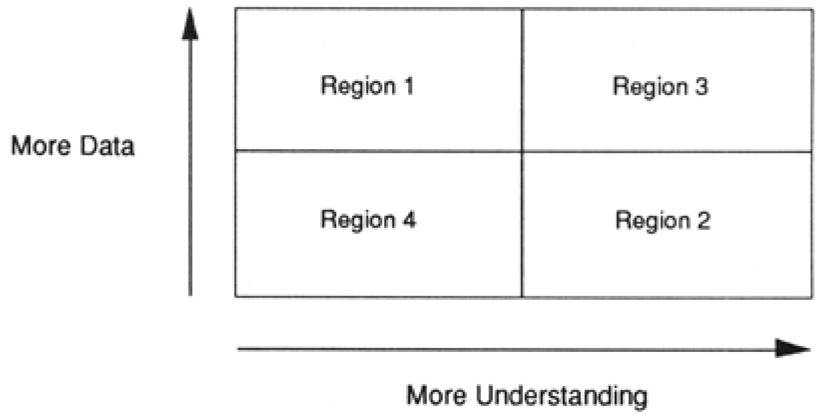

Figure 1.
Types of modeling problems.

Problems of repository performance assessment, according to the scheme shown in Figure 1, belong in Region 2 or at the border between Regions 4 and 2. However, there is a general tendency to assume that we can address them using a Region 3 approach: that is, start with a deterministic model that incorporates all "relevant" contributors to overall behavior, and then attempt to collect enough data to move the problem from Region 2 into Region 3. In reality, however, this approach leads to increasingly complex models and increasingly expensive site evaluations, without a concomitant improvement in either understanding or design. Anthony M. Starfield and

P. A. Cundall have suggested that we sometimes demand answers that the model is incapable of providing because of complexity or input demands. The design of the model should be driven by the questions that the model is supposed to answer, rather than by the details of the system that is being modeled. Under the present HLW program, geophysical models are being asked to provide answers to questions that they were not designed to tackle.[8]

Models and Modeling Problems

Figure 1 illustrates a general classification of the types of modeling problems taken from C. S. Holling.[9] In Region 1 there are good data but little understanding; this is where statistics is the appropriate analytic tool. In Region 3 there are both data and understanding; this is where models can be built, validated, and used with conviction. The use of finite-element models in structural design is a good example of Region 3 models. Regions 2 and 4 contain problems that are data-limited in the sense that the relevant data are unavailable or cannot be placed in a rigorous theoretical framework. In Region 2 the understanding of basic mechanisms is good; it is the detailed information that is unobtainable. In Region 4 there is not even a sound understanding of the basic mechanisms and interactions.

Appropriate Uses for Geophysical Models

In the Board's judgment, a scientifically sound objective of geophysical modeling is learning, over time, how to achieve the long-term isolation of radioactive waste. That is a profoundly different objective from predicting the detailed structure and behavior of a site before, or even after, it is probed in detail. Yet, in the face of public concerns about safety, it is the latter use to which models have been put. The Board believes that this is scientifically unsound. This conclusion is based on review of the modeling approach used by DOE and the regulatory agencies in order to implement the NWPA.

In order to support the regulatory and political argument that a site will be safe, it is necessary to make detailed, expensive, and extended extrapolations. These are informed speculations based on existing knowledge. In many instances the guesses are likely to be correct. The geotechnical models used to assure that the foundations of a building or bridge will be secure in the event of earthquakes provide an example of a well-founded predictive use of geophysical modeling. But to predict accurately the response of a complex mass of rock and groundwater as it reacts over thousands of years to the insertion of highly radioactive materials is not possible.

This point is important to the public concerns that have surrounded the U.S. radioactive waste program. Use of complex computer models is neces sary to apply well-known geophysical principles in order to estimate or to set bounds on the behavior of a site, so that its likely suitability for a waste repository can be evaluated. But it is impossible to stretch the almost always incomplete understanding of a site into an accurate quantitative projection of whether a repository will be safe if constructed and operated there. Even after a derailed and costly examination of the site itself, only an informed judgment can be reached, and even then there will be uncertainties.

As modelers have become more aware of the processes they are attempting to model, they are also recognizing that the geological environment is more complex than originally thought and that quantitative prediction is correspondingly more difficult and uncertain. Many computer simulation models of geological environments are based on deterministic models that have been used successfully in branches of mechanics such as aerospace engineering, where the basic phenomena are much better defined. Such models are of limited value for the ill-defined, data-limited, long-term situations such as the repository isolation problem. It is illusory to expect accurate quantitative estimates of radionuclide releases from them.

Sources of Uncertainty in Geophysical Models

Performance assessments—estimates of the repository's ability to isolate HLW—are based on current computer simulations and parameters derived from laboratory and field measurements. As a consequence, they will have large uncertainties associated with the predicted performance. These uncertainties could pose serious obstacles in demonstrating compliance with licensing requirements. Discussions at BRWM's 1988 study session identified four principal causes of uncertainty:

1. ***Structural uncertainty*.** Do the equations adequately represent the operative physical processes? Do we in fact understand the system well enough to model it mathematically? Modeling will be most successful in solving Region 3 problems (see Figure 1), where we have a great deal of data and a good understanding of how the system works.
2. ***Parametric uncertainty*.** Have we chosen the right values for the variables (e.g., permeability) in the equations? Have we in fact chosen the right variables to represent the behavior of the system? Are our measurement techniques valid? Will they produce enough, and good enough, data?
3. ***Uncertainties in initial and boundary conditions*.** Have we interpolated adequately from a few spatially isolated point measurements to a broad three-dimensional domain (e.g., groundwater, heat, in situ stress)?
4. ***Uncertainties in forcing functions*.** How well can we characterize past and future events that might play a part in the fate of the repository (e.g., climate, tectonics, human intrusion)?

Urgent attention should be given to examining these and other causes of uncertainty, but even with continuing research along the present lines, improvement will come slowly. It may even turn out to be appropriate to delay permanent closure of a waste repository until adequate assurances concerning its long-term behavior can be obtained through geophysical studies. Judgments of whether enough is known to proceed with placement of waste in a repository are needed throughout the life of the project. But to repeat the Board's earlier point: these judgments should be based on a comparison of the available alternatives, rather than just a simplistic debate over whether, given current uncertainties, a repository site is "safe." Even when the detailed behavior of an underground repository is still under study, it may well be safer to put waste there, in a way that permits retrieval if necessary, rather than leaving it at reactors or in storage at, or near, the surface of the earth.

Modeling Limitations—An Example

The inherent difficulties of modeling are illustrated by the case of groundwater flow, which is used as an example precisely because it the best developed in terms of modeling. Groundwater flow has been extensively modeled for a broad range of engineering problems, and it consequently has a richer base from which to draw than do many other aspects of repository isolation. Groundwater flow is also generally accepted as the primary mechanism by which radionuclides could move from the repository to the biosphere, so it has been emphasized in modeling studies of repository isolation. Several experts, however, have commented on the difficulty of applying classical hydrology models to the problem of radioactive waste isolation.

> Groundwater hydrologists are becoming increasingly aware that inadequate and insufficient data limit the reliability of traditional deterministic [distributed-parameter] groundwater models. The data may be inadequate because aquifer heterogeneities occur on a scale smaller than can be defined on the basis of available data, time-dependent variables are monitored too infrequently, and measurement errors exist.[10]
>
> To carry out these [repository flow] calculations, hydrogeologists are applying geostatistical models and stochastic simulation methods originally developed to assess piezometric response in near-surface unconsolidated aquifers over limited spatial distances and short time frames with relatively abundant data. . . . These techniques may not be as valuable when applied to the assessment of radionuclide transport in deep rock formations, over large distances and long time frames, under conditions of sparse data availability. . . . [The authors] have repeatedly drawn attention to the potential problems associated with the geostatistical methods (Bayesian and otherwise) when data networks

are sparse and sample sizes small. In our opinion, this is the potential Achilles heel for the application of geostatistics at nuclear repository sites.[11]

With regard to repository isolation modeling, increased study has thus far resulted in the identification of greater complexity. Progress is being made toward including some of this complexity in the models, at least in terms of groundwater studies; but other geotechnical aspects of repository isolation (such as constitutive properties of rock joints, excavation and repository scale deformation behavior, and regional in situ stress) are far less developed. It will take years of additional research to represent them adequately in the models. As a result, the prospects are poor, especially in the short term, for models that can produce reliable quantitative measures of isolation performance.

Appropriate Objectives for Modeling

Repository performance assessments are unlikely to prove beyond doubt that risks are below established limits. Nor do the regulations require it–EPA requires only a "reasonable assurance." The problem is that in a case without clear precedents, it is unclear what is "reasonable." The Board's point is that unsound use of technical information is not a proper substitute for the political reasoning that, in a democratic society, must in the end win consent for taking reasonable steps to advance public health and safety.

In light of the limitations of technical knowledge, the Board concludes that it makes sense to conduct the assessments through an iterative process, in which the assessment provides direction to those characterizing a repository site and developing the repository engineering features. As further information is developed about the candidate site, it is also used in the performance assessment.

Many of the uncertainties associated with a candidate repository site will be technically interesting but irrelevant to overall repository performance. Conversely, the issues that are analytically tractable are not necessarily the most important. A key task for performance modeling is to separate the significant uncertainties and risks from the trivial. Similarly, when there are technical disputes over characteristics and processes that affect calculations of waste transport, sensitivity analysis with alternative models and parameters can indicate where further analysis is required and where enough is known to move on to other concerns.

Using Models to Reduce Uncertainty

Models do have an indispensable role in developing understanding of such problems, provided that the models are developed and used within the proper limitations. In other words, modeling can be used to improve models.

