

DEVELOPMENT OF NEW NRC REGULATIONS FOR THE PROPOSED REPOSITORY AT YUCCA MOUNTAIN, NEVADA

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ABSTRACT

Recommendations of the U.S. National Academy of Sciences (NAS), as well as legislation under consideration by the U.S. Congress, have significant implications for the regulation of high-level waste disposal at a proposed repository at Yucca Mountain, Nevada. Although differences exist among the approaches contemplated, all would necessitate changes to the U.S. Nuclear Regulatory Commission's (NRC's) regulatory framework. The U.S. Environmental Protection Agency (EPA) is obligated to issue health-based standards for Yucca Mountain that are based upon and consistent with the NAS recommendations. NRC is required to modify its technical requirements and criteria to be consistent with final EPA standards. To issue final regulations within the time allotted by law, it has been necessary for development of NRC requirements to proceed in parallel with the development of EPA standards. Early this year, NRC will propose, at 10 CFR Part 63, new, site-specific, risk-informed regulations for Yucca Mountain. These new criteria will apply specifically and exclusively to the proposed repository at Yucca Mountain. In proposing these new regulations, NRC seeks to identify risk-informed requirements for both pre-closure operations and post-closure performance of a Yucca Mountain repository that are straightforward and technically demonstrable, using performance assessment technology available today. The proposed requirements are designed to implement a health-based, safety objective, that is fully protective of public health and safety, and the environment, and is consistent with national and international recommendations for radiation protection standard.

INTRODUCTION

In August 1995, the NAS Committee on the Technical Bases for Yucca Mountain Standards reported its findings and recommendations to EPA (1). This report was made pursuant to the Energy Policy Act of 1992 (EnPA) (2) wherein the NAS was directed to provide EPA with specific advice on the technical bases for environmental standards for the proposed repository at Yucca Mountain. EPA was obligated, under EnPA, to issue final health-based standards for Yucca Mountain that are based upon and consistent with the NAS findings, within one year (i.e., by August 1, 1996). According to EnPA, new EPA standards "shall be the only such standards applicable to the Yucca Mountain site." NRC is directed to modify its technical requirements and criteria to be consistent with the new EPA standards and to implement certain assumptions that are specified in the EnPA, with regard to the effectiveness of post-closure oversight of the repository, to the extent they are consistent with the NAS report. Once final standards are published, NRC will have one year to make these modifications.

In its report, the NAS recommended that standards for Yucca Mountain limit individual risk to the average member of the exposed critical group and that compliance be evaluated at the time and place where greatest risk occurs (up to the limit of geologic predictability of the site, which NAS asserts to be on the order of one million years) following repository closure. No scientific basis was found for limiting the compliance period to ten thousand years as has been specified in prior EPA standards for HLW disposal, although NAS acknowledged that regulatory agencies might elect to do so for other reasons. NAS also recommended that suitable reference biosphere assumptions be defined by rule to preclude speculation on future human lifestyle and behavior. The NAS found no scientific basis for long-term reliance on institutional controls to prevent human intrusion or to include the probability of future human intrusion in the quantitative assessment of overall repository performance. Instead, the NAS recommended that repository resilience to intrusion be evaluated separately, based on a "stylized" scenario, that should also be defined in regulation. In addition, the NAS cautioned NRC against the imposition of quantitative subsystem performance requirements that might result in suboptimal repository design.

Independent of the NAS study, Congress continues to contemplate legislation that, if enacted, could alter the roles of NRC and EPA and mandate changes to existing regulations. NRC has testified that legislative proposals under consideration in the previous Congress, (and, later, passed, separately, by the Senate and House) (3,4) contain the elements of an integrated HLW management system necessary for the protection of the public health and safety. Each of these bills would specify a standard equivalent to 1mSv (100 mrem) per year. Both bills would also preclude the use of quantitative measures of subsystem performance as independent licensing requirements and place greater emphasis in any licensing decision on the first 1,000 years of repository performance. Furthermore, these bills would have NRC assume that active institutional controls, taken together with engineered barriers, will be effective to preclude human intrusion and prevent doses in excess of allowable limits.

Unlike either of the approaches described above, NRC's existing, generic regulations at 10 CFR Part 60 (5) were predicated on an assumption of an overall performance objective that limited integrated radionuclide release over 10,000 years. These regulations also include quantitative criteria for container performance, rates of release from the engineered barrier system, and pre-emplacement groundwater travel time, all of which were intended to contribute to reasonable assurance that the overall system performance objective is met. NRC regulations allow for the consideration of the potential for future human intrusion in the demonstration of compliance with the overall performance objective, subject to specified assumptions.

During the more than 15 years since the initial technical criteria at Part 60 were promulgated, there has been considerable evolution in the capability of technical methods for assessing the performance of a geologic repository at Yucca Mountain (6,7). These changes allow for the application of more effective and efficient methods of analysis for evaluating conditions at Yucca Mountain than do NRC's existing generic criteria. The improved capability of these improved methods was not envisioned when the Part 60

criteria were established, and their implementation for Yucca Mountain will avoid the imposition of unnecessary, ambiguous, or potentially conflicting criteria that could result from the application of some of NRC's generic requirements at Part 60.

