From the U.S. Nuclear Regulatory Commission

Regulating the Development of a Waste Repository

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Three federal agencies share the responsibility for developing and regulating a geologic repository for high-level nuclear waste. The U.S. Department of Energy (DOE) is responsible for siting, designing, constructing, and operating the repository; and the U.S. Environmental Protection Agency (EPA) has been charged with developing "generally applicable environmental radiation protection standards" to set the overall safety standard for high-level waste. The U.S. Nuclear Regulatory Commission (NRC) is responsible for developing the technical criteria to implement the EPA standard and to ensure, by the licensing process, that a proposed repository will satisfy these criteria (see Smith and Morris on federal management—Ed.).

Ensuring the safe isolation of radioactive waste for an extended period of time presents a unique problem for the Nuclear Regulatory Commission. The licensing process for waste isolation requires a finding of "reasonable assurance" that the waste will remain isolated for many thousands of years. Implementing the proposed EPA standard will require quantitative predictions of radionuclide releases to the general environment; ultimately, these predictions will rely on mathematical modeling of the movement of postulated releases from the deeply buried waste through the geologic and hydrologic environment to accessible locations.

Many uncertainties are associated with this modeling, including uncertainties in understanding basic physical processes, uncertainties regarding site characterization, and uncertainties and errors introduced by numerical modeling methods. Although a quantitative analysis of these uncertainties has not been done to date, and may never be fully possible, their consideration will nevertheless be a key element in any NRC judgment of "reasonable assurance" with regard to safety in nuclear waste isolation. Thus, a major concept underlying NRC's rulemaking in this area is the reduction or elimination of uncertainties to the extent practicable, and compensation for unavoidable uncertainties by redundancy in the overall system of major barriers in the repository.

ACTIVITY	NRC LICENSING ACTION
Site Characterization	NRC comments informally on DOE Site Characterization Plan. Public comment is requested.
	Informal, frequent DOE-NRC interaction occurs during Site Characterization.
Construction	DOE applies to NRC for authorization.
	NRC staff reviews application.
	Public participation occurs.
	If application is sound, license is issued.
	DOE commences repository construction.
Operation	Same process as for construction authorization.
Decommissioning	Same process as for construction authorization.

Figure 1. The sequence of events in licensing a geologic repository for high-level nuclear waste.

Licensing Procedures

The procedural portion of the NRC rule specifies a multi-step licensing procedure consisting of site characterization, construction authorization, the license to receive waste, and decommissioning. At each step DOE will make information available to NRC and the public for review; and, with the exception of site characterization, a formal NRC licensing action is also required (Fig. 1). (NRC will comment informally on DOE's site characterization report, however.) This licensing procedure is intended to provide NRC and public in-

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volvement at each step of repository development, and to promote early identification and resolution of potential problems at a repository site.

The procedural rule requires DOE to investigate and characterize a minimum of three sites in at least two different media prior to submitting a license application for a site. This requirement will allow NRC to satisfy the National Environmental Policy Act (NEPA) requirement for considering alternatives, will prevent a premature commitment by DOE to a particular site, and will assure that DOE's preferred site will be chosen from a slate of candidate sites that are among the best that can reasonably be found. As part of the site characterization program, DOE is required to conduct an in situ testing program at depth for each site (see Smedes on the DOE program—Ed.).

On February 25, 1981, NRC published in the *Federal Register* the final rule containing the procedural requirements for licensing a high-level waste repository.

The Technical Rule

Compensating for any uncertainties that would otherwise confound an adequate demonstration of compliance with EPA standards is an essential part of the technical portion of NRC's regulation. Although conservative analyses, bounding assumptions for input data, etc., have been proposed as ways of compensating for uncertainties, NRC considers that this kind of compensation can best be achieved by setting minimum performance standards for *each* of the major system elements (barriers), so as to provide partial redundancy between these barriers. NRC, then, has proposed such performance objectives for a combination of engineered and geologic barriers as the most practical way of achieving this goal.

Performance standards

The overall performance of a geologic repository with respect to releases to the biosphere can be described by three characteristics: (1) the length of time after closure during which radionuclides are contained, (2) the rate at which radionuclides are released from the engineered system after containment fails, and (3) the travel time through the geologic setting for radionuclides to reach the biosphere. The performance of the individual barriers can also be specified in terms of these three characteristics. The performance of waste packages and the underground facility is determined by specifying a containment time and a fractional release rate; site performance is determined by the travel time. Thus, all of the performance standards for the major barriers can be specified in terms of an appropriately chosen containment time, release rate, and travel time.

