RETHINKING HIGH-LEVEL RADIOACTIVE WASTE DISPOSAL: HOW DO WE GET THERE FROM HERE?

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ABSTRACT

There is worldwide consensus that geological disposal is best for disposing of high-level radioactive waste; nevertheless, the U.S. program is unlikely to succeed. The program is hampered by its high degree of inflexibility with respect to both schedule and technical specifications that assume the properties and future behavior of a geological repository can be determined and specified with a very high degree of certainty.

Geological models, and scientific knowledge generally, have been inappropriately applied. Geophysical analysis can and should have a key role in the assessment of long-term repository isolation; however, geophysical models are being asked to predict the detailed structure and behavior of sites over thousands of years. This is scientifically unsound and will lead to bad engineering practice.

The United States has written detailed regulations for repository siting and construction before all of the data are in and is thus bound by requirements that may be impossible to meet. An alternative approach emphasizing flexibility can succeed. It will require time to assess performance, a willingness to respond to problems as they arise, remediation if necessary, and revision of the design and regulations if they are found to impede progress toward the health goal already defined as safe disposal.

THE PROBLEM

This presentation is a digest of a position paper "Rethinking High-Level Radioactive Waste (HLW) Disposal"(1) prepared by the Board on Radioactive Waste Management (BRWM or Board) of the National Research Council. The National Research Council is the operating arm of the National Academies of Science and Engineering and the Institute of Medicine.

The conclusions in this paper are the result of several years of the Board's discussions and, therefore, have a strong base in the decades of scientific and professional experience represented among its members. This experience was augmented at a week-long study session in July 1988 to which the Board invited experts from the United States and abroad.

This group identified two primary reasons why the technical programs on high level radioactive waste disposal carried out by government and industry in the United States have not led to a socially satisfactory resolution of the problem of High-Level Waste (HLW) management and disposal. The first and most obvious is the controversy over nuclear energy and radioactive waste disposal as part of nuclear energy development. The Board takes no position on the use of nuclear energy, but it notes that even if nuclear power were to be discontinued tomorrow--a highly unlikely event--we would still need safe disposal of nuclear waste from existing power plants and defense programs. The second reason that radioactive waste management remains in trouble is the way in which the programs have been designed and carried out. The Board believes that important scientific and technical issues concerning the safe disposal of HLW have been widely misunderstood, resulting in a set of programs that will not achieve their stated goals. Neither the technical nor the social problems of the waste materials already in existence are being handled effectively. Still, the Board believes that the safe and effective isolation of radioactive waste is feasible.

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

Current U.S. Policy and The Program

In the Nuclear Waste Policy Act of 1982 (NWPA)(2) Congress assigned responsibility to the Department of Energy (DOE) for designing and eventually operating a deep geological repository for high-level radioactive waste. The repository must be licensed by the U.S. Nuclear Regulatory Commission (NRC) and must meet performance standards established by the U.S. Environmental Protection Agency (EPA) and regulations issued by the NRC.

The U.S. program has been unique among those of all nations in its rigid schedule, in its insistence on defining in advance detailed technical requirements for each subsystem of the multibarrier system, and in its major emphasis on the geological component of the barrier. Because nuclear waste management necessitates predicting the fate of HLW into the distant future, the undertaking is necessarily full of uncertainty. And accounting for uncertainty runs counter to DOE's mode of operation.

For historical and institutional reasons, DOE managers seem to feel compelled to do things perfectly the first time, rather than to make changes in concept and design as unexpected geological features are encountered and as scientific understanding develops. This "perfect knowledge" approach is unrealistic, given the inherent uncertainties of this unprecedented undertaking, and it runs the risk of encountering "show-stopping" problems and delays that all too often lead to a further deterioration of public and scientific trust. In this sense the government's HLW program and its regulation may be a "scientific trap" for DOE and the U.S. public alike, encouraging the public to expect absolute certainty about the safety of the repository for 10,000 years and encouraging DOE program managers to pretend that they can provide it. To date, because of legislative and regulatory requirements, and the way the program is being carried out, U.S. policy has not led to satisfactory progress on the problem of radioactive waste disposal.