Over the same period, the DOE program for characterizing the Yucca Mountain site as a potential geologic repository has matured. A viability assessment of the site was published in December of 1998 (8). Further, it is expected that DOE will publish a draft environmental impact statement (EIS) in 1999, with a final EIS to be completed in 2000, such that a site suitability recommendation can be made in 2001. Assuming that the Yucca Mountain site can be recommended for development as a geologic repository, DOE would then submit a license application to NRC in 2002. To facilitate preparation of a license application and to permit timely and significant public involvement in the development of implementing regulations, NRC believes it is incumbent upon it to make public as early as possible how it would implement dose- or risk-based standards for Yucca Mountain.

DEVELOPMENT OF A NEW PART 63

In addition to directing NRC to modify its requirements for geologic disposal within a very short time to implement site-specific standards for Yucca Mountain, EnPA also specifies the type of standards NRC is to implement (i.e., standards which limit individual dose, and which are based on and consistent with the NAS recommendations). In view of these constraints, NRC has found it necessary to develop new regulations in parallel with the development of EPA standards. Upon release of the NAS report, NRC and its technical contractor, the Center for Nuclear Waste Regulatory Analysis, undertook a series of focused technical analyses to examine the consequences of implementing a dose- or risk-based performance objective on performance assessments of the proposed repository at Yucca Mountain. The results of these preliminary analyses (9) provided important technical insights in support of NRC's development of new technical criteria.

NRC will propose a new, separate part of its regulations at Part 63 that will apply only to the proposed repository at Yucca Mountain. NRC also intends to leave its existing, generic regulations at Part 60 in place, modified only to indicate that they do not apply, nor may they be the subject of litigation, in any NRC licensing proceeding for a repository at Yucca Mountain. NRC believes this to be the most direct and time-efficient approach to the specification of concise, site specific criteria for Yucca Mountain that are consistent with current assumptions, with site-specific information and performance assessment experience, and with statutory direction and NAS guidance for standards applicable to Yucca Mountain.

It is NRC's intent to propose a coherent body of risk-informed, performance-based criteria for Yucca Mountain that are compatible with NRC's overall philosophy of risk-informed, performance-based regulation. Stated succinctly, risk-informed, performance-based regulation is an approach in which risk insights, engineering analysis and judgment, and performance history are used to: (a) focus attention on the most important activities; (b) establish objective criteria for evaluating performance; (c) develop

measurable or calculable parameters for monitoring system and licensee performance; (d) provide flexibility to determine how to meet the established performance criteria in a way that will encourage and reward improved outcomes; and (e) focus on the results as the primary basis for regulatory decision-making. NRC favors the creation of new regulations to accomplish these objectives, over the modification of its generic requirements, in view of the fundamentally different approach laid out for Yucca Mountain by EnPA and NAS than was contemplated when the generic criteria were promulgated. More specifically, EnPA and NAS have specified an approach that would require the performance of a Yucca Mountain repository to comply with a health-based standard that limits risk to a hypothetical critical group. Such standard would be the only quantitative standard for the post-closure performance of the repository, an approach different from that taken in the existing generic criteria which relies on quantitative, subsystem performance standards.

TECHNICAL CRITERIA

The new technical criteria that will be proposed at Part 63 will specify overall performance objectives (for preclosure and postclosure phases of the repository) and require that compliance with these overall performance objectives be demonstrated through quantitative risk assessments (i.e., an integrated safety analysis, and a performance assessment, respectively). This risk-informed, performance-based approach does not include specification of additional design and siting criteria or quantitative subsystem requirements; however, NRC will propose specific requirements for the content of the quantitative assessments to ensure their adequacy and the sufficiency of the information provided in the license application.

PRECLOSURE PERFORMANCE OBJECTIVE

As a licensed, operating facility, a repository at Yucca Mountain would be subject to the existing regulations at 10 CFR Part 20 (10) that require, among other things, doses to members of the general public to not exceed a total effective dose equivalent of (TEDE) 1 mSv (100 mrem) per year, exclusive of the contribution from background radiation, medical procedures and sanitary sewerage disposals. In addition, prior to permanent closure, repository operations would need to be conducted such that public exposures are maintained as low as reasonably achievable. When the repository is closed, surface facilities must be decommissioned in accordance with Subpart E of Part 20. Finally, during normal operations and anticipated operational occurrences, the annual dose to any real member of the public, located beyond the boundary of the site, shall not exceed a TEDE of 0.25 mSv (25 mrem). This final dose limit, used in this regulation, is adapted from the dose limits specified in 10 CFR Part 72 (11), for effluents and direct radiation during normal operations and anticipated operational occurrences at Monitored Retrievable Storage (MRS) facilities. Like an MRS facility, the operations area at Yucca Mountain is expected to be a large industrial facility equipped to handle the loading, unloading, and decontamination of spent fuel and HLW shipping casks; the removal and packaging or repackaging of spent fuel assemblies and HLW canisters; and the sealing, handling, transport, stowage and periodic monitoring of canisters to contain the spent fuel and HLW during operations. Because the activities contemplated for the operations area, prior to repository closure, pose similar radiological hazards, during normal operations

and anticipated operational occurrences, to those posed at an operating MRS, NRC will propose dose limits for the operations area comparable to those applicable to the MRS, from planned discharges and from direct radiation during operations.

