ABSTRACT

This paper provides a regulatory perspective from the viewpoint of the potential licensee, the U.S. Department of Energy (DOE), on the National Academy of Sciences (NAS) report on Yucca Mountain standards issued in August 1995, and on how the recommendations in that report should be considered in the development of high-level radioactive waste standards applicable to Yucca Mountain. The paper first provides an overview of the DOE perspective and then discusses several of the issues that are of most importance in the development of the regulatory framework for Yucca Mountain, including both the U.S. Environmental Protection Agency (EPA) standard and the U.S. Nuclear Regulatory Commission (NRC) implementing regulation. These issues include: the regulatory time frame, the risk/dose limit, the definition of the reference biosphere, human intrusion, and natural processes and events.

I. INTRODUCTION

The Energy Policy Act of 1992 directed the EPA to conduct a study of reasonable standards for protection of the public health and safety from releases of radioactive materials stored or disposed of in a repository at the Yucca Mountain site. The 1992 law also directed the EPA, based on the recommendations of the NAS, to promulgate public health and safety standards for Yucca Mountain. Furthermore, the NRC was directed to modify its requirements to be consistent with the EPA standards. The NAS formed the Committee on Technical Bases for Yucca Mountain Standards to prepare its recommendations to the EPA. The DOE provided input to the NAS in April 1994. The NAS report, "Technical Bases for Yucca Mountain Standards," containing recommendations to the EPA, was issued in August 1995. The DOE provided comments to the EPA on that report in November 1995. Additional recommendations were provided by the DOE to the EPA in March 1996.
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- The appropriate basis of a quantitative evaluation of compliance should be the mean of calculated results
- The application of quantitative subsystem performance requirements could be counterproductive

Some of the NAS recommendations, however, raise concerns related to the difficulty in implementing the resulting requirements. The DOE believes that it is essential that the EPA standard be understandable, consistent with other radiation protection regulations, and be implementable in a licensing environment. To that end, there are several key issues that need to be addressed during the rulemaking process for the EPA standard, as well as the NRC implementing regulation. The DOE perspective on these issues is discussed below.

III. REGULATORY TIME FRAME

DOE Position

The postclosure regulatory time frame for which compliance with quantitative limits must be demonstrated should be no longer than 10,000 years. Assessments for time periods longer than 10,000 years should be conducted to gain insight into system performance. However, these longer periods should not be regulated to explicit criteria.

Discussion

The NAS recommended regulating to a specified risk limit over the time period of peak risk, within the limits imposed by the long-term stability of the geologic environment, a time scale that is "...on the order of approximately one million years." (p. 72)\(^1\)

The DOE agrees with the NAS that there is no technical justification to limit the compliance period to 10,000 years; for that matter, any time period. This is ultimately a policy decision, as recognized by the NAS. However, we disagree with establishing the compliance time period based on the period of expected long-term stability of the geologic environment. The implication of this recommendation is that a site with a less stable or predictable geologic regime would require a shorter demonstration of compliance. Since geologic disposal of high-level waste was selected because it offers a stable, long-term isolation of those wastes from the environment, a standard for geologic disposal should not discriminate against more "stable" sites by requiring a longer demonstration of compliance from them. However, that is exactly what the NAS recommendation appears to do.

The issue of an appropriate time period for protecting against long-lived radioactive materials has been addressed before, and other precedents supporting a 10,000 year limit have been established. One such precedent concerns the environmental consequences of the uranium fuel cycle associated with the operation of nuclear power plants. During the 1970s and 1980s, licensing boards heard a number of challenges to the NRC's generic treatment of radon emissions in 10 CFR Part 51. The NRC projected releases for 1,000 years into the future, while intervenors recommended assessing health effects much more conservatively and for periods of millions or billions of years. In the leading case of Duke Power Company's Perkins Nuclear Station in 1978, the licensing board made a reasoned judgement on this issue. The board rejected the intervenor's position that health effects should be calculated more than 10,000 years in the future, even though the half-lives of some of the radioactive materials in question were far longer. The board's argument for placing more emphasis on benefits to the present generation than on impacts to future generations was not that the future deserves less protection, but rather that the future impacts are hypothetical while the current benefits are certain.\(^6\)

The NAS' own conclusions concerning the inability to predict future human behavior underlines the highly speculative nature of any calculations of dose or risk over the time period contemplated in their recommendation. Indeed, a time horizon of one million years is longer than the history of the present human species (Homo Sapiens), which is believed to have first appeared on the order of 130,000 years ago,\(^7\) and it is much longer than the history of human civilization.