The following quotations from those concerned with such problems illustrate this point:

> . . . much time can be saved in the early stages of hypothesis formulation by the exploration of these hypotheses through mathematical models. Similarly, mathematical models can be used to investigate phenomena from the viewpoint of existing theories, by the integration of disparate theories into a single working hypothesis, for example. Such models may quickly reveal inadequacies in the current theory and indicate gaps where new theory is required.[12]
>
> The updating properties of the Bayesian approach . . . are well suited to the iterative approach we espouse for the modeling/data gathering sequence at a site. We feel that the first modeling efforts should precede or accompany initial site investigations.[13]

A good example of this general approach is the "regionalized sensitivity analysis" approach, by which G. M. Hornberger and his collaborators have been able to identify the "critical uncertainties" in applying a particular model to several data-sparse ecological problems and, thereby, to define programs of investigations to reduce those uncertainties.[14]

In summary, models should be qualitatively sensible, robust to sensitivity analysis, and independent of minor effects or processes, and they should include acceptable levels of uncertainty. However, models cannot prove that the repository is safe, nor can they resolve public concerns about the repository.

Supplements to Modeling

***Natural Analogues*.** Because models cannot be conclusive with regard to the safety of a repository site, it is important to think carefully about natural analogues. These are natural "test cases," geological settings in which naturally occurring radioactive materials have been subjected to environmental forces for millions of years. These natural experiments demonstrate the action of transport processes that are similar to those that will govern the release of man-made radionuclides from a repository in a similar setting.

The natural analogue approach depends, of course, on whether the natural case is in fact an analogue for a repository situation. Where there is scientific agreement that the analogy applies, however, the approach is powerful because it allows us to predict processes with confidence over many millennia. And natural analogues can serve two additional roles: (1) they can provide a check on performance assessment methodology; and (2) they may be more meaningful than sophisticated numerical predictions to the lay public. The alternative management strategy described in the following section would make substantial use of natural analogues, such as undisturbed natural de posits of radioactive elements and groundwater systems, in order to illuminate the behavior of the geologic environment.

***Professional Judgment*.** A second approach is to use the professional judgment of technical experts as an input to modeling in areas where there is uncertainty as to parameters, structures, or even future events. Such judgments, which may differ from those of DOE program managers and their staffs, should be incorporated early in the process. A model created by this process can redirect the DOE program substantially.

It is important to bear in mind that all uses of technical information entail judgments of what is important and what is less so. If the technical community is to learn from the successes and failures of the DOE program, it is essential that these technical judgments be documented. Setting out the reasoning of DOE staff and of independent outside experts contributes to learning and builds credibility in the process even when the experts disagree with DOE staff and among themselves.

Implications for Program Management

The Board has concluded that geological models, and indeed scientific knowledge generally, are being inappropriately applied in the U.S. radioactive waste repository program. That misapplication prompts this Board to outline an alternative management strategy. The next section describes an alternative management approach that employs natural analogues and professional judgment in a program design that uses science appropriately in the search for a safe disposal system. Putting such an approach into effect, however, would require major changes in the way Congress, the regulatory agencies, and DOE conduct their business. Such changes will be difficult to achieve, but the Board has reluctantly concluded that nothing else will put to rest the problems that plague the national program today.

Strategic Planning

Overview

There is no scientific reason to think that an acceptable HLW repository cannot be built and licensed. For historic and institutional reasons, however, DOE managers often feel compelled to "get it right the first time." This management strategy runs the risk of encountering "show-stopping" problems that may delay licensing and will certainly cause further deterioration of public and scientific trust.

The alternative would be a more flexible, experimental strategy that embodies the following principles:

- respond with conservative design changes as site attributes are discovered;
- use modeling to identify areas where more information is needed; and
- allow for remediation if things do not turn out as planned.

Implicit in this approach is the need to revise both technical design and regulatory criteria as more information is discovered. This is difficult to achieve in a governmental structure that disperses authority among legislative and executive agencies and separates regulation from implementation. When presented with intense controversy, such an institutional arrangement breeds distrust among governmental units and the public. In that setting, partial remedies further entangle the procedural morass.

More practically, however, DOE can enhance the credibility of the program and reduce the likelihood of late-stage surprises by (1) encouraging effective communication within its complex management structure; and (2) providing incentives for field personnel to identify and solve problems. DOE and the USNRC can also enhance credibility by encouraging periodic external reviews of the repository design, construction, and licensing requirements and associated processes.

Policy Context

The present U.S. approach to HLW disposal is increasingly vulnerable to being derailed by minor surprises. This vulnerability does not arise from a lack of talent or effort among the federal agencies and private contractors working on the program. Nor does the design or construction of the repository represent an unusually difficult technical undertaking. Instead, the program is at risk because it is following the wrong approach to implementation. The current predetermined process, in which every step is mandated in detail as in the more than 6,000-page "Site Characterization Plan,"[15] is inappropriate.

The current policy calls for a sequential process in which EPA and the USNRC first establish the criteria for safe disposal, and then DOE describes in detail what steps will be taken to move through site characterization, licensing, and operation of the facility. The result of this approach is that any late change, by any of the participating agencies, is taken as an admission of error.

And late changes are bound to happen. One worker was killed and five injured in an HLW repository under construction in West Germany when a support ring failed unexpectedly. At the Waste Isolation Pilot Plant (WIPP) in New Mexico, the discovery of pockets of pressurized brine in formations below the repository level led to public outcries and a continual National Research Council review of the suitability of the site.

The United States seems to be the only country that has taken the approach of writing detailed regulations before all of the data are in. Almost all other countries have established limitations on the allowable levels of radiation dose to individuals or populations resulting from repository establishment–but have taken a "wait and see" approach on design, while collecting data that may be of use in setting design. The United States, on the other hand, seems to have felt that detailed regulations can be, in fact must be, written without regard to any particular geological setting or other circumstance. As a direct consequence, the U.S. HLW program is bound by requirements that may be impossible to meet, even though overall dose limits can be achieved.

Alternative Management Strategies

The preceding sections have shown that there are a number of unresolved issues in the U.S. radioactive waste disposal program, as well as (and in part because of) high levels of uncertainty and public unease about the performance of the repository. The Board's consideration of these subjects indicates that the proper response to distrust is greater openness in the process, and that the proper response to uncertainty is greater knowledge and flexibility, as well as redundancy of barriers to nuclide transport. The U.S. program will continue to face controversy until it adopts a management strategy based on these principles.

The current approach to the design, construction, and licensing of the Nevada site is derived from the philosophy and procedures used for licensing nuclear power plants. The characteristics of the repository and its geological setting are carefully determined and specified as a basis for a complex set of calculations that describes the behavior of the system. This model is used to generate predictions of the migration of radioactive elements into the biosphere and analyzes the consequences of various events ("scenarios") that might affect the site over the next 10,000 years, in order to demonstrate that the repository site meets regulatory requirements (i.e., is "safe"). Based on the model and geologic studies of the site, the construction of the repository is specified in detail and then carried out under an aggressive quality assurance program, which is designed to withstand regulatory review and legal challenge. Within these requirements it is the geological setting that ensures isolation, not the engineered characteristics of the system; closure aims for complete entombment and discourages subsequent remediation. For all the reasons discussed above, a management process based on the regulation of nuclear power stations (a Region 3 type problem: see Figure 1) is inappropriate to the development of a waste repository.

A well-documented alternative to this approach is being followed, to various degrees, by countries such as Canada and Sweden. The exploration and construction of a geological test facility and a low-level waste repository, respectively, follow a flexible path, allowing each step in the characterization and design to draw on the information and understanding developed during the prior steps, and from prior experience with similar underground construction projects. During and subsequent to the closing of the repository, the emphasis will be on monitoring and on the ability to repair, in order to minimize the possibility that unplanned or unexpected events will compromise the integrity of the disposal system. Engineered modifications can be incorporated (e.g., in the waste containers or in the material used to backfill the repository) if the computer models suggest unacceptable or irreducible uncertainties in the performance of the unmodified containment system.

The Canadian experience at their Underground Research Laboratory provides a good example. All of the major rock structures and groundwater conditions were defined from surface and borehole observations before shaft construction began. Detailed geological structure can never be totally determined from surface information, however, and the final details of the facility design were modified to take account of information gathered during shaft construction.

What are the risks and benefits of the two approaches? The U.S. approach facilitates rigorous oversight and technical auditing. Its goals and standards are clear, and, if carried out according to specifications, this approach is robust in the face of administrative or legal challenge. It is designed to create a sense of confidence in the planning and operation of the repository, and it facilitates precise answers to specific technical questions.

However, such an approach is not consistent with normal geologic or mining practice. It assumes that the properties of the geologic medium can be determined and specified in advance to a degree analogous to that required for man-made components, such as reinforcing rods, structural concrete, or pipes. In reality, geologic exploration and mine construction never proceed in this way. Most underground construction projects are more qualitative, using a "design (and improve the design) as you go" principle. New sections of drill core often reveal surprises that must be incorporated into the geologists' concept of the site, integrated with past experience, and used to modify the exploration plan or mine design. In a project where adherence to predetermined specifications is paramount, the inherent variability of the geologic environment will result in endless changes in the specifications, with resultant delays, frustration for field personnel, high overhead costs, and loss of public confidence in both the suitability of the site and the competence of the professionals working on the project.

The second approach has more in common with research than with conventional engineering practice. This approach continually integrates new data into the expert judgments of geologists and engineers. It makes heavy use of natural analogues, such as undisturbed natural deposits of radioactive elements and groundwater systems, in order to illuminate the behavior of the geologic environment. It can immediately take advantage of favorable surprises and compensate for unfavorable ones. That this approach works well is evidenced by the enormous number of underground construction projects in diverse geologic settings that have been completed successfully around the world. These projects were not designed to contain radioactive waste for thousands of years, but many of them faced technical problems of comparable magnitude, such as crossing active faults, sealing out massive groundwater flows, or stabilizing highly fractured and structurally weak rock masses.