Compliance with these well-established, operational criteria will be proposed as the preclosure performance objective to ensure that the geologic repository operations area is designed and operated to protect against radiation exposures and releases of radioactivity prior to permanent closure. Specifically, protection of the worker and general public is ensured by requiring that the exposure limits codified at Part 20 are maintained, and that during normal operations and anticipated operational occurrences, the annual dose to any real member of the public, located beyond the boundary of the site, shall not exceed a TEDE of 0.25 mSv (25 mrem). Additionally, numerical guides for design objectives have been specified for Category 1 design basis events and Category 2 design basis events. Category 1 design basis events are those events that are expected to occur one or more times before permanent closure. Included in Category 1 design basis events are events that occur regularly or moderately frequently, and that are sometimes identified as "normal operations" associated with receiving, handling, packaging, storing, emplacing, and retrieving high-level waste. Also included in Category 1 design basis events are those events that occur one or more times during the operating lifetime of a facility, and that are sometimes identified as "anticipated operational occurrences" or "accidents." Category 2 design basis events are those event sequences that have at least one chance in 10,000 of occurring before permanent closure. For an operational period of 100 years, this corresponds to an annual probability of occurrence of one chance in 1,000,000. Category 2 design basis events are unlikely, but credible and potentially significant sequences of events. Similar definitions of design basis events and associated dose limits were incorporated in NRC's generic regulations at Part 60 for evaluation of preclosure repository performance.

INTEGRATED SAFETY ANALYSIS OF PRECLOSURE ACTIVITIES

It is expected that compliance with the preclosure performance objectives would be demonstrated through an integrated safety analysis (ISA) of the geologic repository operations area (GROA). The ISA is a systematic examination of potential hazards at the GROA. It identifies the potential hazards, the potential for initiating events, and describes potential event sequences and their consequences, as well as the site, structures, systems, components, equipment, and activities of personnel intended to mitigate or prevent the accident sequence. Its purpose is to ensure that all relevant hazards that could result in unacceptable consequences have been adequately evaluated and appropriate protective measures have been identified such that the GROA will comply with the preclosure requirements for protection against radiation exposures and releases of radioactive material.

A fundamental aspect of the ISA is the identification and analysis of Category 1 and Category 2 design basis events. Category 1 events as described above represent "normal operations" while Category 2 events represent unlikely but credible events that would challenge the design of the GROA to maintain exposures within allowable limits. The analysis of a specific Category 2 design basis event would include an initiating event

(e.g., an earthquake) and the associated combinations of repository system or component failures that can potentially lead to exposure of individuals to radiation. An example design basis event is a postulated earthquake (the initiating event) which results in (1) the failure of a crane lifting a spent fuel waste package inside a waste handling building, (2) damage to the building ventilation (filtration) system, (3) the drop and breach of the waste package, (4) damage to the spent fuel, (5) partitioning of a fraction of the radionuclide inventory to the building atmosphere, (6) release of some radioactive material through the damaged ventilation (filtration) system, and (7) exposure of an individual (either a worker or a member of the public) to the released radioactive material.

This proposed approach, which does not include specification of general design criteria, is thought to be appropriate because prescriptive design criteria may unnecessarily encumber DOE, given the ongoing nature of site characterization of the underground facility and evolution of facility design. The information NRC will need to make a finding of reasonable assurance that the GROA will comply with the risk-based, preclosure requirements will be provided by the ISA. Criteria for the quality and content of the ISA will also be proposed.

EMERGENCY PLANNING

When NRC published final generic criteria for geologic disposal in 1983, licensing requirements for emergency planning were reserved for a later date. Final amendments to Part 72 that codified generic emergency planning licensing requirements for independent spent fuel storage installations (ISFSIs) and MRS facilities were published subsequently in 1985 (11). These amendments provided for enhanced requirements for offsite emergency planning at MRS facilities (as well as at any ISFSIs that conduct similar operations) because of the broader scope of activities that could be performed at these facilities relative to those conducted at simpler storage installations. Like an MRS facility, the GROA at Yucca Mountain is expected to be a large industrial facility equipped to handle the loading, unloading, and decontamination of a large number of spent fuel and HLW shipping casks arriving by rail, heavy haul, and legal weight truck. It will also include facilities to open shipping canisters that are unsuitable for disposal, as well as to package bare fuel assemblies, commercial and defense spent fuel, and commercial and defense HLW in disposable canisters, and seal them for emplacement in the repository. Packaging operations will be conducted in a radiologically-controlled area that can support remote dry and pool-handling operations. At this time, a final GROA design has not been selected by DOE.

