Intergenerational Decision Making for Radioactive Waste Disposal, Policy and Science: Regulatory Protection Forever?

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ABSTRACT

Assumptions about this generation’s duty to future generations underlie decisions on regulatory requirements for disposal of radioactive waste. Regulatory provisions related to time of compliance, dose criteria, and institutional controls, for example, continue to be topics of discussion as regulations are revised or compared. Subjective and difficult ethical issues are either explicit or implicit in these discussions. The information and criteria used must be relevant and help make good decisions that, ideally, increase the overall welfare of future generations.

To what extent can or should science usefully inform such decision-making? Both the National Academies of Science and the National Academy of Public Administration (NAPA) have reported on this topic, albeit from different viewpoints. This paper explains and expands upon the rationale used for setting compliance time periods such as the Department of Energy’s requirement for a 1,000 year time of compliance with dose limits for low-level radioactive waste disposal facilities. It evaluates radioactive waste disposal against principles of equity recommended by NAPA.

Radioactive waste disposal standards require evaluation of impacts much farther into the future than has been common for other endeavors with very long term effects. While performance assessment analyses provide much useful information, their inherent uncertainties over long time periods preclude the projection of reality. Thus, the usefulness of extremely long projections in supporting good decisions that promote the welfare of future generations is limited. Such decisions are fundamentally a question of resource allocation, equity, and fairness.

INTRODUCTION

Different approaches are possible for regulating waste disposal facilities. In general, the design of the facility can be specified, or the allowable releases, exposures, or radiation doses from the facilities can be specified. Most current regulations for radioactive waste disposal facilities specify allowable doses to members of the public at times in the future. Compliance with these dose requirements is to be established by analyses which model the transport of radionuclides

[1] This paper includes historical information regarding the development of various waste management related policy and regulations as well as the authors perspective on such policies. These perspectives represent the authors opinions and except where DOE policies or orders are referenced do not necessarily reflect positions or policies of the Department of Energy.

from the facility through the environment and the postulated resulting exposures and doses to people. These prospective analyses, called performance assessments, use characteristics of the waste, the facility design, the site’s geologic and hydrologic characteristics, and estimates of future processes and events such as climate, population, and human life styles and diets to predict future radiation doses. One issue is: Over how long a period of time must compliance with the dose limits be demonstrated, that is, how far into the future must the performance assessment look in regard to conformance with the dose limit? This time period is referred to in this paper as the time of compliance. The time of compliance should be established considering both technical matters and intergenerational equity giving consideration to appropriate data quality objectives. Scientists and engineers involved in waste management policy and regulation have placed the greater emphasis on technical factors. Although regulations for radioactive waste disposal have been in place for some time, the appropriate time of compliance is frequently an issue. Most recently it is being addressed in proposed changes increasing the compliance time in the Environmental Protection Agency’s (EPA) high-level waste repository standards. It has also been an issue in Nuclear Regulatory Commission (NRC) staff guidance on compliance with low-level waste regulations as well as DOE guidance for its low-level waste management directive. Deliberations on time of compliance for a specific regulation or directive frequently raise questions regarding the need for consistency or a set of consistent criteria for establishing time of compliance requirements or guidance.

This paper will review the history of time of compliance requirements in radioactive waste disposal regulations, and discuss issues of intergenerational fairness and equity, the appropriate role of science in establishing time of compliance, the impact of uncertainties in performance assessment analysis, and the basis for the 1000 year time of compliance in U.S. Department of Energy (DOE) orders governing disposal of low-level radioactive waste (LLW).

REGULATORY HISTORY OF TIME OF COMPLIANCE

The earliest radioactive waste disposal standards did not include requirements for prospective analyses, rather they required wastes to be managed consistent with existing public, and worker radiation protection standards utilizing common practices for managing waste. Although these requirements encouraged waste minimization, waste isolation and measures to mitigate migration, they presumed that the waste would continue to be controlled and monitored as necessary. The implication is that the waste would be managed to comply. In the early 1980’s, radioactive waste regulations began to require prospective analyses of future impacts. Dose limits were included but no specific the time of compliance was stated in the standard. In other cases, long-term effects where assessed in development of the standards and the time of compliance requirements (in the range of a few hundred years to 1000 years) were provided as requirements for the stability of the closed disposal site design. As additional regulations were issued or revised over the next two decades, the times of compliance to be demonstrated in a performance or safety assessment increased to 1,000 years, 10,000 years, and now, for a high-level waste repository, one million years is being proposed.