The second approach, with its reliance on continuous adaptation, would be much more difficult to document, audit, and defend before a licensing authority or court of law than is the more prescriptive approach. Some aspects of quality assurance can work well, such as document and sample control, the use of standard procedures and tools, and personnel qualifications. Other quality assurance techniques are likely to be contentious and may be impossible to implement in the same way they are implemented in nuclear power plants, including design control, instructions, procedures, drawings, inspections, and control of nonconforming items. An alternative is to use an aggressive and independent peer review system to appraise the decisions made and the competence of the technical personnel and managers responsible.

The legal system is able to accept expert opinion as a basis for action or assessments of action, but one cannot predict whether a repository could ever be licensed in the face of the batteries of opposing "experts" who would inevitably be called on to assess a flexibly designed and constructed repository for HLW disposal. The debate will hinge in part on a clear understanding of the alternatives against which a proposed "solution" will be judged. By contrast, the EPA standards and USNRC regulations define requirements that, if met, form the basis for the presumption that the facility is "safe."

Given the unhappy history of radioactive waste disposal in the United States, however, one very real and likely alternative is that nothing at all will be done. In judging disposal options, therefore, one should also adopt inaction or some other likely scenario as a default option, so that comparisons can be made and progress consistently assessed over time. The combination of a conservative engineering approach and designed-in maximum flexibility, to allow unanticipated problems to be corrected, should reassure both technical experts and concerned nonexperts. The barrier is not logical but institutional, and the prescriptive approach in the U.S. program is dictated by a governmental structure that separates regulation from implementation.

Within the present program, for example, "quality assurance" has become the bête noire of frustrated field personnel, who are trying to work within a system that is hostile to surprises in a world that is full of them. Because almost any geologic phenomenon has more than one possible cause, flexibility (including the recognition that uncertainty is inevitable and must be accommodated) is more likely to lead to the design and construction of a safe repository system than are rigid, predetermined protocols. In employing and evaluating such an adaptive approach to construction, emphasis focuses on those decisions that have irreversible or noncorrectable consequences on disposal, rather than on the myriad small adjustments that do not affect the basic flexibility and robustness of a repository.

The Elements of a More Flexible System

In a program governed by this alternative approach, change would not be seen as an admission of error; the system would be receptive and responsive to a continuing stream of information from site characterization. The main actors would reduce their reliance on detailed preplanning during initial site characterization, making it possible to debug the preliminary design during rather than before characterization.[16] But the necessary conditions of the system are flexibility and resiliency—flexibility to respond rapidly to ongoing findings in the geology, geohydrology, and geochemistry (within broad constraints); and resiliency to continuously adjust the performance assessment to reflect new information, especially where such information indicates possible precursors of substantial increases in risk. These qualities could be developed through the following steps:

- ***Iterative performance assessment*.** The basic approach outlined here would start with a simplified performance assessment, based on known data and methods of interpretation. Given the inherent uncertainties and technical difficulties of the process, the present system may well expend large efforts on small risks, and vice versa. An iterative approach, on the other hand, could allow characterization efforts to give priority to major uncertainties and risks, while there is still time and money left to do something about them. As in probabilistic risk assessment, analysis focuses on efforts to reduce the important risks and uncertainties. In this case, that means acquiring information on the design features and licensing criteria that are most likely to determine whether the site is suitable or should be abandoned.
- ***Fixing problems vs. anticipating problems*.** The underlying concept of the present, anticipatory U.S. management strategy is "Get it right the first time." One result is a 6,300-page "Site Characterization Plan" for Yucca Mountain. For the reasons described above, however, a process based on getting all of the needed measurements and analysis on the first pass, with acceptably high quality, is not likely to succeed. The geological environment will always produce surprises, like the pockets of pressurized brine at WIPP. No matter what technical approach is initially adopted, the design can be improved by matching it with specific features of the site. Experiments are now being conducted at WIPP with backfill material and other engineered barriers that were not part of the original design. These

are being tried as ways to make the disposal system as a whole robust in the face of newly discovered uncertainties in the geology.

- ***Define the problem broadly.*** As characterization proceeds, especially if it is done without the guidance of iterative performance assessment, DOE may eventually find it difficult or impossible to meet some of the criteria set by the USNRC and/or EPA. This will not mean that Yucca Mountain is unsuitable for a repository—the problem could be with the detailed criteria. This is no reason to arbitrarily abandon the release limits—it is the more detailed requirements that may need to be reconsidered, since they ultimately affect the release limits and the imputed dose. However, one should not take EPA's release standards or the USNRC's detailed licensing requirements as immutable constraints. They are roadmarkers to, and surrogates for, dose limits. Although the EPA standards and the USNRC regulations recognize and accept a certain level of uncertainty, the discussion to date of the application of these standards and regulations does not warrant confidence in the acceptance of uncertainty in licensing procedures.

Some process is needed in order to determine whether DOE's inability to meet a particular requirement is due to a disqualifying deficiency in the site or to an unreasonable regulatory demand, one that is unlikely to be met at any site and is unnecessary to protect public health. And to the extent that regulatory criteria can be corrected earlier instead of later in the process, they are more likely to be perceived as technical adjustments rather than as a diminution of public safety. Given the history of U.S. efforts to dispose of radioactive waste, current plans for the program have little chance of progressing without major modification in the 20 years or more that will be required to get a repository into operation.

RECOMMENDATIONS

The Board's conclusions are explicit or implicit throughout this document, as are many of the actions it would recommend to the various players. These recommendations are summarized below.

1. Congress should reconsider the rigid, inflexible schedule embodied in NWPA and the 1987 amendments. It may be appropriate to delay the licensing application, or even the scheduled opening of the repository, until more of the uncertainties can be resolved. The Secretary of Energy's recent announcement of a more realistic schedule, with the repository opening in 2010 rather than 2003, is a welcome step.
2. The Environmental Protection Agency, during its revision of the remanded 40 CFR Part 191, should reconsider the detailed performance standards to be met by the repository, to determine how they affect the level of health risks that will be considered acceptable. In addition, EPA should reexamine the use of quantitative probabilistic release criteria in the standard and examine what will constitute a reasonable: level of assurance (i.e., by what combination of methods and strategies can DOE demonstrate that those standards will be met?).

   All other countries use only a dose requirement. In setting regulatory standards and licensing requirements, the EPA should consider using only dose requirements.
3. The U.S. Nuclear Regulatory Commission, likewise, should reconsider the detailed licensing requirements for the repository. For example:

- What level of statistical or modeling evidence is really necessary, obtainable, or even feasible?
- To what extent is it necessary to prescribe engineering design, rather than allowing alternatives that accomplish the same goal?
- What can be done to accommodate design changes necessitated by surprises during construction?
- What new strategies (e.g., engineered features like copper containers) might be allowed or encouraged as events dictate?

4. The Department of Energy, for its part, should continue and also expand its current efforts to become a more responsive player in these regulatory issues. The following activities should be included:

- publicly negotiated prelicensing agreements with the USNRC on how to deal with the high levels of uncertainty arising from numerical predictions of repository performance;

- publicly negotiated prelicensing agreements with the USNRC on improved strategies for performance assessment;
- active negotiations with EPA and the USNRC on the real goals and precise definitions of their standards and requirements;
- an extramural grant program, in cooperation with the National Science Foundation, for the development of improved modeling methodology, in combination with training programs and public education efforts;
- expanded use of expert scientists from outside the program to review and critique detailed aspects and to provide additional professional judgment;
- greatly expanded risk communication efforts, aimed at reaching appropriate and achievable goals acceptable to the U.S. public;
- meaningful dialogue with state and local governments, Indian tribes, environmental public interest groups, and other interested organizations.

5. The Department of Energy should make greater use of conservative engineering design instead of using unproven engineering design based on scientific principles.
6. The Department of Energy should participate more actively in international studies and forums, such as those sponsored by the International Atomic Energy Agency, the Nuclear Energy Agency, and the Commission of European Communities, and should subject its plans and procedures to international scientific review, as Sweden, Switzerland, and the United Kingdom have already done.
7. Although geologic disposal has been the national policy for many years, and the Board believes it to be feasible, contingency planning for other sites and options (for example Subseabed Disposal of spent fuel and high-level radioactive waste) should be pursued. The nation, the Congress, the federal government, utilities, and the nuclear industry should recognize the importance of contingency planning in the event that some issue should make it impossible to license a geologic repository.

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Appendix B

40 CFR Part 191

SUBCHAPTER F—RADIATION PROTECTION PROGRAMS

Part 190—Environmental Radiation Protection Standards for Nuclear Power Operations

AUTHORITY: Atomic Energy Act of 1954, as amended; Reorganization Plan No. 3, of 1970.

SOURCE: 42 FR 2860, Jan. 13, 1977, unless otherwise noted.

Subpart A—General Provisions

§; 190.01 Applicability.

The provisions of this part apply to radiation doses received by members of the public in the general environment and to radioactive materials introduced into the general environment as the result of operations which are part of a nuclear fuel cycle.

§ 190.02 Definitions.

(a) "Nuclear fuel cycle" means the operations defined to be associated with the production of electrical power for public use by any fuel cycle through utilization of nuclear energy.

(b) "Uranium fuel cycle" means the operations of milling of uranium ore, chemical conversion of uranium, isotopic enrichment of uranium, fabrication of uranium fuel, generation of electricity by a light-water-cooled nuclear power plant using uranium fuel, and reprocessing of spent uranium fuel, to the extent that these directly support the production of electrical power for public use utilizing nuclear energy, but excludes mining operations, operations at waste disposal sites, transportation of any radioactive material in support of these operations, and the reuse of recovered nonuranium special nuclear and by-product materials from the cycle.

(c) "General environment" means the total terrestrial, atmospheric and aquatic environments outside sites upon which any operation which is part of a nuclear fuel cycle is conducted.

(d) "Site" means the area contained within the boundary of a location under the control of persons possessing or using radioactive material on which is conducted one or more operations covered by this part.

(e) "Radiation" means any or all of the following: Alpha, beta, gamma, or X-rays; neutrons; and high-energy electrons, protons, or other atomic particles; but not sound or radio waves, nor visible, infrared, or ultraviolet light.

