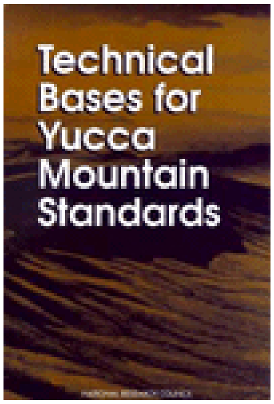
Free Executive Summary



Technical Bases for Yucca Mountain Standards

Committee on Technical Bases for Yucca Mountain Standards, National Research Council

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The United States currently has no place to dispose of the high-level radioactive waste resulting from the production of the nuclear weapons and the operation of nuclear electronic power plants. The only option under formal consideration at this time is to place the waste in an underground geologic repository at Yucca Mountain in Nevada. However, there is strong public debate about whether such a repository could protect humans from the radioactive waste that will be dangerous for many thousands of years. This book shows the extent to which our scientific knowledge can guide the federal government in developing a standard to protect the health of the public from wastes in such a repository at Yucca Mountain. The U.S. Environmental Protection Agency is required to use the recommendations presented in this book as it develops its standard.

EXECUTIVE SUMMARY

Proper management of high-level radioactive wastes, including those resulting from the production of nuclear weapons and the operation of nuclear electric power plants, is vital for the protection of the public health and safety. It has been longstanding federal policy to dispose of these wastes underground in a mined geologic repository. The U.S. Department of Energy (DOE) is charged with the development and eventual operation of a repository. The U.S. Environmental Protection Agency (EPA) and the U.S. Nuclear Regulatory Commission (USNRC) share the responsibility for regulating the disposal program to ensure adequate protection of the health and safety of the public.

EPA promulgated its first standard for deep geologic disposal of high-level radioactive waste in 1985; this standard was challenged, litigated, and ultimately reissued in 40 CFR 191 in December 1993. Before EPA promulgated the new standard, however, Congress enacted the Energy Policy Act of 1992, which mandated a separate process for setting a standard specifically for the proposed repository at Yucca Mountain, Nevada. In Section 801 of the Act, Congress required EPA to arrange for an analysis by the National Academy of Sciences of the scientific basis for a standard to be applied at the Yucca Mountain site and directed EPA," based upon and consistent with the finding and recommendations of the National Academy of Sciences, [to] promulgate, by rule, public health and safety standards for protection of the public from releases from radioactive materials stored in or disposed of in the repository at the Yucca Mountain site." This report responds to the charge of Section 801.

Implicit in setting a Yucca Mountain standard, is the assumption that EPA, USNRC, and DOE can, with some degree of confidence, assess the future performance of a repository system for time scales that are so long that experimental methods cannot be used to confirm directly predictions of the behavior of the system or even of its components. This premise raises the basic issue of whether scientifically justifiable analyses of repository behavior over many thousands of years in the future can be made. We conclude that such analyses are possible, within restrictions noted in this report. Nevertheless, these assessments of repository performance must contend with substantial uncertainties, and some areas

— projecting the behavior of human society over very long periods, for example — are beyond the limits of scientific analysis. We have made explicit those instances, and have also pointed out where we believe it is appropriate to rely on informed judgments and reasonable assumptions to supplement scientific analysis.

In attempting to make the best use of the scientific understanding that is available, we have arrived at recommendations that differ in important ways from the approach followed by EPA in 40 CFR 191. In particular, we recommend:

- The use of a standard that sets a limit on the risk to individuals of adverse health effects from releases from the repository. 40 CFR 191 contains an individual dose standard, and it continues to rely on a containment requirement that limits the releases of radionuclides to the accessible environment. The stated goal of the containment requirement was to limit the number of health effects to the global population to 1,000 incremental fatalities over 10,000 years. We do not recommend that a release limit be adopted.
- That compliance with the standard be measured at the time of peak risk, whenever it occurs.[1] The standard in 40 CFR 191 applies for a period of 10,000 years. Based on performance assessment calculations provided to us, it appears that peak risks might occur tens to hundreds of thousands of years or even farther into the future.
- Against a risk-based calculation of the adverse effect of human intrusion into the repository. Under 40 CFR 191, an assessment must be made of the frequency and consequences of human intrusion for purposes of demonstrating compliance with containment requirements. In contrast, we conclude that it is not possible to assess the frequency of intrusion far into the future. We do recommend that the consequences of an intrusion be calculated to assess the resilience of the repository to intrusion.