Another regulatory precedent can be found in EPA's implementation of the Resource Conservation and Recovery Act (RCRA) of 1976 with respect to EPA granting conditional variances from the land disposal restrictions of 40 CFR Part 268. The EPA has interpreted the RCRA requirement of demonstration of compliance "for as long as the waste remains hazardous" to be sufficient if projected
for 10,000 years. EPA stated "...for the purposes of demonstrating compliance with RCRA no-migration standards, it is not particularly useful to extend this model beyond 10,000 years into the future." 

EPA’s Science Advisory Board (SAB), which reviewed the draft EPA standard, found that the 10,000 year limit was a “scientifically acceptable approach.” It stated: "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." 

The final EPA position reflected that view: "A period of 10,000 years...appears to be long enough to distinguish geologic repositories with relatively good capabilities to isolate wastes from those with relatively poor capabilities. On the other hand, this period is short enough so that major geologic changes are unlikely and repository performance might be reasonably projected." 

Citing among other things the SAB review, the court that remanded 40 CFR Part 191 affirmed "...the Agency's decision to select 10,000 years for the repository assessment period as being rational, technologically based and within the Agency's discretion..." 

The NAS notes that the peak doses from some radionuclides could occur considerably later than 10,000 years. This conclusion was taken into account by EPA when it adopted the 10,000 year limit in 40 CFR Part 191. In reviewing the draft standard, the SAB had reported to EPA: "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." 

Having a regulatory time frame for more than 10,000 years also appears to be inconsistent with the position of Congress in the Energy Policy Act of 1992 which implicitly assumed that the time limit for the Yucca Mountain regulation would be 10,000 years. Specifically, the third question that the Act directed the NAS to address was: "Whether it is 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." (Emphasis added.) This qualification suggests that Congress did not contemplate a longer regulatory period than what was already being used in the current repository regulations.

The DOE further notes that this concern with imposing a standard for very long time frames is consistent with the 1990 NAS "Rethinking" report which recommends de-emphasizing quantitative model predictions. It should also be kept in mind that it is precisely for the reasons noted above, that is, predicting the future for any extended time frame is too speculative and insupportable to be meaningful in a regulatory context, that both the EPA and NRC have historically rejected attempts to extend the period of regulatory concern beyond 1,000 to 10,000 years.

IV. RISK/DOSE LIMIT

DOE Position

The risk or dose limit should be consistent with other radiation protection standards and with recommendations of national and international advisory groups. Furthermore, the limit should be consistent with other provisions of the standard. For a risk standard, the limit should be between $10^{-4}$ to $10^4$ fatal cancers per year (this is equivalent to 20 to 200 mrem per year (0.0002 to 0.002 Sv/yr) if the probability of the dose is one). For a dose standard, the limit should be on the order of 100 mrem per year (0.001 Sv/yr).

Discussion

The DOE considers any form of a health-based standard (e.g., risk, dose, etc.) to be potentially workable, as long as it is properly specified and consistent with the Energy Policy Act of 1992. Whatever the form, the level of protection should be
commensurate with other radiation protection standards. Furthermore, the philosophy used in setting the level of protection should recognize the approach required to demonstrate compliance with the limit.

The NAS suggested using a risk level of \(10^{-6}\) to \(10^{-5}\) fatal cancers per year as a starting point for the EPA rulemaking (p. 49). This would be equivalent to 2 to 20 mrem per year (0.00002 to 0.0002 Sv/yr) if the probability of the dose is one. The NAS noted that this range is consistent with other U.S. nuclear regulations. However, those other regulations are typically applied to current, measurable activities or relatively shorter-term projections of performance, not to hypothetical persons in the very distant future (i.e., hundreds of thousands of years or longer). Also, the actual range of the risk levels for the regulations contained in the table in the NAS report goes as high as \(4 \times 10^{-4}\) fatal cancers per year (p. 50).