(f) "Radioactive material" means any material which spontaneously emits radiation.

(g) "Curie" (Ci) means that quantity of radioactive material producing 37 billion nuclear transformations per second. (One millicurie (mCi) = 0.001 Ci.)

(h) "Dose equivalent" means the product of absorbed dose and appropriate factors to account for differences in biological effectiveness due to the quality of radiation and its spatial distribution in the body. The unit of dose equivalent is the "rem." (One millirem (mrem) = 0.001 rem.)

(i) "Organ" means any human organ exclusive of the dermis, the epidermis, or the cornea.

(j) "Gigawatt-year" refers to the quantity of electrical energy produced at the busbar of a generating station. A gigawatt is equal to one billion watts. A gigawatt-year is equivalent to the amount of energy output represented by an average electric power level of one gigawatt sustained for one year.

(k) "Member of the public" means any individual that can receive a radiation dose in the general environment, whether he may or may not also be exposed to radiation in an occupation associated with a nuclear fuel cycle. However, an individual is not consid ered a member of the public during any period in which he is engaged in carrying out any operation which is part of a nuclear fuel cycle.

(l) "Regulatory agency" means the government agency responsible for issuing regulations governing the use of sources of radiation or radioactive materials or emissions therefrom and carrying out inspection and enforcement activities to assure compliance with such regulations.

Subpart B—Environmental Standards for the Uranium Fuel Cycle

§ 190.10 Standards for normal operations.

Operations covered by this subpart shall be conducted in such a manner as to provide reasonable assurance that:

(a) The annual dose equivalent does not exceed 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ of any member of the public as the result of exposures to planned discharges of radioactive materials, radon and its daughters excepted, to the general environment from uranium fuel cycle operations and to radiation from these operations.

(b) The total quantity of radioactive materials entering the general environment from the entire uranium fuel cycle, per gigawatt-year of electrical energy produced by the fuel cycle, contains less than 50,000 curies of krypton-85, 5 millicuries of iodine-129, and 0.5 millicuries combined of plutonium-239 and other alpha-emitting transuranic radionuclides with half-lives greater than one year.

§ 190.11 Variances for unusual operations.

The standards specified in § 190.10 may be exceeded if:

(a) The regulatory agency has granted a variance based upon its determination that a temporary and unusual operating condition exists and continued operation is in the public interest, and

(b) Information is promptly made a matter of public record delineating the nature of unusual operating conditions, the degree to which this operation is expected to result in levels in excess of the standards, the basis of the variance, and the schedule for achieving conformance with the standards.

§ 190.12 Effective date.

(a) The standards in § 190.10(a) shall be effective December 1, 1979, except that for doses arising from operations associated with the milling of uranium ore the effective date shall be December 1, 1980.

(b) The standards in § 190.10(b) shall be effective December 1, 1979, except that the standards for krypton-85 and iodine-129 shall be effective January 1, 1983, for any such radioactive materials generated by the fission process after these dates.

Part 191—Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes

Subpart A—Environmental Standards for Management and Storage

Sec.

Subpart B—Environmental Standards for Disposal

AUTHORITY: The Atomic Energy Act of 1954, as amended; Reorganization Plan No. 3 of 1970; and the Nuclear Waste Policy Act of 1982.

SOURCE: 50 FR 38084, Sept. 19, 1985, unless otherwise noted.

Subpart A—Environmental Standards for Management and Storage

§ 191.01 Applicability.

This subpart applies to:

(a) Radiation doses received by members of the public as a result of the management (except for transportation) and storage of spent nuclear fuel or high-level or transuranic radioactive wastes at any facility regulated by the Nuclear Regulatory Commission or by Agreement States, to the extent that such management and storage operations are not subject to the provisions of Part 190 of Title 40; and

(b) Radiation doses received by members of the public as a result of the management and storage of spent nuclear fuel or high-level or transuranic wastes at any disposal facility that is operated by the Department of Energy and that is not regulated by the Commission or by Agreement States.

§ 191.02 Definitions.

Unless otherwise indicated in this subpart, all terms shall have the same meaning as in Subpart A of Part 190.

(a) "Agency" means the Environmental Protection Agency.

(b) "Administrator" means the Administrator of the Environmental Protection Agency.

(c) "Commission" means the Nuclear Regulatory Commission.

(d) "Department" means the Department of Energy.

(e) "NWPA" means the Nuclear Waste Policy Act of 1982 (Pub. L. 97-425).

(f) "Agreement State" means any State with which the Commission or the Atomic Energy Commission has entered into an effective agreement under subsection 274b of the Atomic Energy Act of 1954, as amended (68 Stat. 919).

(g) "Spent nuclear fuel" means fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing.

(h) "High-level radioactive waste," as used in this part, means high-level radioactive waste as defined in the Nuclear Waste Policy Act of 1982 (Pub. L. 97-425).

(i) "Transuranic radioactive waste," as used in this part, means waste containing more than 100 nanocuries of alpha-emitting transuranic isotopes, with half-lives greater than twenty years, per gram of waste, except for: (1) High-level radioactive wastes; (2) wastes that the Department has determined, with the concurrence of the Administrator, do not need the degree of isolation required by this part; or (3) wastes that the Commission has approved for disposal on a case-by-case basis in accordance with 10 CFR Part 61.

(j) "Radioactive waste," as used in this part, means the high-level and transuranic radioactive waste covered by this part.

(k) "Storage" means retention of spent nuclear fuel or radioactive wastes with the intent and capability to readily retrieve such fuel or waste for subsequent use, processing, or disposal.

(l) "Disposal" means permanent isolation of spent nuclear fuel or radioactive waste from the accessible environment with no intent of recovery, whether or not such isolation permits the recovery of such fuel or waste. For example, disposal of waste in a mined geologic repository occurs when all of the shafts to the repository are back-filled and sealed.

(m) "Management" means any activity, operation, or process (except for transportation) conducted to prepare spent nuclear fuel or radioactive waste for storage or disposal, or the activities associated with placing such fuel or waste in a disposal system.

(n) "Site" means an area contained within the boundary of a location under the effective control of persons possessing or using spent nuclear fuel or radioactive waste that are involved in any activity, operation, or process covered by this subpart.

(o) "General environment" means the total terrestrial, atmospheric, and aquatic environments outside sites within which any activity, operation, or process associated with the management and storage of spent nuclear fuel or radioactive waste is conducted.

(p) "Member of the public" means any individual except during the time when that individual is a worker engaged in any activity, operation, or process that is covered by the Atomic Energy Act of 1954, as amended.

(q) "Critical organ" means the most exposed human organ or tissue exclusive of the integumentary system (skin) and the cornea.

§ 191.03 Standards.

(a) Management and storage of spent nuclear fuel or high-level or transuranic radioactive wastes at all facilities regulated by the Commission or by Agreement States shall be conducted in such a manner as to provide reasonable assurance that the combined annual dose equivalent to any member of the public in the general environment resulting from: (1) Discharges of radioactive material and direct radiation from such management and storage and (2) all operations covered by Part 190; shall not exceed 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other critical organ.

(b) Management and storage of spent nuclear fuel or high-level or transuranic radioactive wastes at all facilities for the disposal of such fuel or waste that are operated by the Department and that are not regulated by the Commission or Agreement States shall be conducted in such a manner as to provide reasonable assurance that the combined annual dose equivalent to any member of the public in the general environment resuiting from discharges of radioactive material and direct radiation from such management and storage shall not exceed 25 millirems to the whole body and 75 millirems to any critical organ.

§ 191.04 Alternative standards.

(a) The Administrator may issue alternative standards from those standards established in § 191.03(b) for waste management and storage activities at facilities that are not regulated by the Commission or Agreement States if, upon review of an application for such alternative standards:

(1) The Administrator determines that such alternative standards will prevent any member of the public from receiving a continuous exposure of more than 100 millirems per year dose equivalent and an infrequent exposure of more than 500 millirems dose equivalent in a year from all sources, excluding natural background and medical procedures; and

(2) The Administrator promptly makes a matter of public record the degree to which continued operation of the facility is expected to result in levels in excess of the standards specified in § 191.03(b).

(b) An application for alternative standards shall be submitted as soon as possible after the Department determines that continued operation of a facility will exceed the levels specified in § 191.03(b) and shall include all information necessary for the Administrator to make the determinations called for in § 191.04(a).

(c) Requests for alternative standards shall be submitted to the Administrator, U.S. Environmental Protection Agency, 401 M Street, SW., Washington, DC 20460.

§ 191.05 Effective date.

The standards in this subpart shall be effective on November 18, 1985.

Subpart B—Environmental Standards for Disposal

§ 191.11 Applicability.

(a) This subpart applies to:

(1) Radioactive materials released into the accessible environment as a result of the disposal of spent nuclear fuel or high-level or transuranic radioactive wastes;

(2) Radiation doses received by members of the public as a result of such disposal; and

(3) Radioactive contamination of certain sources of ground water in the vicinity of disposal systems for such fuel or wastes.

(b) However, this subpart does not apply to disposal directly into the oceans or ocean sediments. This subpart also does not apply to wastes disposed of before the effective date of this rule.

§ 191.12 Definitions.

Unless otherwise indicated in this subpart, all terms shall have the same meaning as in Subpart A of this part.

(a) "Disposal system" means any combination of engineered and natural barriers that isolate spent nuclear fuel or radioactive waste after disposal.

(b) "Waste," as used in this subpart, means any spent nuclear fuel or radioactive waste isolated in a disposal system.

(c) "Waste form" means the materials comprising the radioactive components of waste and any encapsulating or stabilizing matrix.

(d) "Barrier" means any material or structure that prevents or substantially delays movement of water or radionuclides toward the accessible environment. For example, a barrier may be a geologic structure, a canister, a waste form with physical and chemical characteristics that significantly decrease the mobility of radionuclides, or a material placed over and around waste, provided that the material or structure substantially delays movement of water or radionuclides.