[1] Within the limits imposed by the long-term stability of the geologic environment, which is on the order of one million years.

Finally, we have identified several instances where science cannot provide all of the guidance necessary to resolve an issue. This is particularly true in developing procedures for compliance assessment. Setting the standard, therefore requires addressing policy questions as well as scientific ones. We recommend that resolution of policy issues be done through a rulemaking process that allows opportunity for wide-ranging input from all interested parties. In these cases, we have tried to suggest positions that could be used by the responsible agency in formulating a proposed rule. Other starting positions are possible, and of course the final rule could differ markedly from any of them.

Although we have taken a broad view of the scientific basis for the standard, we have not addressed the social, political, and economic issues that might have more effect on the repository program than the health standard. In particular, we have not recommended what levels of risk are acceptable; we have not considered whether the development of a permanent repository should proceed at this time; nor have we made a judgment about the potential for the Yucca Mountain site to comply with the standard eventually adopted.

PROTECTING HUMAN HEALTH

In Section 801, Congress directs that EPA set a standard for Yucca Mountain by specifying the maximum annual effective dose equivalent to individual members of the public. The first question posed in Section 801 is whether such a standard will provide a reasonable basis for protecting the health and safety of the general public. We recommend the use of a standard designed to limit individual risk, and describe how a standard might be structured on this basis. We then address the specific question of protection of public health in the context of the individual-risk standard and compare this standard to the one currently used by EPA. Based on this analysis, we conclude not only that the individual risk standard would protect the health of the general public, but also that it is a particularly appropriate standard for the Yucca Mountain site in light of the characteristics of this site.

The risks to humans from exposures to low levels of radiation have been assessed in detail by national and international organizations. These assessments are fraught with uncertainty, but it has been possible to reach a reasonable consensus within the scientific community on the relationship of dose and health effects, which is generally considered to provide an acceptable basis for evaluating the risks attributable to a given dose or the degree of protection afforded by a given limitation of exposure. Additionally, a general consensus exists among national and international bodies on a framework for protecting the public health that provides a limit of 1 milliSievert (mSv) (100 millirem (mrem)) per year effective dose for continuous or frequent exposures from all anthropogenic sources of ionizing radiation other than medical exposures. A general consensus also appears to exist among national authorities in various countries to accept and use the principle of apportioning this total radiation dose limit among the respective anthropogenic sources of exposure, typically allocating to high-level waste disposal a range of 0.1 to 0.3 mSv (10 to 30 mrem) per year.

Elements of the Standard

A standard is a societally acceptable limit on some aspect of repository performance that should not be exceeded if the repository is to be judged safe. We recommend the use of a standard that sets a limit on the risk to individuals of adverse health effects from releases from the repository. A risk-based standard would not have to be revised in subsequent rulemaking if advances in scientific knowledge reveal that the dose-response relationship is different from that envisaged today. Such changes have occurred frequently in the past, and can be expected to occur in the future. For example, ongoing revisions in estimates of the radiation doses received by atomic bomb survivors of Hiroshima and Nagasaki might significantly modify the apparent dose-response relationships for carcinogenic effects in this population, as have previous revisions in dosimetry (see Straume et al., 1992). Moreover, risks to human health from different sources, such as nuclear power plants and toxic chemicals can be compared in reasonably understandable terms.

It is essential to define specifically how to calculate risk, however, for otherwise it will not be clear what number to use to compare to the risk limit established in the standard. We define risk as the expected value of a probabilistic distribution of health effects. The first step in calculating risk is to develop a distribution of doses received by individuals. A probabilistic distribution of health effects can be developed as the product of each value of dose received and the health effect per unit dose.