Nuclear Regulatory Commission (NRC) Low-level Waste Regulation

Atomic Energy Commission (AEC) (the NRC's predecessor agency) requirements [1] for disposal of LLW were that it "may be stored in conventional burial grounds approved by the AEC."[2]

The NRC regulation for land disposal of radioactive waste [2], promulgated in 1982, was one of the earliest addressing disposal of radioactive waste. These regulations provided that "In choosing a disposal site, site characteristics should be considered in terms of the indefinite future and evaluated for at least a 500-year timeframe."[3] And, "Waste that will not decay to levels which present an acceptable hazard to an intruder within 100 years is designated as Class C waste. This waste is disposed of at a greater depth that the other classes of waste so that subsequent surface activities by an intruder will not disturb the waste. Where the site conditions prevent deeper disposal, intruder barriers such as concrete covers may be used. The effective life of these intruder barriers should be 500 years."[4] In the Performance Objectives[5], no time frame for analysis of compliance with the dose limits is mentioned. However - given the references to 500 years in Section 61.7, and the class C limits being based on an acceptable hazard at 500 years - a common presumption was that, if a site were licensed under Part 61, the timeframe for analysis would have been 500 years. No site has ever applied for a license under Part 61, so this presumption was never verified.

Fourteen years later, in 1996, the NRC staff published for comment a proposed Branch Technical Position (BTP) [3] setting out proposed staff positions on regulatory issues in LLW performance assessment, including time of compliance. The staff recommended a regulatory compliance period of 10,000 years. Parties including DOE and Agreement States criticized this recommendation. For example, one state commented that the BTP was "unnecessary and disruptive" based on its belief that 10 CFR Part 61 does not mandate a compliance calculation beyond 500 years, and, in any case, inherent limitations of performance assessment "abilities" limit the credibility of these assessments to a 500-year timeframe of consideration.[6] The Commissioners did not approve issuance of the BTP. Thus the staff issued their recommended technical and policy approaches as simply a technical report [4] so that they would not be viewed as defacto NRC standards. The report stated that the approaches "were not intended as substitutes for NRC's regulations, and compliance with these recommendations was never intended to be obligatory."[7]

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[2] AEC Manual, Chapter 0511, 044d.(3)
[3] 10 CFR 61.7(a)
[4] 10 CFR 61.7(b)(5)
[5] 10 CFR Subpart C, Performance Objectives
[6] SECY-97-125, Comments on Draft Branch Technical Position on Low-Level Radioactive Waste Performance Assessment, June 18, 1997.
[7] Forward to the report, pages xv and xvi, "--- a number of commenters expressed concern that the proposed guidance, particularly in the area of the recommended policy approaches --- would be viewed --- as defacto NRC standards ---. --- The recommended technical and policy approaches in this NUREG were not intended to be obligatory. --- the staff no longer refers to this document as the draft BTP; it is now Simply (sic) a technical report, representing the views and recommendations of NRC's PAWG."

Regulation of Mill Tailings

Environmental Protection Agency (EPA) standards for disposal of uranium mill tailings [5] were issued in 1983, shortly after NRC's issuance of 10 CFR Part 61. These standards specify: "Control of residual radioactive materials and their listed constituents shall be designed to be effective for up to one thousand years, to the extent reasonably achievable, and, in any case, for at least 200 years."[8] EPA required no performance assessment but rather required monitoring upon closure and long-term maintenance of the disposal facility.