(e) "Passive institutional control" means: (1) Permanent markers placed at a disposal site, (2) public records and archives, (3) government ownership and regulations regarding land or resource use, and (4) other methods of preserving knowledge about the location, design, and contents of a disposal system.

(f) "Active institutional control" means: (1) Controlling access to a disposal site by any means other than passive institutional controls; (2) performing maintenance operations or remedial actions at a site, (3) controlling or cleaning up releases from a site, or (4) monitoring parameters related to disposal system performance.

(g) "Controlled area" means: (1) A surface location, to be identified by passive institutional controls, that encompasses no more than 100 square kilometers and extends horizontally no more than five kilometers in any direction from the outer boundary of the original location of the radioactive wastes in a disposal system; and (2) the subsurface underlying such a surface location.

(h) "Ground water" means water below the land surface in a zone of saturation.

(i) "Aquifer" means an underground geological formation, group of formations, or part of a formation that is capable of yielding a significant amount of water to a well or spring.

(j) "Lithosphere" means the solid part of the Earth below the surface, including any ground water contained within it.

(k) "Accessible environment" means: (1) The atmosphere; (2) land surfaces; (3) surface waters; (4) oceans; and (5) all of the lithosphere that is beyond the controlled area.

(l) "Transmissivity" means the hydraulic conductivity integrated over the saturated thickness of an underground formation. The transmissivity of a series of formations is the sum of the individual transmissivities of each formation comprising the series.

(m) "Community water system" means a system for the provision to the public of piped water for human consumption, if such system has at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents,

(n) "Significant source of ground water," as used in this part, means: (1) An aquifer that: (i) Is saturated with water having less than 10,000 milligrams per liter of total dissolved solids; (ii) is within 2,500 feet of the land surface; (iii) has a transmissivity greater than 200 gallons per day per foot, *Provided,* That any formation or part of a formation included within the source of ground water has a hydraulic conductivity greater than 2 gallons per day per square foot; and (iv) is capable of continuously yielding at least 10,000 gallons per day to a pumped or flowing well for a period of at least a year; or (2) an aquifer that provides the primary source of water for a community water system as of the effective date of this subpart.

(o) "Special source of ground water," as used in this part, means those Class I ground waters identified in accordance with the Agency's Ground-Water Protection Strategy published in August 1984 that: (1) Are within the controlled area encompassing a disposal system or are less than five kilome ters beyond the controlled area; (2) are supplying drinking water for thousands of persons as of the date that the Department chooses a location within that area for detailed characterization as a potential site for a disposal system (e.g., in accordance with section 112(b)(1)(B) of the NWPA); and (3) are irreplaceable in that no reasonable alternative source of drinking water is available to that population.

(p) "Undisturbed performance" means the predicted behavior of a disposal system, including consideration of the uncertainties in predicted behavior, if the disposal system is not disrupted by human intrusion or the occurrence of unlikely natural events.

(q) "Performance assessment" means an analysis that: (1) Identifies the processes and events that might affect the disposal system; (2) examines the effects of these processes and events on the performance of the disposal system; and (3) estimates the cumulative releases of radionuclides, considering the associated uncertainties, caused by all significant processes and events. These estimates shall be incorporated into an overall probability distribution of cumulative release to the extent practicable.

(r) "Heavy metal" means all uranium, plutonium, or thorium placed into a nuclear reactor.

(s) "Implementing agency," as used in this subpart, means the Commission for spent nuclear fuel or high-level or transuranic wastes to be disposed of in facilities licensed by the Commission in accordance with the Energy Reorganization Act of 1974 and the Nuclear Waste Policy Act of 1982, and it means the Department for all other radioactive wastes covered by this part.

§ 191.13 Containment requirements.

(a) Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation, based upon performance assessments, that the cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system shall:

(1) Have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table 1 (Appendix A); and

(2) Have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated according to Table 1 (Appendix A).

(b) Performance assessments need not provide complete assurance that the requirements of § 191.13(a) will be met. Because of the long time period involved and the nature of the events and processes of interest, there will inevitably be substantial uncertainties in projecting disposal system performance. Proof of the future performance of a disposal system is not to be had in the ordinary sense of the word in situations that deal with much shorter time frames. Instead, what is required is a reasonable expectation, on the basis of the record before the implementing agency, that compliance with § 191.13 (a) will be achieved.

§ 191.14 Assurance requirements.

To provide the confidence needed for long-term compliance with the requirements of § 191.13, disposal of spent nuclear fuel or high-level or transuranic wastes shall be conducted in accordance with the following provisions, except that these provisions do not apply to facilities regulated by the Commission (see 10 CFR Part 60 for comparable provisions applicable to facilities regulated by the Commission):

(a) Active institutional controls over disposal sites should be maintained for as long a period of time as is practicable after disposal; however, performance assessments that assess isolation of the wastes from the accessible environment shall not consider any contributions from active institutional controls for more than 100 years after disposal.

(b) Disposal systems shall be monitored after disposal to detect substantial and detrimental deviations from expected performance. This monitoring shall be done with techniques that do not jeopardize the isolation of the wastes and shall be conducted until there are no significant concerns to be addressed by further monitoring.

(c) Disposal sites shall be designated by the most permanent markers, records, and other passive institutional controls practicable to indicate the dangers of the wastes and their location.

(d) Disposal systems shall use different types of barriers to isolate the wastes from the accessible environment. Both engineered and natural barriers shall be included.

(e) Places where there has been mining for resources, or where there is a reasonable expectation of exploration for scarce or easily accessible resources, or where there is a significant concentration of any material that is not widely available from other sources, should be avoided in selecting disposal sites. Resources to be considered shall include minerals, petroleum or natural gas, valuable geologic formations, and ground waters that are either irreplaceable because there is no reasonable alternative source of drinking water available for substantial populations or that are vital to the preservation of unique and sensitive ecosystems. Such places shall not be used for disposal of the wastes covered by this part unless the favorable characteristics of such places compensate for their greater likelihood of being disturbed in the future.

(f) Disposal systems shall be selected so that removal of most of the wastes is not precluded for a reasonable period of time after disposal.

§ 191.15 Individual protection requirements.

Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation that, for 1,000 years after disposal, undisturbed performance of the disposal system shall not cause the annual dose equivalent from the disposal system to any member of the public in the accessible environment to exceed 25 millirems to the whole body or 75 millirems to any critical organ. All potential pathways (associated with undisturbed performance) from the disposal system to people shall be considered, including the assumption that individuals consume 2 liters per clay of drinking water rom any significant source of ground water outside of the controlled area.

§ 191.16 Ground water protection requirements.

(a) Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation that, for 1,000 years after disposal, undisturbed performance of the disposal system shall not cause the radionuclide concentrations averaged over any year in water withdrawn from any portion of a special source of ground water to exceed:

(1) 5 picocuries per liter of radium-226 and radium-228;

(2) 15 picocuries per liter of alpha-emitting radionuclides (including radium-226 and radium-228 but excluding radon); or

(3) The combined concentrations of radionuclides that emit either beta or gamma radiation that would produce an annual dose equivalent to the total body or any internal organ greater than 4 millirems per year if an individual consumed 2 liters per day of drinking water from such a source of ground water.

(b) If any of the average annual radionuclide concentrations existing in a special source of ground water before construction of the disposal system already exceed the limits in § 191.16(a), the disposal system shall be designed to provide a reasonable expectation that, for 1,000 years after disposal, undisturbed performance of the disposal system shall not increase the existing average annual radionuclide concentrations in water withdrawn from that special source of ground water by more than the limits established in § 191.16(a).

§ 191.17 Alternative provisions for disposal.

The Administrator may, by rule, substitute for any of the provisions of Subpart B alternative provisions chosen after:

(a) The alternative provisions have been proposed for public comment in the FEDERAL REGISTER together with information describing the costs, risks, and benefits of disposal in accordance with the alternative provisions and the reasons why compliance with the existing provisions of Subpart B appears inappropriate;

(b) A public comment period of at least 90 days has been completed, during which an opportunity for public hearings in affected areas of the country has been provided; and
(c) The public comments received have been fully considered in developing the final version of such alternative provisions.

§ 191.18 Effective date.

The standards in this subpart shall be effective on November 18, 1985.

[50 FR 38084, Sept. 19, 1985; 50 FR 40003, Oct. 1, 1985]

APPENDIX A—TABLE FOR SUBPART B

TABLE 1—RELEASE LIMITS FOR CONTAINMENT REQUIREMENTS [Cumulative releases to the accessible environment for 10,000 years after disposal]

Radionuclide	Release limit per 1,000 MTHM or other unit of waste (see notes) (curies)
Americium-241 or -243	100
Carbon-14	100
Cesium-135 or -137	1,000
lodium-129	100
Neptunium-237	100
Plutonium-238, -239, or -242	100
Radium-226	100
Strontium-90	1,000
Technetium-99	10,000
Thorium-230 or -232	10
Tin-126	1,000
Uranium-233, -235, -236, or -238	100
Any other alpha-emitting radionuclide with a half-life greater than 20 years	100
Any other radionuclide with a half-life greater than 20 years that does not emit alpha particles	1000

APPLICATION OF TABLE 1

NOTE 1: *Units of Waste*. The Release Limits in Table 1 apply to the amount of wastes in any one of the following:

(a) An amount of spent nuclear fuel containing 1,000 metric tons of heavy metal (MTHM) exposed to a burnup between 25,000 megawatt-days per metric ton of heavy metal (MWd/MTHM) and 40,000 MWd/MTHM;
(b) The high-level radioactive wastes generated from reprocessing each 1,000 MTHM exposed to a burnup between 25,000 MWd/ MTHM and 40,000 MWd/MTHM;
(c) Each 100,000,000 curies of gamma or beta-emitting radionuclides with half-lives greater than 20 years but less than 100 years (for use as discussed in Note 5 or with materials that are identified by the Commission as high-level radioactive waste in accordance with part B of the definition of high-level waste in the NWPA);
(d) Each 1,000,000 curies of other radionuclides (i.e., gamma or beta-emitters with half-lives greater than 100 years or any alpha-emitters with half-lives greater than 20 years) (for use as discussed in Note 5 or with materials that are identified by the Commission as high-level radioactive waste in accordance with part B of the definition of high-level waste in the NWPA); or
(e) An amount of transuranic (TRU) wastes coring one million curies of alpha-emitting transuranic radionuclides with half-lives greater than 20 years.