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

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

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

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

The Inevitability of Uncertainty

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

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

Second, safety is in part a social judgment, not just a technical one. How safe is safe enough? Is it safer to leave the waste where it is, mostly at reactor sites, or to put it in an underground repository? In either case safety cannot be 100 percent guaranteed. Technical analyses can provide background for answering such questions, but ultimately the answers depend on choices made by the citizens of a democratic society. The EPA has not based its standards on such realistic alternatives. Both of these important limitations of the analysis (no proof in the conventional sense and safety as a societal decision), have been understated.

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

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

The Proper Use And The Limitations Of Modeling For Geological Processes

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

Models of the repository system are useful, indeed indispensable. The computerized mathematical models that describe the geological structure and hydrological behavior of the rock are needed to manage the complex calculations that are necessary to evaluate a proposed site. Models are vital for two purposes: (1) to understand the history and present characteristics of the site; and (2) to predict its possible future behavior. But putting the available data into a coherent conceptual framework should focus attention on the kinds of uncertainty that exist. For example, the modeling of groundwater flow through fractured rock lies at the heart of understanding whether and how a repository in hard rock will perform its essential task of isolating radioactive materials. The studies done over the past two decades have led to the realization that the phenomena are somewhat more complicated than had been thought. Ground water modelling is better understood than almost any other component of the repository system, yet as Leonard Konikow points out in a post audit of the accuracy of ground water models, the results are not totally satisfactory(3). Rather than decreasing our uncertainty, this line of research has increased the number of ways in which we know that we are uncertain. This does not mean that science has failed; we have learned a great deal about these phenomena. But it is a commonplace of human experience that increased knowledge can lead to greater humility about one's ability to fully understand the phenomena involved.

Uncertainty has been treated inappropriately in the simulation models used to describe the characteristics of the waste repository. As the quantity of information about natural geological settings grows, so too does our appreciation of their variability and unpredictability. This point has often been ignored. Indeed, the very existence of large databases and sophisticated computer models suggests, erroneously, that it is appropriate to design a geological repository as if it were a nuclear power plant or jet airliner, both of which have predictable attributes over their relatively short lifetimes. That assumption of accurate predictability will continue to produce frustration and failure.

Under the present program, models are being asked to provide answers to questions that they were not designed to address. A scientifically sound objective of geological modeling is to learn, over time, how to achieve reasonable assurance about the long-term isolation of radioactive waste. That objective is profoundly different from trying to predict quantitatively the long-term behavior of a repository. Yet, in the face of public concerns about the safety of HLW disposal, DOE has done exactly that!

The Board believes that this use of geological information and analytical modeling--to pretend to be able to make very accurate predictions of long-term site behavior--is scientifically unsound. Its conclusion is based on detailed reviews of the methods used by DOE and the regulatory agencies in implementing the Nuclear Waste Policy Act(2).

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

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

It may even turn out to be appropriate to delay permanent closure of a waste repository until adequate assurances concerning its long-term behavior can be obtained through continued in-situ geological studies. Judgments of whether enough is known to proceed with placement of waste in a repository will be appropriate throughout the life of the project. But these judgments should be based on a comparison of available alternatives, rather than a simplistic debate over whether, given current uncertainties, a repository site is "safe."

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

An Alternative Strategy

As we have noted earlier, there is no scientific reason to think that an acceptable HLW repository cannot be built and licensed, but for historic and institutional reasons, DOE managers seem to feel compelled to "get it right the first time" and this management strategy runs the risk of encountering "show-stopping" problems that may delay licensing and will certainly cause further deterioration of public and scientific trust.

An alternative management strategy would be more flexible and experimental, and would embody three principles:

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

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

As the current U.S. program seems unlikely to succeed, the Board proposes an alternative approach that is built on well-defined goals and objectives, utilizes established scientific principles, and can be achieved with known management capabilities. What is needed is an institutional approach that is more flexible and experimental--in other words, a strategy that acknowledges two important premises:

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

This is a flexible approach. It really is not that complicated, and it can be summarized in three key principles:

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

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

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

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

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

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

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

The Risk Of Failing To Act

Given the history of radioactive waste management in the United States, it is more likely that the program will continue as at present. That would leave the nation's inventory of high-level waste, indefinitely, where it is now: mostly at reactor sites on or near the earth's surface. This alternative is safe enough in the short term--onsite storage systems are safe for at least 100 years, according to present evidence(4). But at-surface storage by default may be irresponsible for the long run because of the uncertainties associated with maintaining institutional control over HLW at or near the surface for centuries.

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

REFERENCES

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