In promulgating final amendments to Part 72, NRC conducted an analysis of potential onsite and offsite consequences of accidental release associated with the operation of an MRS (12). Because the activities contemplated for the GROA prior to repository closure pose similar radiological hazards to those analyzed for operations at an MRS, NRC will propose that emergency planning licensing requirements for preclosure operations at the Yucca Mountain repository be comparable to those already codified for MRS facilities. Therefore, NRC will require that DOE develop, and be prepared to implement, a plan to

cope with radiological emergencies that may occur at the GROA prior to permanent closure, that is based on the criteria of Part 72.

INDIVIDUAL PROTECTION STANDARD FOR POSTCLOSURE PERFORMANCE

As already stated, the authority and responsibility for setting public health and safety standards for radioactive waste disposal at Yucca Mountain rest with EPA. Once final standards are issued, it is NRC's responsibility to implement those standards in its licensing actions and ensure that public health and safety are protected. Although the details of EPA's final standards are not yet available, the NAS recommendations, with which the EPA standards must be consistent, have been public for more than 3 years. In the absence of final (or proposed) EPA standards for disposal of HLW at Yucca Mountain, NRC will propose an individual dose limit that it believes is generally consistent with EnPA and with the conclusions and recommendations of NAS. Although EnPA required that EPA specify a limit based on individual dose, NAS recommended a limit be established on risk to individuals (i.e., the probability that an individual or individuals receive an adverse health effect). An equivalent level of radiation protection is afforded individuals by a standard expressed either as a risk or a dose limit when the evaluation of dose or risk considers the probability of incurring a dose and both limits are based on similar dosimetry assumptions (i.e., consistent dose to health effects conversion). NRC favors an individual dose limit because it believes a dose limit may be more readily understood by the public and is the form of a standard more frequently used to regulate nuclear activities. When EPA issues final standards for Yucca Mountain, or if new legislation is enacted into law, NRC will amend its criteria at Part 63, as needed.

As the appropriate objective for repository performance after permanent closure, NRC will propose a constraint that, if met, would provide reasonable assurance that doses to members of the general public will remain within acceptable levels. International guidance on dose limits suggests establishing constraint limits for specific sources (such as a HLW repository) to ensure that exposure to members of the public from all sources, excluding background radiation, is less than the public dose limit. In the case of operational releases, compliance with the requirements of Part 20 can be expected, based on NRC's experience with its other licensed facilities, to limit effluents far below the public annual dose limit of 1 mSv (100 mrem). For postclosure exposures, the performance of the repository must depend on passive systems limiting the exposure. Therefore, the performance objective for postclosure must be established such that the public would not receive doses, from all possible sources of radiation, excluding background, in excess of 1 mSv (100 mrem) per year.

NRC will propose a limit of 0.25 mSv (25 mrem) expected total effective dose equivalent, received in a single year and weighted by the probability of occurrence, by the average member of the critical group, as the overall system performance objective for the repository, following permanent closure. This criterion would limit the dose received from all possible pathways to the critical group at Yucca Mountain, including direct exposure, drinking of contaminated water, eating food that was irrigated with contaminated groundwater or grown in contaminated soil, exposure to airborne releases,

etc. NRC believes that application of a single, all-pathway standard is protective of public health and safety, and obviates the need for separate, single pathway limits. NRC has established the 0.25 mSv (25 mrem) annual dose limit as the overall safety objective for both decommissioning of nuclear facilities and for low-level radioactive waste disposal facilities (10,13). It is within the range of international constraints that allocate doses from high-level waste disposal to between 0.1 and 0.3 mSv (10 and 30 mrem) per year (14), and is comparable to the risk range recommended by NAS as a reasonable starting point for EPA's rulemaking (a risk range of between one chance in 100,000 and one chance in a million per year, approximately equivalent to annual doses between 0.02 and 0.2 mSv (2 and 20 mrem)). A dose limit of 0.25 mSv (25 mrem) per year is sufficiently below the public dose limit that no members of the public near Yucca Mountain would be expected to receive doses from all sources, exclusive of background, in excess of 1 mSv (100 mrem) per year. For purposes of comparison, it should be noted that the average individual exposure in the U.S. for natural background radiation is on the order of 3 mSv (300 mrem) per year, or three times the Part 20 public dose limit and 12 times the standard proposed for Yucca Mountain.

CRITICAL GROUP AND REFERENCE BIOSPHERE FOR YUCCA MOUNTAIN

In addition to establishing an individual protection limit as an overall system performance objective, it is necessary to specify the individual or individuals for whom the performance calculation is to be made, as well as the environment in which the individual(s) resides, and the relevant pathways for potential exposure. In this regard, the NAS observed that the appropriate objective should be to "protect the vast majority of members of the public while also ensuring that the decision on the acceptability of a repository is not prejudiced by the risks imposed on a very small number of individuals with unusual habits or sensitivities." NAS recommended that the characteristics of the critical group and reference biosphere be defined in regulation. Citing guidance of the International Commission on Radiological Protection (ICRP) (14), NAS recommended the critical group be representative of those individuals in the population expected to receive the highest dose equivalent; be relatively homogeneous with respect to the location, habits, and metabolic characteristics that affect the doses received; and exhibit habits and characteristics that reflect present knowledge using cautious, but reasonable, assumptions. Although the ICRP guidance was developed for present day releases to existing populations that could be surveyed, monitored, and screened to find the few actual individuals that would be members of the critical group, NRC has applied the ICRP principles in developing specifications for the critical group and reference biosphere, consistent with general guidance contained in the NAS recommendations.