Regulation of High-Level Waste (HLW)

In 1985, after several years of deliberation and debate, EPA issued final standards for disposal of high-level waste [6]. The earlier proposed standards had a containment requirement that limited the releases of radionuclides from the repository's controlled area into the accessible environment for a period of 10,000 years. It did not have a requirement limiting doses to individuals. The final rule retained the containment requirement and added an individual dose requirement. Although EPA's Science Advisory Board recommended a time of compliance of 500 years for individual dose limits[9], EPA selected 1,000 years stating "demonstrating compliance with individual exposure limits for times much longer than 1,000 years appears to be quite difficult."[10]

In 1987, following a legal challenge, a court noted discrepancies between the individual protection standard and standards under the Safe Drinking Water Act and remanded the standard to EPA for further explanation of the 1,000 year time frame.[11] This court expressly found that the 10,000-year timeframe for the containment standard was adequately justified. In 1993 EPA issued a revised standard [7] that increased the time of compliance for doses to individuals to 10,000 years.[12] However, this applied only to doses from undisturbed performance, that is, when the disposal system is not disrupted by human intrusion or unlikely natural events.

The Energy Policy Act of 1992, issued shortly before EPA's 40 CFR 191 revision, mandated that EPA issue a separate, site specific, standard for the Yucca Mountain site. It required that the standard prescribe the maximum dose to individual members of the public and that it be based on and consistent with recommendations in a study required to be conducted by the National Academy of Sciences (NAS). This study was issued in 1995 [8]. It contained statements that were later construed by a court of law to constitute a recommendation that the time of compliance should extend to the time of peak dose out to as far as one million years. However, it was not clear to EPA (or to many others) that the NAS statements were intended to be recommendations for actual regulations or that the NAS recommendations would be found to be mandatory requirements. Thus, in 2001 EPA issued a standard for the Yucca Mountain site [9]

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[8] 40 CFR 192.02
[9] See 50 Fed. Reg. 38078
[10] 50 Fed. Reg. 38073
[11] NRDC v. EPA, 824 F.2d 1258 (1st Cir. 1987)
[12] 40 CFR 197, 58 Fed.Reg. 66398

with a time of compliance of 10,000 years[13]. In 2004, following a legal challenge, a court vacated the time of compliance provisions finding they were not based upon and consistent with the NAS recommendations. In August, 2005, EPA issued a proposed rule [10] that requires the time of compliance to extend to the time of peak dose up to one million years.[14]

DOE Regulation of LLW

Early directives and guidelines from the Department and its predecessor agencies did not specifically require performance assessments[15] but required that the public and workers be protected to applicable requirements in radiation protection directives. DOE Order 5820.2 *Radioactive Waste Management* [11], issued in 1984, required that design criteria be established based on a performance assessment to assure that the performance objectives of the order be met. The objectives were to “adequately protect the public health and safety in accordance with radiation protection standards specified in DOE Orders.”[16] No time of compliance was specified. DOE Order 5820.2A *Radioactive Waste Management* [12], issued in 1988, required that a dose limit to members of the public from a waste disposal site be demonstrated by a performance assessment, but was also silent on specifying the timeframe for analyzing the potential doses to the public from low-level radioactive waste disposal facilities.

In 1999 DOE issued Radioactive Waste Management Order 435.1 [13]. The Order Manual[17] [14] required performance assessments to include calculations for a 1,000-year period after closure of potential doses to representative future members of the public and potential releases from the facility not to exceed the low-level waste performance objectives. The Order Guidelines[18][15] explain that this timeframe was selected to encompass the likely processes and migration of radionuclides most likely to contribute to the calculated dose. Longer times of assessment are not used to assess compliance because of the inherently large uncertainties in extrapolating such calculations over longer timeframes[19]. The guide[20] states that although the period of performance is 1,000 years it may be helpful to extend the calculation to include the maximum impact (peak dose) even if the maximum is not realized for tens of thousand of years. This calculation may increase the understanding of the models used and the disposal facility performance, but are not used for determining compliance with the performance objectives. It further explains that caution must be exercised when interpreting such results calculated thousands of years due to compounding of errors that cause results to be nonsensical. Although the guidance uses 1,000 years as the time of compliance for supporting a decision on compliance with the performance objectives based on prospective assessments, the existing order, like its 1970s predecessor (AEC 0511, *Radioactive Waste Management*), continues to require that the waste site be managed so as to comply with radiation protection requirements (DOE 5400.5, *Radiation Protection of the Public and Environment*) for as long as the waste is hazardous.