Structuring of the individual-risk standard requires specifying what level of protection is to be afforded, who is to be protected, and for how long. We acknowledge that determining what risk level is acceptable is not ultimately a question of science but of public policy. We note, however, that EPA has already used a dose limit equivalent to a risk level of 5×10^{-4} health effects in an average lifetime, or a little less than 10^{-5} effects per year assuming an average lifetime of 70 years, as an acceptable risk limit in its recently published 40 CFR 191. This limit is consistent with limits established by other federal nuclear regulations. In addition, the risk equivalent of the dose limits set by authorities outside the United States is also in the range of 10^{-5} to 10^{-6} per year (except for exposure to radon indoors or releases from mill tailings). This range is a reasonable starting point for EPA's rulemaking.

To determine whether a repository complies with the standard, it is necessary to calculate the risk to some individual or representative group of individuals and then to compare the result to the risk limit established in the standard. Therefore, the standard must specify the individual or individuals for whom the risk calculation is to be made. Although not strictly a scientific issue, we believe that the appropriate objective is to protect the vast majority of members of the public while also ensuring that the decision on the acceptability of a repository is not unduly influenced by the risks imposed on a very small number of individuals with unusual habits or sensitivities. The situation to be avoided, therefore, is an extreme case defined by unreasonable assumptions regarding the factors affecting dose and risk, while meeting the objectives of protecting the vast majority of the public. An approach that is consistent with this objective, and is used extensively elsewhere in the world, is the critical-group approach. <u>We recommend that the critical-group approach be used in the Yucca Mountain standards</u>.

The critical group has been defined by the International Commission on Radiological Protection (ICRP) as a relatively homogeneous group of people whose location and habits are such that they are representative of those individuals expected to receive the highest doses[2] as a result of the discharges of radionuclides. Therefore, as the ICRP notes, "because the actual doses in the entire population will constitute a distribution for which the critical group represents the extreme, this procedure is intended to ensure that no individual doses are unacceptably high." (ICRP, 1985a, at paragraph 46). In the context of an individual-risk standard, and using cautious, but reasonable, assumptions, the group would include the persons expected to be at highest risk, would be homogeneous in risk[3], and would be small in number. The critical-group risk calculated for purposes of comparison with the risk limit established in the standard would be the mean of the risks to the members of the group.

This definition requires specifying the persons who are likely to be at highest risk. In the present and near future, these persons are real; that is, they are the persons now living in the near vicinity of the repository and in the direction of the postulated flow of the plume of radionuclides. For the far future, however, it will be necessary to define hypothetical persons by making assumptions about lifestyle, location, eating habits, and other factors. The ICRP recommends use of present knowledge and cautious, but reasonable, assumptions.

The current EPA standard contains a time limit of 10,000 years for the purpose of assessing compliance. We find that there is no scientific basis for limiting the time period of an individual-risk standard in this way. We believe that compliance assessment is feasible for most physical and geologic aspects of repository performance on the time scale of the long-term stability of the fundamental geologic regime — a time scale that is on the order of 10^6 years at Yucca Mountain — and that at least some potentially important exposures might not occur until after several hundred thousand years. For these reasons, we recommend that compliance

[2] The ICRP defines critical group in dose terms. We use the ICRP terminology here to describe the concept as developed by the ICRP, and later adapt the concept to the risk framework.

[3] That is, the difference between the highest and lowest risk faced by individuals in the group should be relatively small. Should a radiation dose occur, however, it may affect only a few members of the group. This is the difference between risk (the chance of an adverse health effect) and outcome (a cancer that actually develops). Risk can be homogeneous, even when outcomes are quite diverse.

assessment be conducted for the time when the greatest risk occurs, within the limits imposed by long-term stability of the geologic environment.

Another time-related regulatory concern, based on ethical principles, is that of intergenerational equity. A health-based risk standard could be specified to apply uniformly over time and generations. Such an approach would be consistent with the principle of intergenerational equity that requires that the risks to future generations be no greater than the risks that would be accepted today. Whether to adopt this or some other expression of the principle of intergenerational equity is a matter for social judgment.