Accordingly, NRC has proposed a multi-barrier approach, which defines performance objectives for each of these three barriers. The waste package must be designed to contain the waste for 1,000 years; the engineered system must be designed to limit annual releases of waste after 1,000 years to 10^{-5} of the inventory of waste in the repository; and the geologic setting must provide a ground water travel time of at least 1,000 years. As a further step to protect public health and safety, NRC considers that the repository should be designed to permit the retrieval of the waste for a period of up to 50 years after the completion of emplacement operations. NRC published these performance objectives for comment as a proposed rule in the *Federal Register* on July 8, 1981.

In specifying a *containment time* for the radionuclides, the NRC staff recognized that containment for 1,000 years would prevent releases from occurring until the most hazardous components of the waste, the fission products, have essentially disappeared and rates of heat generation from decay have decreased by three orders of magnitude. Furthermore, containment for 1,000 years has the effect of delaying radionuclide releases until the temperatures in the underground facility have passed their peak and are decreasing, and until the thermal gradients in the underground facility and surrounding rock have decreased substantially. Lower temperatures and temperature gradients allow the release rates and the radionuclide migration rates to be predicted with greater confidence. Therefore, the Commission has framed its performance objective for the waste package to require the design of the package to provide reasonable assurance of containment for at least 1,000 years.

A radionuclide *release rate* on the order of 10^{-5} of the total in a repository per year (or less) after 1,000 years serves two purposes. First, it allows substantial decay of some of the more hazardous of the long-lived species (e.g., more than two thirds of the Pu-239, Am-241, and Am-243). Second, it provides substantial dilution of the long-lived nuclides which do migrate from the engineered system. NRC considers that, based on the technology being developed by DOE, an annual release rate of 10^{-5} of the waste inventory can be achieved at a reasonable cost, using a combination of waste forms and other engineered barriers.

In specifying a requirement for a *travel time*, the NRC staff considered whether to regulate the nuclide travel time or the ground water travel time. The staff reasoned that minimum ground water travel times of 1,000 years

After drilling a slot around a large block of granite and inserting flat jacks to determine the mechanical response of the granite, researchers at the Colorado School of Mines emplace various instruments to measure the effects.

from repository depths to the accessible environment can be identified in many hydrologic systems. Because of the greater confidence in our ability to measure hydraulic than geochemical parameters, and because of the element of conservatism that is introduced, it seems prudent to select the water travel time as the parameter to be regulated rather than the radionuclide travel time, which involves predicting retardation. Therefore, the Commission has framed its site performance objective in the proposed rule so that the ground water travel time from the repository to the accessible environment must be at least 1,000 years. Furthermore, NRC expects DOE to recognize that sites with even longer water travel times are preferable.

Siting, design, and package criteria

NRC has proposed a number of additional criteria for the repository site, the design of the repository, and the waste package, and most of these criteria are qualitative rather than quantitative. Some criteria are intended to promote public health and safety directly through sound practice in repository development—avoiding sites with exploitable mineral resources, performance standards for shaft and borehole seals, etc.; others are intended to reduce uncertainties, to the extent practicable, by avoiding environments where the potential impact on a repository is difficult to analyze (e.g., proximity to surface water impoundments or potential chemical incompatibilities between the waste package and the host rock). Together with the performance objectives and requirements for testing and quality assurance, these criteria will promote confidence that a repository will perform as intended (see St. John on repository design—Ed.).

Site-specific issues

A number of the issues that will be addressed in a licensing proceeding involve site-specific conditions which must be investigated as part of site characterization. As early as possible in the site investigation process, DOE and NRC need to reach agreement on what the key siting issues are and on the kinds of tests and data that will be required to resolve them. An agreement on how to investigate these issues in a manner that will provide a substantially complete license application can be worked out only by close interaction between NRC and the DOE staff working on these problems in the field.