Demonstration of compliance with an individual dose limit over thousands of years requires the use of certain assumptions about the characteristics of the individual or group to be protected, as well as the characteristics of the biosphere in which the critical group resides. Difficulties in forecasting the characteristics of future society, especially those influencing exposure, lead to large uncertainties in the estimates of who will be exposed, by how much, and when. To limit speculation, NRC proposes to limit speculation by specifying assumptions to be used by DOE in developing the assumed critical group and reference biosphere appropriate for Yucca Mountain. The intent here is to define

characteristics that would otherwise be subject to unlimited speculation, and to identify how available information is to be used by DOE to identify the average member of the critical group. The identification of those individuals expected to receive the highest dose will be most sensitive to attributes such as location, percentage of diet from locally-produced food, lifestyle, and land use. Based on present day knowledge of the habits and characteristics of the local population in the vicinity of Yucca Mountain, NRC will specify a farming critical group located approximately 20 km south from the underground facility (i.e., in the general location of U.S. Route 95 and Nevada Route 373, near Lathrop Wells). A farming critical group is considered to be reasonably representative of those individuals expected to receive the highest dose from radionuclides released from a Yucca Mountain repository for a number of reasons. First, farming activities involve more exposure pathways than other known human activities in the region (e.g., ingestion pathway through consumption of contaminated water, crops, and animal products; inhalation and direct pathways from surface contamination exacerbated by the significant outdoor activity of a farming lifestyle). Second, the relatively large demand for ground water for irrigation increases the likelihood of drawing contaminated water to the surface where human exposures could occur. And third, farming activities currently exist in the Yucca Mountain region.

The 20 km location (near Lathrop Wells) represents an informed assumption regarding the accessibility of groundwater for irrigation considering current irrigation practices, depth to the water table, and the recognition that soil conditions at this location are generally similar to those further down gradient, near Amargosa Valley, where farming is currently practiced. Locations much closer to the proposed repository have soil conditions that are considerably less favorable for farming. Review of current well use information for Nevada suggests that irrigation wells constructed for water table depths greater than 150 meters are rare. Because well cost is related to depth, it is economically preferable to establish irrigation wells in areas where the water table is near the surface. The water table at Yucca Mountain is deep (i.e., greater than 300 meters) and decreases with distance down-gradient, which would also be the eventual path for radionuclide releases in the ground-water pathway. The area near U.S. Route 95 and Nevada Route 373 is the general location where the depth to water is approximately 100 meters with more shallow depths to water occurring further south. Because current farming practices are concentrated in the Amargosa Farms region (approximately 30 km south of Yucca Mountain), the 20 km critical group distance is considered reasonably conservative.

Other activities that currently exist in the area represent more limited potential for exposures (e.g., casino resort/hotel, residential dwellings). Activities such as residential housing are certainly feasible at locations closer than 20 km, where potential release concentrations are likely to be higher. However, the bases for determining precise locations of such groups are likely to be highly speculative, and largely arbitrary, when compared to a farming critical group based on existing living patterns. Additionally, the small water demand of a residential community, and even smaller demand of a single residence, relative to a farming community, further increases the uncertainty of dose estimates. Finally, because releases to the groundwater are expected to be quite variable

spatially, due to the characteristics of fractured rock, the likelihood of any particular, randomly selected, withdrawal well intercepting contaminated water, at a specific location, would be quite small.

Exposures to the average member of the critical group will increase with the amount of contaminated water, crops, and animal products consumed, assuming the ground water pathway is the most likely release pathway. Individuals expected to receive the highest dose would be those for whom locally-produced, contaminated food represents a significant fraction of their diet. For these reasons, NRC will propose that the consumption of locally produced food for the average member of the critical group be based on the mean of the range of the dietary habits consistent with the current conditions in the Yucca Mountain region. It is reasonable to assume that a farming community of sufficient size (as opposed to a few isolated farms) would be needed to supply the range of locally produced food that is currently consumed in the Yucca Mountain region. Such a farming community of up to 100 individuals, residing on approximately 15 to 25 farms, is consistent with current conditions of the region (substantially more farms would increase water demand and further decrease radionuclide concentrations in pumped water; substantially fewer farms would restrict the availability of locally-produced food relative to the regional average). Thus, it would be expected that the average member of the critical group resides within a farming community and has dietary habits which will result in the exposures being among the highest.

Exposures to the average member of the critical group will also be affected by the degree to which the locally produced food is contaminated. Variability in farming and water well withdrawal practices, as well as the spatial variability of radionuclide concentrations in ground water, will produce variation in the amount and degree of contamination of locally produced food. It will not be possible to precisely determine concentrations in ground water at specific locations or to avoid speculation regarding individual farm and water well withdrawal practices. The concentration of radionuclides in the water used by a larger farming community, by contrast, can be determined by dividing the annual release of radionuclides to the farming community by its annual water demand. For a community of sufficient size, it can be assumed that water demand is large enough to “capture” the entirety of the contaminated plume. Thus, NRC believes it would be reasonable to consider all the locally produced food consumed by the farming community to be contaminated from the use of contaminated ground water and to assume that the average member of the critical group consumes contaminated food in all categories of locally produced food. Use of mean values for defining dietary habits ensures that dose estimates would not be unduly biased by unusual habits of a few individuals, and speculation is minimized with respect to where crops are grown relative to the spatial distribution of concentration.