Protection of the General Public

Congress has asked whether a standard intended to protect individuals would also protect the general public in the case of Yucca Mountain. We conclude that an individual-risk standard would protect public health, given the particular characteristics of the site, provided that policy makers and the public are prepared to accept that very low radiation doses pose a negligibly small risk.

The individual risk-standard that we recommend is intended to protect a critical group. In this context, the general public includes both global populations as well as local populations that lie outside the critical group. Global populations might be affected because radionuclide releases from a repository can in theory be diffused throughout a very large and dispersed population. In the case of Yucca Mountain, the likely pathway leading to widely dispersed radionuclides is via the atmosphere beginning with release of carbon dioxide gas containing the carbon-14 (^{14}C) radioactive isotope which might escape from the waste canisters.

The risks of radiation produced by such wide, dispersion are likely to be several orders of magnitude below those of a local critical group. Great uncertainty exists about the number of health effects that would be imposed on the global population because of the difficulties in interpreting the risks associated with very small incremental doses of radiation. As noted in the BEIR V report (NRC, 1990a), the lower limit of the range of uncertainty in such risk estimates extends to zero (no effects). To address scenarios of widespread but extremely low-level doses, the radiation protection community has introduced the concept of negligible incremental dose (above background levels). For example, the National Council on Radiation Protection and Measurements (NCRP) has recommended a value of 0.01 mSv/yr (1 mrem/yr) per radiation source or practice (NCRP 1993), which currently would correspond to a projected risk of about 5×10^{-7}/yr for fatal cancers, assuming the linear hypothesis. We believe that this concept can be extended to risk and can be applied to the establishment of a radiation standard at Yucca Mountain. Defining the level of incremental risk that is negligible is a policy judgment. We suggest the risk equivalent of the negligible individual incremental dose recommended by the NCRP as a reasonable starting point for developing consensus.

Persons in some population outside the critical group may, however, still be exposed to risks in excess of the level of the negligible incremental risk but below the level of the critical group risk. The risks to these persons as individuals are, by definition, acceptable, but whether the effects on this population as a whole are acceptable remains a matter of judgment. Based on our review, we conclude that there is no technical basis for a population-risk standard by which to make such a judgment.

ASSESSING COMPLIANCE

Any standard to protect individuals and the public after the proposed repository is closed will require assessments of performance at times so far in the future that a direct demonstration of compliance is out of the question. The only way to evaluate the risks of adverse health effects and to compare them with the standard is to assess the estimated potential future behavior of the entire repository system and its potential effects on humans. This procedure, involving modeling of processes and events that might lead to releases and exposures, is called performance assessment.

The technical feasibility of developing performance assessment calculations to evaluate compliance with a risk standard at Yucca Mountain depends on the feasibility of modeling the relevant events and processes (including their probabilities) specific to that site. By soliciting technical appraisals at our open meetings, reviewing solicited and unsolicited written contributions, and drawing on the available literature and our own experience and expertise, we have assessed the types, magnitudes, and time-dependencies of the uncertainties associated with potential radionuclide transport from a Yucca Mountain repository, the effects of potential natural and human modifiers of repository performance, and the pathways through the biosphere.

Physical and Geologic Processes

The properties and processes leading to transport of radionuclides away from the repository include release from the waste form, transport to the near-field zone, gas phase transport to the atmosphere above Yucca Mountain and its dispersal in the world atmosphere, and transport from the unsaturated zone to the water table and from the aquifer beneath the repository to other locations from which water might be extracted by humans. We conclude that these physical and geologic processes are sufficiently quantifiable and the related uncertainties sufficiently boundable that the performance can be assessed over time frames during which the geologic system is relatively stable or varies in a boundable manner. The geologic record suggests that this time frame is on the order of 10^6 years. We further conclude that the probabilities and consequences of modifications by climate change, seismic activity, and volcanic eruptions at Yucca Mountain are sufficiently boundable that these factors can be included in performance assessments that extend over this time frame.