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[13] 66 Fed. Reg. 32074
[14] 70 Fed. Reg. 49014
[15] AEC Manual 0511 and DOE Order 5820.1
[16] DOE 5820.2, 5. Objective
[17] DOE M 435.1-1 P(2)
[18] DOE G 435.1-1 Section IV page 191
[19] The appropriateness of applying the same metric of public protection performance (same dose limit) over large time periods where public priorities would change was also questioned during the development of the requirements
[20] DOE Guide 435.1-1 Section IV page 195

Regulation of Hazardous Waste

EPA regulations for RCRA disposal facilities specify detailed waste form and design requirements and requirements for post-closure institutional controls such as maintenance and monitoring. For example, design requirements are specified for top and bottom liners, leachate collection and removal systems, and leak detection.[21] Continued post-closure operation of the leachate collection and removal system is required.[22] The regulation specifies that: "Post-closure care --- must begin after completion of closure of the unit and continue for 30 years after that date ---."[23] This post-closure care period may be extended if necessary to protect human health and the environment.[24] No prospective long-term analysis to predict compliance with release or exposure limits is required by the regulation. Instead of using hypothetical projections of future events, performance is assured through design requirements and institutional controls and verified by continuing monitoring.

It is noted that this regulatory system has been successful insofar as many hazardous waste disposal facilities have been approved, opened, and are providing regulated disposal capability under this system. This is as opposed to the radioactive waste regulatory approach under which there have been several failed efforts and no new commercial disposal facilities have become operational in over 18 years.

CONSIDERATIONS OF FAIRNESS AND ETHICS

Goals for Intergenerational Decision Making

A primary goal of decisions that will affect future generations is to fairly and equitably balance the risks, costs, and benefits between generations. Setting standards for radioactive waste disposal that are intended to provide protection for people many generations in the future in a manner which fairly balances risks and benefits between the current and future generations is not a simple task. It is herein suggested that regulatory approaches that simply attempt to guarantee that radiation doses to people in the distant future will not exceed regulatory limits for current populations, and require analytical "proof" of compliance, may not appropriately balance costs and benefits.

It would seem that achieving the above primary goal would require that resources that are expended today in an effort to benefit future generations be expended in the manner that provides the maximum benefit. For example, if the benefit to be provided is improved health, then resources should be spent first on those endeavors that will provide the greatest health improvement.

Principles for Intergenerational Decision Making

[21] 40 CFR 264.301
[22] 40 CFR 264.310(b)(2)
[23] 40 CFR 264.117(a)(1)
[24] 40 CFR 264.117(a)(2)(ii)

The National Academy of Public Administration (NAPA) addressed the issue of equity and fairness to future generations after an extensive four year study in the 1997 document *Deciding for the Future: Balancing Risks, Costs, and Benefits Fairly Across the Generations*. [16] NAPA is an independent organization chartered by Congress to advise government entities on matters of public policy and administration. The Academy formed a panel of distinguished experts with a wide range of appropriate expertise to address this issue. The group included experts on hazardous waste, risk (analysis, assessment, and management), the environment, public service, ethics, economics, energy production and management, cost benefit analysis, sustainable development, philosophy, administrative decision-making, public administration, and government. It also included members from industry, colleges and universities, and government.

In the first phase of the study an extensive literature search was undertaken to acquire the broadest possible and most current thinking on issues related to intergenerational decision-making. In the second phase the panel sponsored a workshop with about 50 people of diverse backgrounds and expertise who used information and issue papers from the literature search to, among other things, develop a draft set of guiding principles for intergenerational decision making for consideration by the panel. These principles are:

- no generation should (needlessly) deprive its successor of the opportunity to enjoy a quality of life similar to its own
- every generation is the trustee for those that follow
- there is an obligation to protect future generations provided the interests of the present generation and near term generations are not jeopardized
- near term concrete hazards have priority over long term hypothetical hazards
- however, this preference for the present and near-future is reduced where questions of irreversible harm for future generations are concerned
- when action poses a plausible threat of catastrophic effects, then that action should not be pursued absent some significant countervailing need
- the reduction of resource stocks entail a duty to develop substitutes.