The biosphere in which the critical group resides affects the group’s behavior and characteristics and defines how the group could be exposed to radionuclide releases from Yucca Mountain. The precise future state of the biosphere over the time period considered during a performance assessment is highly uncertain. Both natural and man-made processes may affect attributes of the biosphere (e.g., climate, topography,

hydrology and soils), and thereby influence exposure pathways. As noted earlier, NAS recommended that the assumptions about the biosphere make use of present knowledge and be cautious, but reasonable.

Application of the reference biosphere concept in the proposed regulations takes the form of four primary requirements. These include that (a) features, events, and processes that describe the reference biosphere shall be consistent with present knowledge and conditions in the region surrounding the Yucca Mountain site, (b) biosphere pathways shall be consistent with arid or semi-arid conditions, (c) climate evolution shall be consistent with the geologic record of natural climate change in the region surrounding Yucca Mountain, and (d) evolution of the geologic setting shall be consistent with present knowledge of natural processes.

COMPLIANCE PERIOD

In selecting the length of time over which the individual dose limit should be applied, NRC has taken into account technical, policy, and legal considerations. In the absence of final EPA standards, NRC will propose the use of 10,000 years for evaluating compliance with the overall system objective for postclosure performance. When EPA issues final standards for Yucca Mountain that specify a different compliance period, NRC will amend its criteria at Part 63, as necessary, to comply with EnPA requirements for consistency with final EPA standards.

Three considerations form the basis for NRC's proposal. First, the inherent radiological hazard of spent fuel decreases rapidly and significantly during the initial 10,000 years due to radioactive decay dominated by fission products, with the relative hazard diminished by approximately 90 percent at 100 years, 99 percent at about 1,000 years and 99.9 percent at 10,000 years. Therefore, the compliance period selected corresponds to the time period when the waste is inherently most hazardous.

Second, analysis of repository performance over 10,000 years provides an opportunity to examine the impact of a range of geologic conditions (e.g., seismic events, fault movement, igneous activity, and climate variation on the scale of global changes due to glaciation) on the capability of the engineered and natural barriers to limit radiation exposures below the dose limit. It is possible that DOE may attempt to demonstrate that its engineered barrier system design is sufficiently robust as to preclude any significant releases during a 10,000-year compliance period. If DOE is able to convincingly demonstrate that its waste package can preclude radionuclide releases beyond the compliance period, a 10,000-year evaluation, it might be argued, would only illustrate the effect of the natural system on the degradation of the engineered barriers. Under such circumstances, DOE would not be constrained to confirm the capacity of existing natural barriers to restrict movement of radionuclides following release from the waste packages, and thereby, limit exposures to members of the critical group. In conducting its performance assessment, however, NRC expects that DOE will account for the susceptibility of some fraction of the more than 7,000 emplaced canisters to early failures, attributable to such causes as manufacturing defects, lapses in quality assurance programs, etc. The ability of the geologic barriers to retard transport of radionuclides

released as a result of these early failures would clearly need to be evaluated. Furthermore, the assumed intrusion scenario specified in the proposed requirements, and discussed later, would require a stylized analysis of the consequences of a compromised waste package, and will also test the contribution of the geologic barriers to overall performance. Irrespective of the projected lifetime of the waste package design, the capability of the natural barriers to limit exposures would need to be evaluated in the context of the multiple barrier requirement.

Finally, from a policy perspective, a 10,000-year compliance period is consistent with other regulations involving geologic disposal of long-lived hazardous materials, including radionuclides. EPA has already codified a 10,000-year compliance period at 40 CFR 191 applicable to the Waste Isolation Pilot Plant (WIPP), a similar type of disposal system as that proposed at Yucca Mountain (15). A 10,000-year performance period is also referenced in EPA guidance on no-migration petitions for facilities seeking exemption from certain land-disposal restrictions for long-lived hazardous, nonradioactive materials. Additionally, a 10,000-year compliance period is specified in NRC's Draft Technical Position on a Performance Assessment Methodology for Low-Level Radioactive Waste Disposal Facilities (16). All of these land disposal situations, like HLW disposal, involve disposed wastes containing long-lived, hazardous materials which are of concern, because they can become mobile in the groundwater pathway.

MULTIPLE BARRIERS

Geologic disposal of HLW is predicated on the expectation that a portion of the geologic setting will act as a barrier, both to water reaching the waste, and to dissolved radionuclides migrating away from the repository, and thus, contribute to the isolation of radioactive waste. Although there exists an extensive geologic record ranging from thousands to millions of years, this record is subject to interpretation and includes many uncertainties. These uncertainties can be quantified generally and are addressed by requiring the use of a multiple barrier approach; specifically, an engineered barrier system, consisting of one or more distinct engineered barriers, is required in addition to the natural barriers implicit in a geologic setting. Similarly, although the composition and configuration of engineered structures, as well as their capacity to function as barriers, can be defined with a degree of precision not possible for natural barriers, it is recognized that except for a few archaeologic analogues, there is no experience base for the performance of complex, engineered structures over periods longer than a few hundred years. It is expected that DOE will demonstrate that the natural barriers and the engineered barrier system will work in combination to enhance overall performance of the geologic repository.