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Status of the Technical Rule

By the end of 1981, NRC had received more than 80 comments on its proposed technical rule which expressed the views of federal and state agencies, industry, public interest groups, and private individuals. Many of the comments reflect concern over how the performance objectives in the proposed rule would be implemented—what would be required to demonstrate a reasonable assurance of compliance with the proposed numerical values. A number of comments point out specific examples, such as defense high-level wastes or aged commercial wastes, where the specific numerical values contained in the performance objectives do not contribute to accomplishing the Commission's objective of ensuring that the EPA standard will be met. The comments suggest a number of approaches for dealing with these concerns, such as eliminating the numerical values altogether, revising the rule to allow flexibility in meeting the subsystem performance objectives (while still requiring that the overall system performance objective be met), treating the numerical values as design goals rather than performance objectives, and delaying the selection of final values until agreement is reached on how to demonstrate compliance with the criteria.

These comments have raised many valid concerns that the Nuclear Regulatory Commission will need to consider in developing its final rule. The Commission recognizes that the technology for isolating high-level waste is still developing and that DOE needs flexibility to deal with conditions at a particular site or with particular design considerations. NRC is particularly aware of the need to develop an agreement within the technical community on how to test the components of the waste isolation system and how to evaluate, with reasonable assurance, whether isolation has indeed been achieved. In developing the final criteria, the Commission will need to consider carefully questions raised by the public in its comments on the criteria, and the Commission will ensure that its final rule has the flexibility necessary to make the rule implementable. NRC is confident that mechanisms can be worked out for dealing with these issues, and that it will accomplish its goal of providing a reasonable assurance of the protection of public health and safety without restricting unnecessarily DOE's ability to take advantage of favorable conditions at a particular site or new developments in engineering methods.

From the U.S. Department of Energy

The National Program for Isolating High-Level Nuclear Waste

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For some time, the U.S. program for managing high-level radioactive waste has focused on the method of deep geologic isolation. This paper summarizes the national objectives for waste isolation in this manner and describes the status and outlook of the program designed to carry out the objectives. It gives attention to the goals and plans of the U.S. Department of Energy, describes the Department's work, and pinpoints the key issues in siting a geologic repository for high-level waste.

The radioactive waste program of the U.S. Department of Energy (DOE) focuses on the method of isolation in deep geologic formations, using concepts that are compatible with the provisions of the National Environmental Policy Act (NEPA). An environmental impact statement addressing this method was reviewed publicly and published in final form in 1980 (DOE 1980a). A record of decision was then published in the *Federal Register* (DOE 1981a) which formally declared a strategy for waste isolation based upon the development of mined geologic repositories. This strategy is therefore the current policy of the U.S. Department of Energy (see Smith and Morris on federal management—Ed.).

The construction of these repositories will involve sinking vertical shafts 1,000–3,000 ft; developing a grid of horizontal drifts and chambers at the bases of the shafts; and placing the waste in corrosion-resistant containers to be laid on the floors or sealed in holes drilled into the floors of these drifts. After the waste is emplaced, the rooms and drifts will be backfilled and sealed. Finally, the shafts themselves will be filled and sealed (see St. John on repository design—Ed.).

The most likely way for waste to migrate from a repository into the biological environment is through dissolution in and transportation by ground water. DOE plans to select repository sites only in structurally sound, stable rocks of low permeability where waste can be isolated during its extremely long hazardous lifetime. Thus, the geologic and hydrologic conditions of the site provide the ultimate barriers to waste migration (see Hustrulid on host media—Ed.). Additional safety is provided by engineered barriers, including the composition and form of the waste, the canister, packing, and backfill.

Program Goals and Plans

The completion of a first full-scale operational repository in about 25 years continues to be a primary goal of DOE. The proposed system is advantageous because (1) it does not depend upon scientific or engineering breakthroughs; (2) it can be assessed with current capabilities; and (3) it will not require active maintenance or surveillance for a very long period of time into the future. DOE's program was described in detail in the Department's statement of position, which is part of the Confidence Rulemaking Proceedings of the Nuclear Regulatory Commission (DOE 1980b and 1980c). These proceedings stem from the decision of the Nuclear Regulatory Commission (NRC) to re-examine the basis for confidence in the future off-site storage or isolation of spent nuclear fuel.

Until recently, the attitude of the Department of Energy was, in effect, "Trust us; in 25 years a full-scale repository will be available." That program was sharply criticized because, after decades of government procrastination and partial solutions, it seemed that another 25 years was too long to wait with only assurances that the goal would be met. DOE decided that the regulatory process and public confi-

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