Exposure Scenarios

Performance assessment of physical and geologic processes will produce estimates of potential concentrations of radionuclides in ground water or air at different locations and times in the future. To proceed from these concentrations to calculations of risks to a critical group requires the development of an exposure scenario that specifies the pathways by which persons would be exposed to radionuclides released from the repository. Once an exposure scenario has been adopted, performance assessment calculations can be carried out with a degree of uncertainty comparable to the uncertainty associated with geologic processes and engineered systems.

Based upon our review of the literature, we conclude, however, that it is not possible to predict on the basis of scientific analyses the societal factors required for an exposure scenario. Specifying exposure scenarios therefore requires a policy decision that is appropriately made in a rulemaking process conducted by EPA. We recommend against placing the burden of postulating and defending an exposure scenario on the applicant for the license.

As with other aspects of defining standards and demonstrating compliance that involve scientific knowledge but must ultimately rest on policy judgments, we considered what to suggest to EPA as a useful starting point for rulemaking on exposure scenarios. Reflecting the disagreement inherent in the literature, we have not reached complete consensus on this question. It is essential that the scenario that is ultimately selected be consistent with the critical-group concept that we have advanced. Additionally, EPA should rely on the guidance of ICRP that the critical group be defined using present-day knowledge with cautious, but reasonable, assumptions.

We considered two illustrative approaches to the design of an exposure scenario that EPA might propose to initiate the rulemaking process. The approaches have many elements in common but differ in their treatment of assumptions about the location and lifestyle of persons who might be exposed to releases from the repository, and in the method of calculating the average risk of the members of the critical group. A substantial majority of the committee members, but not all, considers one of the approaches to be more consistent with the foregoing criteria. This particular approach explicitly accounts for how the physical characteristics of the site might influence population distribution and identifies the makeup of the critical group probabilistically.

HUMAN INTRUSION

Human activity that penetrates the repository (by drilling directly into it from the surface, for example) can cause or accelerate the release of radionuclides. Waste material could be brought to the surface and expose the intruder to high radiation doses, or the material could disperse into the biosphere. The second and third questions asked in Section 801 of the Energy Policy Act of 1992 concern the potential that at some time people might intrude into the repository.

With respect to the second question of Section 801, we conclude that it is not reasonable to assume that a system for post-closure oversight of the repository can be developed, based on active institutional controls, that will prevent an unreasonable risk of breaching the repository's engineered barriers or increasing the exposure of individual members of the public to radiation beyond allowable limits. This conclusion is founded on the absence of any scientific basis for making projections over the long-term of the social, institutional, or technological status of future societies. Additionally, there is no technical basis for making forecasts about the long-term reliability of passive institutional controls, such as markers, monuments, and records.

With respect to the third question in Section 801, we conclude that it is not possible to make scientifically supportable predictions of the probability that a repository's engineered or geologic barriers will be breached as a result of human intrusion over a period of 10,000 years. We reach this conclusion because we cannot predict the probability that a future intrusion would occur in a given future time period or the probability that a future intrusion would be detected and remediated, either when it occurs or later. In addition, we cannot predict which resources will be discovered or will become valuable enough to be the objective of an intruder's activity. We cannot predict the characteristics of future technologies for resource exploration and extraction, although continued developments in current noninvasive geophysical techniques could substantially reduce the frequency of exploratory boreholes.

Although there is no scientific basis for judging whether active institutional controls can prevent an unreasonable risk of human intrusion, we think that, if the repository is built, such controls and other activities might be helpful in reducing the risk of intrusion, at least for some initial period of time after a repository is closed. Therefore, we believe that a collection of prescriptive requirements, including active institutional controls, record-keeping, and passive barriers and markers would help to reduce the risk of human intrusion, at least in the near term.

Moreover, because it is not technically feasible to assess the probability of human intrusion into a repository over the long-term, we do not believe that it is scientifically justified to incorporate alternative scenarios of human intrusion into a fully risk-based compliance assessment. We do, however, conclude that it is possible to carry out calculations of the consequences for particular types of intrusion events.

The key performance issue is whether repository performance would be substantially degraded as a consequence of an intrusion of the type postulated. For this purpose, we have focused on the particular class of cases in which the intrusion is inadvertent and the intruder does not recognize that a hazardous situation has been created.