NOTE 2: *Release Limits for Specific Disposal Systems*. To develop Release Limits for a particular disposal system, the quantities in Table 1 shall be adjusted for the amount of waste included in the disposal system compared to the various units of waste defined in Note 1. For example:

(a) If a particular disposal system contained the high-level wastes from 50,000 MTHM, the Release Limits for that system would be the quantities in Table 1 multiplied by 50 (50,000 MTHM divided by 1,000 MTHM).
(b) If a particular disposal system contained three million curies of alpha-emitting transuranic wastes, the Release Limits for that system would be the quantities in Table 1 multiplied by three (three million curies divided by one million curies).
(c) If a particular disposal system contained both the high-level wastes from 50,000 MTHM *and* 5 million curies of alpha-emitting transuranic wastes, the Release Limits for that system would be the quantities In Table 1 multiplied by 55:

$$\frac{50{,}000 \text{ MTHM}}{1{,}000 \text{ MTHM}} + \frac{5{,}000{,}000 \text{ curies TRU}}{1{,}000{,}000 \text{ curies TRU}} = 55$$

NOTE 3: *Adjustments for Reactor FueLs with Different Burnup*. For disposal systems containing reactor fuels (or the high-level wastes from reactor fuels) exposed to an average burnup of less than 25,000 MWd/ MTHM or greater than 40,000 MWd/ MTHM, the units of waste defined in (a) and (b) of Note 1 shall be adjusted. The unit shall be multiplied by the ratio of 30,000 MWd/MTHM divided by the fuel's actual average burnup, except that a value of 5,000 MWd/MTHM may be used when the average fuel burnup is below 5,000 MWd/ MTHM and a value of 100,000 MWd/ MTHM shall be used when the average fuel burnup is above 100,000 MWd/MTHM. This adjusted unit of waste shall then be used in determining the Release Limits for the disposal system.

For example, if a particular disposal system contained only high-level wastes with an average burnup of 3,000 MWd/ MTHM, the unit of waste for that system would be:

$$1{,}000 \text{ MTHM} \times \frac{(30{,}000)}{(5{,}000)} = 6{,}000 \text{ MTHM}$$

If that disposal system contained the high-level wastes from 60,000 MTHM (with an average burnup of 3,000 MWd/MTHM). then the Release Limits for that system would be the quantities in Table 1 multiplied by ten:

$$\frac{60{,}000 \text{ MTHM}}{6{,}000 \text{ MTHM}} = 10$$

which is the same as:

$$\frac{60{,}000 \text{ MTHM}}{1{,}000 \text{ MTHM}} \times \frac{(5{,}000 \text{ MWd/MTHM})}{(30{,}000 \text{ MWd/MTHM})} = 10$$

NOTE 4: *Treatment of Fractionated High-Level Wastes*. In some cases, a high-level waste stream from reprocessing spent nuclear fuel may have been (or will be) separated into two or more high-level waste components destined for different disposal systems. In such cases, the implementing agency may allocate the Release Limit multiplier (based upon the original MTHM and the average fuel burnup of the high-level waste stream) among the various disposal systems as it chooses, provided that the total Release Limit multiplier used for that waste stream at all of its disposal systems may not exceed the Release Limit multiplier that would be used if the entire waste stream were disposed of in one disposal system.

NOTE 5: *Treatment of Wastes with Poorly Known Burnups or Original MTHM*. In some cases, the records associated with particular high-level waste streams may not be adequate to accurately determine the original metric tons of heavy metal in the reactor fuel that created the waste, or to determine the average burnup that the fuel was exposed to. If the uncertainties are such that the original amount of heavy metal or the average fuel burnup for particular high-level waste streams cannot be quantified, the units of waste derived from (a) and (b) of Note 1 shall no longer be used. Instead, the units of waste defined in (c) and (d) of Note 1 shall be used for such high-level waste streams. If the uncertainties in such information allow a range of values to be associated with the original amount of heavy metal or the average fuel burnup, then the calculations described in previous Notes will be conducted using the values that result in the smallest Release Limits, except that the Release Limits need not be smaller than those that would be calculated using the units of waste defined in (c) and (d) of Note 1.

NOTE 6: *Uses of Release Limits to Determine Compliance with § 191.13* Once release limits for a particular disposal system have been determined in accordance with Notes 1 through 5, these release limits shall be used to determine compliance with the requirements of § 191.13 as follows. In cases where a mixture of radionuclides is projected to be released to the accessible environment, the limiting values shall be determined as follows: For each radionuclide in the mixture, determine the ratio between the cumulative release quantity projected over 10,000 years and the limit for that radionuclide as determined from Table 1 and Notes I through 5. The sum of such ratios for all the radionuclides in the mixture may not exceed one with regard to § 191.13(a)(1) and may not exceed ten with regard to § 191.13(a)(2).

For example, if radionuclides A, B, and C are projected to be released in amounts Q_a, Q_b, and Q_c, and if the applicable Release Limits are RL_a, RL_b, and RL_c, then the cumulative releases over 10,000 years shall be limited so that the following relationship exists:

$$\frac{Q_a}{RL_a} + \frac{Q_b}{RL_b} + \frac{Q_c}{RL_c} < 1$$

APPENDIX B—GUIDANCE FOR IMPLEMENTATION OF SUBPART B

[NOTE: The supplemental information in this appendix is not an integral part of 40 CFR Part 191. Therefore, the implementing agencies are not bound to follow this guidance. However, it is included because it describes the Agency's assumptions regarding the implementation of Subpart B. This appendix will appear in the Code of Federal Regulations.]

The Agency believes that the implementing agencies must determine compliance with §§ 191.13, 191.15, and 191.16 of Subpart B by evaluating long-term predictions of disposal system performance. Determining compliance with § 191.13 will also involve predicting the likelihood of events and processes that may disturb the disposal system. In making these various predictions, it will be appropriate for the implementing agencies to make use of rather complex computational models, analytical theories, and prevalent expert judgment relevant to the numerical predictions. Substantial uncertainties are likely to be encountered in making these predictions. In fact, sole reliance on these numerical predictions to determine compliance may not be appropriate; the implementing agencies may choose to supplement such predictions with qualitative judgments as well. Because the procedures for determining compliance with Subpart B have not been formulated and tested yet, this appendix to the rule indicates the Agency's assumptions regarding certain issues that may arise when implementing §§ 191.13, 191.15, and 191.16. Most of this guidance applies to any type of disposal system for the wastes covered by this rule. However, several sections apply only to disposal in mined geologic repositories and would be inappropriate for other types of disposal systems.

Consideration of Total Disposal System. When predicting disposal system performance, the Agency assumes that reasonable projections of the protection expected from all of the engineered and natural barriers of a disposal system will be considered. Portions of the disposal system should not be disregarded, even if projected performance is uncertain, except for portions of the system that make negligible contributions to the overall isolation provided by the disposal system.

Scope of Performance Assessments. Section 191.13 requires the implementing agencies to evaluate compliance through performance assessments as defined in § 191.12(q). The Agency assumes that such performance assessments need not consider categories of events or processes that are estimated to have less than one chance in 10,000 of occurring over 10,000 years. Furthermore, the performance assessments need not evaluate in detail the releases from all events and processes estimated to have a greater likelihood of occurrence. Some of these events and processes may be omitted from the performance assessments if there is a reasonable expectation that the remaining probability distribution of cumulative releases would not be significantly changed by such omissions.

Compliance with § 191.13. The Agency assumes that, whenever practicable, the implementing agency will assemble all of the results of the performance assessments to determine compliance with § 191.13 into a "complementary cumulative distribution function" that indicates the probability of exceeding various levels of cumulative release. When the uncertainties in parameters are considered in a performance assessment, the effects of the uncertainties considered can be incorporated into a single such distribution function for each disposal system considered. The Agency assumes that a disposal system can be considered to be in compliance with § 191.13 if this single distribution function meets the requirements of § 191.13(a).

Compliance with §§ 191.15 and 191.16. When the uncertainties in undisturbed performance of a disposal system are considered, the implementing agencies need not require that a very large percentage of the range of estimated radiation exposures or radionuclide concentrations fall below limits established in §§ 191.15 and 191.16, respectively. The Agency assumes that compliance can be determined based upon "best estimate" predictions (e.g., the mean or the median of the appropriate distribution, whichever is higher).

Institutional Controls. To comply with § 191.14(a), the implementing agency will assume that none of the active institutional controls prevent or reduce radionuclide releases for more than 100 years after disposal. However, the Federal Government is committed to retaining ownership of all disposal sites for spent nuclear fuel and high-level and transuranic radioactive wastes and will establish appropriate markers and records, consistent with § 191.14(c). The Agency assumes that, as long as such passive institutional controls endure and are understood, they: (1) Can be effective in deterring systematic or persistent exploitation of these disposal sites; and (2) can reduce the likelihood of inadvertent, intermittent human intrusion to a degree to be determined by the implementing agency. However, the Agency believes that passive institutional controls can never be assumed to eliminate the chance of inadvertent and intermittent human intrusion into these disposal sites.

Consideration of Inadvertent Human Intrusion into Geologic Repositories . The most speculative potential disruptions of a mined geologic repository are those associated with inadvertent human intrusion. Some types of intrusion would have virtually no effect on a repository's containment of waste. On the other hand, it is possible to conceive of intrusions (involving widespread societal loss of knowledge regarding radioactive wastes) that could result in major disruptions that no reasonable repository selection or design precautions could alleviate. The Agency believes that the most productive consideration of inadvertent intrusion concerns those realistic possibilities that may be usefully mitigated by repository design, site selection, or use of passive controls (although passive institutional controls should not be assumed to completely rule out the possibility of intrusion). Therefore, inadvertent and intermittent intrusion by exploratory drilling for resources (other than any provided by the disposal system itself) can be the most severe intrusion scenario assumed by the implementing agencies. Furthermore, the implementing agencies can assume that passive institutional controls or the intruders' own exploratory procedures are adequate for the intruders to soon detect, or be warned of, the incompatibility of the area with their activities.