It would be easy to overestimate the future risk to persons living in the vicinity of Yucca Mountain. While the DOE agrees with the NAS that it is impossible to predict future human behavior, it is possible to make reasonable assessments of possible human activities and to make decisions on the implications of those assessments. There are basically two potential scenarios: (1) members of a technically unsophisticated culture, who do not have the ability to test or treat ground water, use water from shallow wells or springs for irrigation, livestock, and drinking, or (2) members of a technically sophisticated culture (similar to today’s) do the same but test and treat the water. The implicit assumption that future humans can and will access contaminated ground water, but will not possess the ability to test and treat their water supply, as we can today, is extremely conservative and insupportable. Furthermore, if future societies are technically unsophisticated cultures, the hazards posed by contaminated ground water would most likely be insignificant when compared to other hazards like disease, malnutrition, and a general breakdown of civilization.

For a dose standard, a limit on the order of 100 mrem/yr (0.001 Sv/yr) would appear to be reasonable for individuals who might be exposed to ionizing radiation from a nuclear waste repository. In 10 CFR Part 20, the NRC set the limit on exposure of the general public to man-made radiation (excluding medical) at 100 mrem/yr. In addition, a limit of 100 mrem/yr for public exposure to all sources of man-made ionizing radiation other than medical has been proposed by the National Council on Radiation Protection and Measurements and the International Commission on Radiological Protection. The 100 mrem/yr limit is also consistent with recommendation 3 of EPA’s Radiation Protection Guidance and with the safety standards recently published by the International Atomic Energy Agency.

A common theme in the various references cited above regarding the 100 mrem/yr limit is that such a limit should apply to all sources to which the individual is exposed. In the case of Yucca Mountain, the only other potential contributor to individual exposure in the vicinity would be the operations at the Nevada Test Site. Therefore, while the DOE recommends that a dose limit for a Yucca Mountain repository be on the order of 100 mrem/yr, it is understood that such a limit would have to include all sources in the general vicinity.

V. REFERENCE BIOSPHERE

DOE Position

The reference biosphere should be based on the characteristics of the current population living down gradient from Yucca Mountain using cautious but reasonable assumptions. This concept should be included in the EPA standard, with further details on such reference biosphere contained in the NRC regulation. The critical population group is a relatively small, homogeneous group that is representative of those individuals potentially expected to receive the largest radiation dose (hereafter referred to as the critical group). The critical group should be identified based on the location, lifestyles, and eating habits of that population. Their water supply should be from ground-water wells that are currently in use.

Discussion

The DOE agrees with the NAS recommendations that the critical group approach be used as the basis for the Yucca Mountain standards. The NAS provided two approaches to developing the exposure scenario: one based on a probabilistic critical group (Appendix C) and the other based on the subsistence farmer.
critical group (Appendix D). Both of these approaches relied on the lifestyles of the current population. The DOE believes that the probabilistic approach in Appendix C is far too complex, both for the general public and for use in an NRC licensing proceeding. Assumptions leading to hypothetical exposures should be kept as simple as possible. In addition, this probabilistic approach is untested and not accepted in the world community, as is pointed out by the NAS. The DOE believes that the subsistence farmer approach, which is generally accepted, is easier to understand. However, this approach, as used in Appendix D, is likely to be unreasonably conservative primarily because of the unrealistic location of the ground-water well that is assumed. Assuming that a well to be used for drinking water and irrigation is located directly adjacent to the repository is not reasonable because the well is located at the point where the water table is the deepest of any location along the flow path. At this location, because of the depth, a well would be the most expensive and the most difficult to construct. In addition, the assumptions are already conservative because the farmer is assumed to not have the ability to test or treat the water, as we can today.

Also, the assumption that such a subsistence farmer would exist in the first place is extremely conservative. When one evaluates the current practices of the representative population of the Amargosa Valley area, the people most at risk from potential future radionuclide releases from Yucca Mountain, it is clear that not all the food consumed by this community is grown locally. In fact, some of it is brought in from outside the community and sold in local stores, including bottled water.