It is important that NRC's proposed approach to the treatment of multiple barriers acknowledge the experience and improvements in the technology of performance assessment, acquired over more than 15 years, that now provides significantly greater confidence in the technical ability to assess comprehensively overall repository performance, and to address and quantify the corresponding uncertainty. In addition to extensive reviews of evolving performance assessments produced by DOE and its

contractors, NRC, itself, has developed and exercised its own technical capability in the field of repository performance assessment (17,18)

Drawing from this experience, NRC intends to require that DOE evaluate the behavior of barriers important to waste isolation in the context of the performance of the geologic repository. Discrete numerical goals for the performance of individual barriers, however, will not be specified in the regulations. Such an approach will require DOE to provide an analysis that: (a) identifies those design features of the engineered barrier system, and natural features of the geologic setting, that are considered barriers important to waste isolation; (b) describes the capability of these barriers to isolate waste, taking into account uncertainties in characterizing and modeling the barriers; and (c) provides the technical basis for the description of the capability of these barriers. In implementing this approach, NRC will incorporate flexibility into its regulations by requiring DOE to demonstrate that the geologic repository comprises multiple barriers but not prescribe which barriers are important to waste isolation or the methods to describe their capability to isolate waste.

DOE may select from a variety of methods in order to demonstrate the capability of barriers to isolate waste. Regardless of the method and the level of quantification, it is expected that the capability of individual barriers to perform their intended function and the relationship of that function to limiting radiological exposure would be described. In parallel with this rulemaking, NRC is developing guidance in the form of a Yucca Mountain Review Plan. In this review plan, guidance will be provided on acceptable methods for demonstrating compliance with the multiple barrier requirement that could include, but not necessarily be limited to, performing sensitivity analyses, modeling the behavior of individual barriers, quantifying how individual barriers contribute to performance, and delineating the capabilities of the barriers to isolate waste. NRC believes that it is appropriate to afford DOE flexibility in selecting the methods to demonstrate the waste isolation capability of the multiple barriers that must comprise its repository design.

PERFORMANCE ASSESSMENT

Demonstration of compliance with the postclosure performance objective will require a performance assessment that quantitatively estimates the expected annual dose, over the compliance period and weighted by probability of occurrence, to the average member of the critical group. Performance assessment is a systematic analysis of what can happen at the repository after permanent closure, how likely it is to happen, and what can result, in terms of dose to the average member of the critical group. Taking into account, as appropriate, the uncertainties associated with data, methods, and assumptions used to quantify repository performance, the performance assessment is expected to provide a quantitative evaluation of the overall system's ability to achieve the performance objective. Consistent with EnPA and NAS recommendations, NRC will propose that the results of performance assessment shall be the sole quantitative measure used to demonstrate compliance with the postclosure individual dose limit.

In order to find that issuance of a license will not constitute an unreasonable risk to the health and safety of the public, NRC must have reasonable assurance that the required performance assessment has demonstrated that, following permanent closure, for the duration of the compliance period and considering the likelihood of occurrence of adverse natural events, expected annual exposures to the average member of the critical group will not exceed the individual dose limit of .25 mSv (25 mrem) TEDE. Although this objective is expressed in unqualified terms, it is not expected that complete assurance that the requirement will be met can be presented. A reasonable assurance, on the basis of the record before the Commission, that the performance objective will be met is the general standard that is required. The performance assessment will rely, by necessity, on computer modeling to determine whether a proposed geologic repository meets the performance objectives. Such reliance on computer simulation has become commonplace for determining the likely performance of complex engineered systems. In most applications, it is accompanied by a rigorous testing program, involving model “validation” and “verification,” to ensure that the simulated system behavior is sufficiently consistent with empirically observed behavior to meet the need of the application at hand. NRC expects that DOE will take reasonable and practical measures to ensure that its performance assessment provides a credible representation of a geologic repository at Yucca Mountain. For example, assurance of the soundness of the performance assessment cannot and will not involve the comparison of simulated behavior of a geologic repository with empirical observation over tens of kilometers and tens of thousands of years. At best, assurance for the performance assessment will involve comparison of simulations with observations drawn from an integrated program of laboratory tests, field tests, and analog studies that starts with site characterization and continues, as appropriate, through the performance confirmation period.