Frequency and Severity of Inadvertent Human Intrusion into Geologic Repositories. The implementing agencies should consider the effects of each particular disposal system's site, design, and passive institutional controls in judging the likelihood and consequences of such inadvertent exploratory drilling. However, the Agency assumes that the likelihood of such inadvertent and intermittent drilling need not be taken to be greater than 30 boreholes per square kilometer of repository area per 10,000 years for geologic repositories in proximity to sedimentary rock formations, or more than 3 boreholes per square kilometer per 10,000 years for repositories in other geologic formations. Furthermore, the Agency assumes that the consequences of such inadvertent drilling need not be assumed to be more severe than: (1) Direct release to the land surface of all the ground water in the repository horizon that would promptly flow through the newly created borehole to the surface clue to natural lithostatic pressure—or (if pumping would be required to raise water to the surface) release of 200 cubic meters of ground water pumped to the surface if that much water is readily available to be pumped; and (2) creation of a ground water flow path with a permeability typical of a borehole filled by the soil or gravel that would normally settle into an open hole over time—not the permeability of a carefully sealed borehole.

Appendix C

AGENDA

Symposium on Radioactive Waste Repository Licensing
Board on Radioactive Waste Management
National Academy of Sciences/National Research Council
Auditorium
2101 Constitution Avenue NW
Washington, DC

Monday, Sept.17, 1990

Session IA-Chairman: Frank Parker, Chairman BRWM, Vanderbilt University		
0900–0915	Welcome & Introduction	Frank L. Parker, Chairman, BRWM
0915–1000	Keynote Address Repository Performance— The Regulatory Challenge	James Curtiss Commissioner, USNRC
1000–1040	Criteria For High-Level Radioactive Waste Disposal In The OECD/NEA Area	J.P. Olivier OECD/NEA
1040–1100	Break	
Session IB-Chairman: Susan Wiltshire, Member BRWM, J.K. Associates		
1100–1130	(How) Can We Demonstrate Compliance With Safety Criteria For Licensing Repositories? — A European Perspective	Charles McCombie NAGRA
1130–1200	The Regulatory Process For Licensing Of A Final Repository For Spent Fuel In Sweden	Sören Norrby SKI
1200–1230	Assessing The Acceptability of Nuclear Fuel Waste Disposal In Canada	Kenneth Dormuth AECL
1230–1330	Lunch	

Session IC-Chairman: Charles Fairhurst, Vice Chairman BRWM, University of Minnesota		
1330–1410	United States Approach To High-Level Radioactive Waste Regulation	Thomas Cotton J.K. Associates
1410–1425	NWTRB Concerns With The Licensing Process	Don U. Deere Chairman, NWTRB Melvin W. Carter Member, NWTRB
1425–1440	A Review Of Comments And Recommendations Of The ACNW USNRC	Dade W. Moeller Chairman, ACNW, USNRC
1440–1500	"11,990 A.D." Environmental Radiation Protection Standards	Arthur Kubo Robert W. Bishop, Esq. Blue Ribbon Panel
1500–1515	Break	
1515–1540	WIPP And Its Compliance With The EPA Standard	Wendell Weart Sandia Nat'l Lab.
1540–1600	Practical Aspects Of Supporting A License Application For Yucca Mountain	Thomas O. Hunter Sandia Nat'l Lab.
Roundtable I-Chairman: G. ROSS Heath, Member BRWM, University of Washington		
1600–1730	Roundtable Discussion	All Session I Speakers

Tuesday, Sept. 18, 1990

Session IIA-Chairman: William Colglazier, Member BRWM, University of Tennessee		
0830–0900	EPA Views On Scientific Advisories	Richard Guimond EPA
0900–0930	Comments on NAS/NRC Report: "Rethinking High-Level Radioactive Waste Disposal"	Robert Bernero USNRC
0930–1000	USDOE Role In Regulatory Issues	John Bartlett DOE
1000–1030	A Citizens' Group Perspective On Regulatory Aspects Of The HLRW And TRU Disposal Programs	Dan Reicher NRDC
1030–1045	Break	

1045–1100	Nevada's View Of The Current Program As It Relates To Licensing A HLRW Repository	Robert Loux Nevada
1100–1115	New Mexico Environmental Evaluation Group Perspective on Transuranic and High-Level Waste Disposal Regulations	Robert Neill Director, EEG
1115–1130	Congressional Perspectives On Radioactive Waste Repository Licensing	Benjamin Cooper Staff-U.S. Senate Committee on Energy and Natural Resources
1130–1145	Observations On Integrated HLW Repository Performance Assessment And Related Regulatory Issues	Robert Shaw EPRI
1145–1300	Lunch	
Session IIB-Chairman: Chris Whipple, Member BRWM, Clement International		
1300–1330	Perspective On 40 CFR 191 and 10 CFR 60 Based On Results From Waste Package Studies For An Unsaturated Tuff Repository	Lawrence Ramspott LLNL
1330–1400	Risk Based Compliance Evaluation Of The Yucca Mountain Site Including Impacts Of Repository Design Features	Paul Gnirk RE/SPEC
1400–1430	Hydrogeologic Considerations In Setting Environmental Standards For HLRW	James W. Mercer GeoTrans, Inc.
1430–1445	Break	
1445–1510	Uncertainty And The Implementation Of Regulatory Standards	David L. Pentz Golder Assoc., Inc.
1510–1535	Considerations Based On The USEPA Science Advisory Board Subcommittee 1984 Report On 40 CFR 191	Robert Budnitz FRA, Inc.
1535–1615	Can Alternative Dispute Resolution Approaches Help?	Gail Bingham Conservation Found.
Roundtable II-Chairman: Frank Parker, Chairman BRWM, Vanderbilt University		
1615–1645	Improving the Licensing Process for the Disposal of TRU and High-Level Radioactive Waste	All Session I & II Chairmen
1645–1700	Closing Remarks	Frank L. Parker Chairman, BRWM

Appendix D

LIST OF SPEAKERS

Symposium on Radioactive Waste Repository Licensing
National Academy of Sciences/National Research Council
September 17–18, 1990

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* This speaker may be contacted for a copy of his remarks or vu-graphs.

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At the time of the symposium, Mr. Guimond was the Director of the Office of Radiation Programs for EPA.

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Appendix E

REPORT on the review of PROPOSED ENVIRONMENTAL STANDARDS FOR THE MANAGEMENT AND DISPOSAL OF SPENT NUCLEAR FUEL, HIGH-LEVEL AND TRANSURANIC RADIOACTIVE WASTES (40 CFR PART 191)

by the High-Level Radioactive Waste Disposal Subcommittee

Science Advisory Board

U.S. Environmental Protection Agency

January 1984

EXECUTIVE SUMMARY

The High-Level Radioactive Waste Disposal Subcommittee (HLRW) of the Executive Committee of the Science Advisory Board (SAB) has completed an extensive review of the scientific and technical basis for EPA's proposed rule for the disposal of high level radioactive wastes, the highlights of which are presented in this summary.

Technologies now exist for the disposal of such wastes, and standards adopted for them should strike an appropriate balance between conservatism and practicality. Overall, the Subcommittee is confident that, consistent with the intent of this standard-setting program, the job of disposing of high-level radioactive waste can be achieved with reasonable assurance for the well-being of present and future generations.

The Subcommittee supports the general form of the proposed standards, including (a) the use of a societal objective as an upper bound of acceptable health (cancer and genetic) effects, (b) the focus on performance standards in terms of release limits rather than individual exposures, (c) the reference level of the initial 10,000 year time frame applicable to both the societal objective and the release limits, (d) the use of a probabilistic approach, and (e) the use of qualitative assurance requirements, as modified by the Subcommittee, but issued as Federal Radiation Protection Guidance to other Federal agencies in lieu of inclusion in the proposed rule.

The Subcommittee, while accepting the general form of the proposed standards, recommends several changes in the standards and improvements in the supporting methodology. The principal recommendations are highlighted in the following summation. A more comprehensive and detailed presentation of these and other major recommendations can be found in Section IV, Major Findings and Recommendations.

A. The Standard

1. The Subcommittee recommends that the release limits specified in Table 2 of the proposed standards be increased by a factor of ten, thereby causing a related ten-fold relaxation of the proposed societal objective (population risk of cancer).*

The Subcommittee notes that the proposed release limits are directly related to the societal objective of not exceeding 1,000 deaths in 10,000 years, and thus, compliance with this recommendation carries with it a

* Two members of the Subcommittee, Dr. Lash and Dr. Giletti, dissent from this view. They believe that the Office of Radiation Programs' more stringent standard is justified and can be met by sufficient numbers of proposed disposal sites.

related ten-fold increase in the societal objective. The relaxation of the release limits is, in the Subcommittee's opinion, justified for the following reasons. First, the proposed release limits in Table 2, and therefore the proposed societal objective, are considerably more stringent than those standards generally required or adopted in today's society (see for instance Table A on page 12 of this report). Second, in addition to the fact that some of the cancer deaths which might result from these releases are calculated using conservative assumptions that probably overestimate the number, some of these deaths would have resulted at least in part from the unmined ore from which the wastes were subsequently generated, and thus are substitutional rather than additional in nature. Third, the Subcommittee believes that the compounding of conservatism by EPA in the choice of probabilities and specific model parameters used throughout the analysis is not warranted.

EPA should also clarify the analytical framework that forms the basis for the limits in Table 2 of the proposed standards. The Subcommittee believes that such clarification will help to establish clearly the relationship between the release limits and the societal objective, and will facilitate future amendments to the standard as knowledge increases regarding radiation health effects or radionuclide migration in the biosphere.