Because any attempt to predict individual human behavior, or societal behavior tens or hundreds of thousands of years into the future would be speculative and indefensible in a regulatory context, the DOE believes that the critical group should be based on the lifestyles of the population currently living downgradient from Yucca Mountain. The lifestyle and eating habits of the critical group would be derived from that of current population and their location would be where they now live. The primary pathway will be from drinking ground water. Other pathways might include the use of ground water for irrigated crops for food and livestock, domestic gardens and orchards, fish farms, and bathing, and from inhalation and ingestion of soil contaminated as a result of irrigation.

The single most important issue in determining the critical group in the distant future is defining the location of ground-water wells. This one factor can have more influence on the exposure of the average member of the group than any of the other assumptions. Predicting exactly where and when wells may be drilled, if at all, in the distant future is no more certain than attempting to predict lifestyles and sizes of future populations. However, there are some cautious but reasonable assumptions that can be made. The simplest approach would be to use the wells that are already in existence. Currently, and as would be expected, wells used for irrigation tend to be in places where the water table is shallow (i.e., Amargosa Valley). The feasibility of well irrigation is generally governed by the depth to the water table because of the cost of the power required to lift water to the land surface (i.e., the deeper the well the higher the cost). With this cost factor in mind it is reasonable to assume that future well locations will be near current locations, where the water table is relatively accessible.

We believe that a critical group derived from current activities of the population would be accepted and easily understood by the public. By defining the current population and lifestyle for regulatory purposes, greater certainty can be brought to the regulatory process while avoiding the problem of attempting to sort through various predictions of the distant future.

VI. HUMAN INTRUSION

DOE Position

The EPA standard should not require explicit quantitative consideration of the effects of inadvertent human intrusion on the repository as part of the test of compliance. If considered at all, that issue should be addressed in NRC's implementing regulations, in a manner similar to the treatment of "beyond-design-basis accidents" in reactor licensing. The regulations should require separate qualitative, rather than quantitative, evaluations of human intrusion. These evaluations should be used to provide insight regarding possible mitigation measures that might be incorporated into the design of the repository, but would not be used in a
quantitative compliance test. In addition, the regulations should require the DOE to identify and establish appropriate passive institutional controls prior to permanent closure of the repository to reduce the likelihood of inadvertent intrusion in the future.

Discussion

The possibility of inadvertent human intrusion is inherent in the concept of using a deep geologic repository to dispose of spent nuclear fuel and high-level nuclear waste. The DOE agrees with the NAS that "...there is no scientific basis for estimating the probability of intrusion at far-future times." (p. 107)

The DOE also agrees with the recommendation that human intrusion not be included in probabilistic calculations of repository performance. Adoption of this recommendation would greatly simplify the task of showing compliance with a long-term performance standard and eliminate a potential source of contention and delay during licensing.

However, the NAS also made another recommendation that would bring debates about intrusion back into the center of the compliance demonstration. This recommendation was that EPA should consider the consequences of a single intrusion event (without calculating the probability) to assess whether repository performance would be substantially degraded by such an intrusion. The NAS recommended that EPA identify an intrusion scenario in its rulemaking, and implied that an appropriate scenario would be a borehole through a waste canister and down to the water table. The NAS recommended that EPA require that the estimated risk calculated from this scenario be no greater than the risk limit adopted for an undisturbed repository (p. 12).

The DOE disagrees with these recommendations. These recommendations in effect would make the new EPA standard a limit for "a repository with a hole in it." Since performance of a repository after human intrusion would certainly be not as good as the performance of an undisturbed repository, the intruded case would be controlling. There would be no point in assessing compliance for the undisturbed case. This would assure that the determination of the precise intrusion scenario (the location and size of the hole, the type of closure of the hole, etc.) would be the subject of intense controversy during rulemaking, and that the analysis of the impacts of that hole on repository performance would be the subject of litigation during licensing.