Because of the significance of the performance assessment as the sole quantitative measure of compliance, it is essential that the performance assessment be scientifically defensible and transparent. For this reason, NRC considers it important to specify requirements for a complete and high-quality performance assessment. A defensible performance assessment should contain a technical rationale for those features, events, and processes that have been included in the performance calculation, as well as those that have been considered but were excluded. The features, events, and processes (i.e., specific conditions or attributes of the geologic setting; degradation, deterioration, or alteration of the engineered barriers; and interactions between the natural and engineered barriers) considered for inclusion in the assessment should represent a wide range of beneficial and detrimental effects on performance. Features, events, and processes should be considered in light of available data and current scientific understanding, and alternative conceptual models that are consistent with such data and understanding should be evaluated. Inclusion of alternative models should be based, however, on reasonable interpretation of available information, and should not be driven by open-ended speculation. To this end, NRC intends to constrain speculation by defining a lower limit on the probability of events and processes that need to be considered and requiring inclusion of only those features and processes, and higher probability events that significantly change the expected annual dose.

To be transparent, DOE's performance assessment must contain an evaluation of the performance of the geologic repository relative to compliance with the individual dose limit and an explanation of how the estimated performance was achieved. Compliance with the individual dose limit will need to be demonstrated through the calculation of an expected annual dose. The expected annual dose is the expected value of the annual dose considering the probability of the occurrence of the events and the uncertainty, or variability, in parameter values used to describe the behavior of the geologic repository (the expected annual dose is calculated by accumulating the dose estimates for each year, where the dose estimates are weighted by the probability of the events and the parameters leading to the dose estimate). Explanation of how the estimated performance was achieved should reveal an understanding of the relationship between the performance of individual components or subsystems of the geologic repository and the total system performance. Such understanding would be used to build confidence that the expected annual dose, as asserted in the license application, is a reasonable estimate of the performance of the geologic repository. Consistent with a performance-based philosophy, NRC proposes to permit DOE the flexibility to select the approach for demonstrating this relationship that is most appropriate to its analysis.

INSTITUTIONAL CONTROLS

Under NRC's proposed requirements, DOE will be required to institute active, as well as passive, control measures to reduce the potential for inadvertent human intrusion into the site. Reasonably prudent, active institutional controls, consistent with the requirements of EnPA, should be maintained at the site for as long as possible. NRC is also proposing that DOE's passive control measures should be designed to serve their intended purpose for as long as practicable. It is recognized, however, consistent with the conclusions of NAS, that it is not reasonable to assume that a system for postclosure oversight, based on active institutional controls, can be developed that will eliminate entirely, over thousands of years, the possibility of human activity that could degrade the long-term performance of the repository.

HUMAN INTRUSION

The geologic record provides a basis for evaluating the likelihood of geologic processes and events, but no similar record of extended duration exists that can be used to constrain either the probability that human intrusion could occur or the nature of such intrusion. Although designs can seek to warn potential intruders or to mitigate effects associated with intrusion that does occur, they cannot remove the potential for intrusion to occur. Similarly, repositories cannot be designed to mitigate the full range of possible ways that human intrusion could occur. Therefore, NRC will propose requirements that DOE take reasonable and prudent steps to reduce the likelihood of human intrusion, and that DOE's repository design must still perform as intended, if an assumed, limited intrusion does occur.

As noted earlier, the NAS concluded that it is not possible to make scientifically supportable predictions of the probability of human intrusion breaching the repository's geologic or engineered barriers over a period of 10,000 years. The NAS report recommended that human intrusion be excluded from the performance assessment, but

that the consequences of an assumed human intrusion scenario should be calculated to determine if repository performance would be substantially degraded as a result of the intrusion. To permit consideration of the potential detriment from human intrusion in the evaluation of repository performance, NRC intends to require DOE to perform a consequence analysis that includes an assumed intrusion scenario. This consequence analysis would be identical to the performance assessment, except that a specified human intrusion scenario is assumed to occur. In the event of this assumed scenario, the repository is required to perform such that the dose to the average member of the critical group is also within allowable limits. Hazards to the intruders themselves (drillers, miners, etc.) or to the public from material brought to the surface by the assumed intrusion should not be included in this analysis, according to NAS, because analyses of these hazards would be unlikely to provide any useful basis for judging the resilience of a particular repository or design to intrusion.

DOE would be required to use current practices for resource exploration to establish properties (e.g., diameter of the borehole, drilling rate, composition of drilling fluids) for the intrusion scenario. However, because NRC intends for this analysis to show that the repository can still adequately perform if its barriers are breached, NRC is requiring DOE to assume that the borehole is not adequately sealed to prevent infiltrating water. Traditionally, NRC has limited the extent to which reliance may be placed on institutional controls to prevent unacceptable radiological exposures from the disposal of other radioactive wastes. Consistent with this approach, NRC is proposing that the intrusion scenario be assumed to occur 100 years after repository closure.

SUMMARY

This paper has summarized many of the principle technical requirements of draft, site specific regulations for the proposed repository at Yucca Mountain soon to be proposed by NRC. The Commission approved publication of these proposed requirements on January 12, 1999. A Federal Register Notice announcing NRC's proposed regulations at Part 63, and soliciting public comment thereon, will be published in February 1999. Over the course of a 75-day public-comment period, NRC staff members will conduct one or more public meetings to encourage public input and interaction on the substance of the NRC proposal. Upon completion of the public comment period, NRC will review and analyze all comments received, and incorporate the results of its analysis in final regulations by the end of the year.

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