To provide for the broadest consideration of what human intrusion scenario or scenarios might be most appropriate, we recommend that EPA make this determination in its rulemaking to adopt a standard. For simplicity, we considered a stylized intrusion scenario consisting of one borehole of a specified diameter drilled from the surface through a canister of waste to the underlying aquifer. In our view, the performance of the repository, having been intruded upon, should be assessed using the same analytical methods and assumptions, including those about the biosphere and critical groups, used in the assessment of performance for the undisturbed case. <u>We recommend that EPA require that the estimated risk calculated from the assumed intrusion scenario be no greater than the risk limit adopted for the undisturbed-repository case because a repository that is suitable for safe long-term disposal should be able to continue to provide acceptable waste isolation after some type of intrusion</u>. As with other policy-related aspects of our recommendations, we note that EPA might decide that some other risk level is appropriate.

IMPLICATIONS OF OUR CONCLUSIONS

Limits of the Scientific Basis

It might be possible that some of the current gaps in scientific knowledge and uncertainties that we have identified might be reduced by future research. It seems reasonable, therefore, to ask what gaps could be closed by taking time to obtain more scientific and technical knowledge on such matters as the nature of the waste, its potential use, the health effects of radionuclides, the value of waste products for later generations, and the security of retrievable storage containers. New information in these and other areas could improve the basis for setting the standards.

Whether the benefit of new information would be worth the additional time and resources required to obtain it is a matter of judgment. This judgment would be strengthened by a careful appraisal of the probable costs and risks of continuing the present temporary waste disposal practices and storage facilities as compared to those attaching to the proposed repository. No such comprehensive appraisal is now available. Conducting such an appraisal, however, should not be seen as a reason to slow down ongoing research and development programs, including geologic site characterization, or the process of establishing a standard to protect public health.

Technology-Based Standards

Technology-based standards play an important role in regulations designed to protect the public health from the risks associated with nuclear facilities. We have examined three technological approaches in our study.

The "as low as reasonably achievable" (ALARA) principle is intended to be applied after threshold regulatory requirements have been met, and calls for additional measures to be taken to achieve further reduction in the calculated health effects. While ALARA continues to be widely recommended as a philosophically desirable goal, its applicability to geologic disposal of high-level waste is limited at best because the technological alternatives available for designing a geologic repository are quite limited. Further, the difficulties of demonstrating technical or legal compliance with any such requirement for the post-closure phase could well prove insuperable even if it were restricted to engineering and design issues. <u>We conclude that there is no scientific basis for incorporating the ALARA principle into the EPA standard or USNRC regulations for the repository</u>.

If EPA issues standards based on individual risk, the USNRC would be required to revise its current regulations embodied in 10 CFR 60 to be consistent with such standards. One purpose of 10 CFR 60, which contains technology specifications, is to help ensure multiple barriers within the repository system. We conclude that because it is the performance of the total system in light of the risk-based standard that is crucial, imposing subsystem performance requirements might result in suboptimal repository design.

Finally, several persons suggested to our committee the use of a technology-based standard that would specify a strict release limit from an engineered barrier system during the early life of the repository. We find that such a limitation on early releases would have no effect on the results of compliance analysis over the long-term. Nonetheless some members of the committee believe that such a limitation might provide added assurance of safety in the near-term, and EPA might wish to consider this as a policy matter.

Administrative Consequences

Our recommendations, if adopted, imply the development of regulatory and analytical approaches for Yucca Mountain that are different from those employed in the past and from some approaches currently used elsewhere by EPA. The change in approach and the time required to develop a thorough and consistent regulatory proposal and to provide for full public participation in the rulemaking process will require considerable effort by EPA. This process probably will take more than the year, currently provided in statute, for EPA to complete development of a Yucca Mountain standard in a technically competent way. This does not mean that DOE's Yucca Mountain Site Characterization Project cannot proceed usefully in the interim.

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Board on Radioactive Waste Management

Commission on Geosciences, Environment, and Resources

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