If human intrusion is considered at all, it should be considered qualitatively, rather than quantitatively, and this position is compatible with the analysis provided in the NAS report. In fact, the recommendation for a precise quantitative compliance test of the effects of intrusion is not supported by the extensive discussion of intrusion in the body of the NAS report. In that discussion, the NAS noted that while analysis of the effects of intrusion could provide useful insight, the value of such analysis at Yucca Mountain would be limited because analysis of the effects of intrusion would be "...more meaningful in selecting among alternative sites (such as by avoiding sites that have potentially valuable mineral, energy, and ground-water resources) than in assessing the performance of a particular site and design." (p. 109)

A different approach to the regulatory treatment of human intrusion should be considered. While a quantitative test is not useful, qualitative requirements that address inadvertent human intrusion could be helpful to the extent that resulting analyses can provide insight about measures that can significantly reduce the likelihood and/or consequences of inadvertent human intrusion. However, such requirements should be established in the NRC's implementing regulation, perhaps by drawing upon analogies from nuclear power plant licensing. While the EPA sets the general radiation protection standards with which a nuclear power plant must comply, it is NRC that determines how to deal with the expected consequences of "beyond-design-basis accidents." Human intrusion could be treated in the same way that large-but-unlikely nuclear power plant accidents ("Class 9 accidents") are treated in licensing: an analysis of the consequences is performed, but is not part of the formal determination of compliance with the regulations. The analysis can provide insight about possible mitigation measures that might be incorporated into the design, but does not lead to a quantitative compliance test. A similar analogy is the treatment of human intrusion (i.e., sabotage) scenarios in nuclear power plant licensing.
VII. NATURAL PROCESSES AND EVENTS

DOE Position

The EPA standard should apply only to the undisturbed case of the repository (the anticipated case under NRC terminology). In the undisturbed case, only those natural processes and events that have been operative at the Yucca Mountain site during the Quaternary Period and are representative of the site's current geologic, hydrologic, and climatic regime need to be considered. Gaps in the geologic record are expected and allowance should be made for trends in frequency and rate. Plausible but unlikely processes and events, such as new faulting or igneous intrusion at the site, should only be considered under the disturbed case of the repository (the unanticipated case under NRC terminology). The disturbed case should be handled in the NRC implementing regulations in a qualitative manner, similar to the way "beyond-design-basis accidents" are handled for nuclear power plant licensing.

Discussion

In the process of making their recommendations to the EPA, the NAS developed a position on the geologic stability of Yucca Mountain, stating that: "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." (p. 9)

While the DOE accepts the premise that natural processes and events can be technically bounded, the concern still exists regarding the fact that these bounded projections would have to be justified and defended in an adjudicatory licensing proceeding. Because of the nature of such a proceeding, it may be very difficult to reach resolution on long-term prediction of these processes and events. Therefore, the EPA standard and implementing NRC regulation should ensure that the resulting requirements reflect a situation in which resolution can be reached.

For this reason, the DOE recommends that the scope of the EPA standard be limited to only the undisturbed performance of the repository (the anticipated case under NRC terminology), regardless of the time period of regulatory concern. In addressing undisturbed performance, it would be assumed that, for regulatory compliance purposes, the natural processes and events will be the same as they are at the present, that is, that they are bounded by what has occurred at the Yucca Mountain site during that portion of the Quaternary Period that is representative of the site's current geologic, hydrologic, and climatic regime. Such undisturbed performance would be projected based on continuance or recurrence of those processes and events that have occurred previously at the Yucca Mountain site. For these natural processes and events, gaps in the record are expected and allowance should be made for trends in frequency and rate.

Limiting the EPA standard to only undisturbed performance, that is, consistent with the current geologic, hydrologic, and climatic regime at the site, would facilitate reaching resolution during the licensing proceeding. This is because the demonstration of compliance will then be focused on a discussion of the events that have occurred within the Quaternary Period that are representative of the Yucca Mountain site, as opposed to proving in a court of law which events will never occur. Analysis of possible changes in these natural processes and events that are not evident from the geologic record results in technical speculation that would be of questionable value in a demonstration of compliance. Also, limiting the scope of the EPA standard to only undisturbed performance would be consistent with the EPA's treatment of individual protection in 40 CFR Part 191, which is a dose standard that applies only to the undisturbed performance of a repository.

The case of disturbed performance (the unanticipated case under NRC terminology) could be handled in NRC's implementing regulation in a way similar to how "beyond-design-basis accidents" are handled in nuclear power plant licensing (refer to similar discussion under human intrusion above). For the disturbed case, a qualitative standard such as, no significant increase in risk (dose) over the EPA standard, could be applied.
REFERENCES