Note: In Section IV, #7(Models) and #13(Geochemical Data), the Subcommittee has recommended that EPA make certain specific changes and corrections to their predictive models. Some of these changes will result in changes to the release limits for individual radionuclides given in Table 2 of the proposed standards, and will be separate from the ten-fold change in the release limits recommended above. The Subcommittee believes that the changes in the release limits, resulting from the changes to the predictive models, are independent of and would not lead to additional modification to the proposed societal objective beyond the ten-fold increase discussed above.

B. Uncertainty and the Standard

1. We recommend that the probabilistic release criteria in the draft standard be modified to read "analysis of repository performance shall demonstrate that there is less than a 50% chance of exceeding the Table 2 limits, modified as is appropriate. Events whose median frequency is less than one in one-thousand in 10,000 years need not be considered."

2. We recommend that use of a quantitative probabilistic condition on the modified Table 2 release limits be made dependent on EPA's ability to provide convincing evidence that such a condition is practical to meet and will not lead to serious impediments, legal or other

wise, to the licensing of high-level-waste geologic repositories. If such evidence cannot be provided, we recommend that EPA adopt qualitative criteria, such as those suggested by the NRC.

The Subcommittee believes that the modified probabilistic criteria will make the proposed standards more practical to apply without undue, time-consuming disagreements. Further risk studies need to be performed and subjected to systematic, critical evaluation in order to establish a more acceptable probabilistic basis for the standard.

C. The Time Frame-10,000 years and Beyond

1. We recommend that EPA retain the 10,000 year time period as the basis for determining the adequacy of repository performance. We believe that use of formal numerical criteria limited to this approximate time period is a scientifically acceptable regulatory approach.

2. We recommend that the process of selection of sites for disposal systems also take into account potential releases of radioactivity somewhat beyond 10,000 years. Particular attention should be focused on potential releases of long-lived alpha-emitting radionuclides and their decay products.

Although the selection of a time frame is in large part arbitrary, we endorse EPA's choice of 10,000 years. Modeling and risk assessments for the time periods involved in radioactive waste disposal require extension of such developing techniques well beyond usual extrapolations; however, the extension for 10,000 years can be made with reasonable confidence. Also, the period of 10,000 years is likely to be free of major geologic changes, such as volcanism or renewed glaciation, and with proper site selection the risk from such changes can be made negligible. Potential radionuclide releases will not stop with 10,000 years, however, but may continue in amounts equal to or exceeding those estimated for the initial period.

The degree of confidence with which impacts can be modeled much further in the future is much less certain. We do not recommend detailed modeling calculations regarding post-10,000 year releases, but estimates should be made, and should be considered as factors in disposal site selection.

D. Population vs. Individual Risk

1. We recommend that EPA retain the use of a population risk criterion as the measure of performance for the proposed standards.

We find that an approach employing individual dose limits, i.e., considering some "maximally exposed individual" or alternatively some "average exposed individual" would, in practice, make the standard difficult to meet with high assurance for very long times, and that use of a population risk approach is more practical. In our view, however, it is important that for the first several hundred years residents of the region surrounding a repository have very great assurance that they will suffer no, or negligible, ill effects from the repository. For longer periods, we believe that EPA should rely on the existence of continuing requirements similar to its current drinking water standards to protect groups of individuals.

E. Coordination of Policies and Standards

1. We recommend that EPA initiate action within the Federal Government for the establishment of an interagency council to coordinate the development of high-level radioactive waste disposal policy, standards, and regulatory practices and to serve as a forum for exchange of scientific and technological information.

Several Federal agencies are involved in the process of establishing radiation protection policies, standards and operational requirements governing the disposal of high-level radioactive wastes, including EPA, NRC, DOE and DOD, together with states, appropriate entities of Congress and the judiciary. Overlapping and independent authorities and responsibilities exist under present laws. Conflicting terminology and standards exist, e.g., the definitions of high-level and other radioactive wastes. Coordination of Federal policies and practices is essential to the U.S. high-level radioactive waste disposal program. Success of the program will depend on extensive interaction and agreement among the appropriate Federal agencies. While the lead in coordination could be appropriate for the NRC or DOE, the Subcommittee feels that the obligation for achieving mutual interaction more appropriately belongs to the EPA under its authority to issue environmental standards and Federal Radiation Protection Guidance.

F. Research Needs-A Matter of Priority

1. We recommend that EPA support, or encourage other agencies to support, continuing research in technical areas where major uncertainties still exist, particularly in the biological effects of radiation, the geochemical transport of radionuclides, and the characterization of rock-mass deformation.

The Subcommittee strongly endorses support of research aimed at diminishing or clarifying as many of these uncertainties as can be attacked with some hope of resolution. The research, although expensive, could bring about a substantial reduction in the overall cost of the disposal system.

G. Responses to Original Subcommittee Charge

At the time of the Subcommittee's formation, it was directed, by the Executive Committee of the Science Advisory Board, to address six (6) principal issues. Although a brief response to each charge is presented here, the charges are broad in scope and the Subcommittee's review of them generated a number of more explicit and specific issues which are addressed in detail in the body of this report.

1. The scientific and technical rationale behind the choice of a 10,000 year time period as the basis for assessment of disposal facility performance.

This issues has been addressed in C above.

2. The technical basis for the selection of the proposed performance requirements, including risk-assessment methodology, uncertainties in the data and in the analytical methods, and the estimation of premature deaths.

These aspects of the analysis form the basis for the proposed standards and were areas most carefully and critically evaluated by the Subcommittee. Although the Subcommittee makes a number of recommendations regarding risk assessment, pathway and health modeling and the need for improved documentation, we believe that Office of Radiation Programs, EPA, has handled these subjects well and furthermore, has been positively responsive to the recommendations of the Subcommittee. We think, however, that EPA has made overly conservative choices and decisions throughout the development of the technical bases supporting the standards, leading to overestimation of the long-term effect of disposal, and hence that the proposed standards are too restrictive and compliance may be difficult to verify.

3. The scientific appropriateness of concentrating on disposal in geologic media.

This part of the charge needed no consideration by the Subcommittee, since disposal in geologic media is mandated for at least the first two sites by the Nuclear Waste Policy Act of 1982 (PL 97-425), enacted after the charge was prepared. No member of the Subcommittee, however, disagrees with this initial approach.

4. The validity of the conclusion that, under the proposed rule, the risks to future generations will be no greater than the risks from equivalent amounts of naturally occurring uranium ore bodies .

In reviewing this conclusion, we found, and EPA acknowledged, that the comparison is uncertain because of the extreme variability of uranium ore bodies. The Subcommittee thinks that the conclusion is valid in a very general way, if suitably qualified, but feels that it is unwise and not scientifically defensible to use the unmined ore as the only reference for comparison. We recommend that the comparison be extended to include the radioactivity of natural waters and the ambient radiation in the natural environment.

5. The adequacy of the economic analysis.

The Subcommittee considers there are significant shortcomings in the economic analyses supporting the proposed standards. Since the management, storage, and disposal of high-level waste is a multi-billion dollar venture, we believe that the shortcomings are important and should be remedied. It is noteworthy that, even though the savings associated with individual choices may seem relatively insignificant, the absolute costs are so large that even small percentage savings are worthwhile. The high absolute costs appear to be relatively independent of the proposed standard, and simply reflect the decision to use deep mined geologic disposal sites with multiple barriers. Thus, appreciable savings are not likely to be realized in terms of basic cost by relaxation of the standards. However, the cost of demonstrating compliance may be very high, and cost reductions that may be achieved by sophisticated compliance demonstrations could be substantial.

We recognize the need for cost/benefit analyses, using the best available data, but we note that a precise economic analysis will not be possible or meaningful until it is performed upon an actual repository at a specific site.

6. The ability of the analytical methods/models used in the analysis to predict potential releases from the disposal facility and their resultant effects on human health. Included would be an evaluation of the model's ability to deal with uncertainty and the confidence, in a statis

tical sense, that the model predictions are adequate to support selection of projected performance requirements.

In general, EPA's analytical methodology and modeling used throughout the development of the generic repository's performance, including releases and subsequent cancer deaths, are deemed to be conservative. The Subcommittee makes several suggestions for specific improvements and updating. We emphasize that modeling, including the evaluation of uncertainty and confidence therein, is an emerging and developing technique. Adding to the uncertainties implicit in a technique that is still under development are the multitude of poorly known factors associated with the extrapolation in time to 10,000 years and beyond, and the problem of securing public acceptance of the standard. We believe, nevertheless, that the EPA's effort, modified as recommended by this report, will fulfill the intent of the Nuclear Waste Policy Act of 1982.

Appendix F

List of Acronyms

ACNW	Advisory Committee on Nuclear Waste (USNRC)
AECL	Atomic Energy of Canada, Ltd.
BRWM	Board on Radioactive Waste Management
CCDF	Complementary Cumulative Distribution Function-summing process of probabilities of exceeding the standard. Plotted at probability over time compared to standard ratio
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
EEG	New Mexico Environmental Evaluation Group
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
FRA	Future Resources Associates, Inc.
HLRW	high-level radioactive waste
LLNL	Lawrence Livermore National Laboratory
MRS	monitored retrievable storage (long-term)
MTHM	metric tons of heavy metal
NAGRA	National Cooperative for the Storage of Radioactive Waste (Switzerland)
NAS/NRC	National Academy of Sciences/National Research Council
NEA	Nuclear Energy Agency of OECD
NRDC	Natural Resources Defense Council
NWTRB	Nuclear Waste Technical Review Board
OECD	Office of Economic Cooperation and Development-see NEA
RE/SPEC	Research Specialists, Rapid City, SD
SAB	EPA Science Advisory Board
SKI	Swedish Nuclear Power Inspectorate
TRU	transuranic waste
USNRC	U.S. Nuclear Regulatory Commission
WIPP	Waste Isolation Pilot Plant