The panel revised these principles to eliminate overlap and to clarify, simplify, and amplify the intended meaning. The panel defined the following principles:

- Trustee Principle – Every generation has obligations as trustee to protect the interests of future generations.

- Sustainability Principle – No generation should deprive future generations of the opportunity for a quality of life comparable to its own.

- Chain of Obligation Principle – Each generation’s primary obligation is to provide for the needs of the living and succeeding generations. Near-term concrete hazards have priority over long-term hypothetical hazards.

- Precautionary Principle – Actions that pose a realistic threat of irreversible harm or catastrophic consequences should not be pursued unless there is some compelling countervailing need to benefit either current or future generations.

Application of Principles to LLW Disposal Site Time of Compliance

Application of the above principles to LLW disposal suggest that in determining what might be a "undue burden" on future generations the following considerations should be included:

- The benefits to future generations from the activities generating the waste
- The relative risks
- The potential benefits from applying resources elsewhere

There are innumerable benefits to future generations from activities that generate radioactive waste. Generation of electricity with nuclear power conserves irreplaceable petroleum and other fossil fuel resources for future generations and reduces emissions of hazardous combustion products and greenhouse gases. Application of nuclear medicine further advances medical science and leaves a legacy of improved health care. Many advances in scientific research have been made possible through the use of radionuclides. Thus, it is not unreasonable to expect future generation to bear at least some burden such as continued implementation of institutional controls to manage or mitigate slight increases in radiological health risks.

The principles developed by NAPA suggest that when looking far into the future the major concern should be to avoid the possibility of catastrophic consequences. Current disposal standards specify dose limits, which are equivalent to a few medical x-rays, to people in the vicinity of the repository (or to a single reasonably maximally exposed individual). This cannot be considered catastrophic even on an individual level, to say nothing of a regional or national level or in the context of events over the course of hundreds of years. The principles suggest that it would not be ethically required, or even appropriate, to forgo an activity which will provide many benefits to the current generation – and to the future generations as well – to avoid the possibility of such consequences hundreds of years in the future. Thus, it should not be necessary to set a time of compliance with individual dose limits to extremely long times.

Many projects that could have substantial benefits need funding. For example, in December 2005, it was reported[25] that the National Institutes of Health was initiating a pilot project for development of a Cancer Genome Atlas, an effort to identify and categorize all the genetic errors that cause cancer. This could greatly facilitate elimination of cancer[26] as a killer disease. The Director of the National Cancer Institute was quoted saying "The future will look no more like the past than a butterfly resembles a caterpillar." The total cost of the Cancer Atlas is estimated to be 1 to 1.5 billion dollars. The three-year pilot project will cost $100 million; but some people have objected to this expenditure because of its drain on the limited Federal research budget. There are innumerable similar areas where resources could be applied to alleviate both current and future real human suffering. For example, in the United States between 100,000 and 200,000 people die every year from preventable hospital errors.[27] One million people worldwide die every year from malaria, a disease curable with inexpensive drugs.[28]

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[25] Washington Post, December 14, 2005, A14.
[26] Cancer is the principal detriment of concern in establishing radiological dose limits.
[27] Boston Globe, July 27, 2004, citing a HealthGrades study.
[28] Washington Times, January 20, 2006, citing World Health Organization estimates.

While funds for projects such as those above are lacking, compliance times thousands of years in the future result in significant cost burdens. Undertaking the performance assessment analyses alone can cost from hundreds of thousands of dollars for simple LLW sites to millions for HLW repositories. The PA for the Greater Confinement Disposal Boreholes at the Nevada Test Site is reported to have cost significantly more than 10 million dollars. Cancellation of the Ward Valley LLW disposal facility in California resulted in a claim for reimbursement of $162 million for costs from site characterization, performance assessment and licensing. The construction costs for more elaborate and exotic barriers needed to provide confidence in long-term projections of performance can add large costs. As of 2001, $6.7 billion had been spent on the proposed Yucca Mountain HLW repository and the estimated additional cost through closure was $49 billion.

A major difficulty in assessing risks and benefits over long time periods is knowing the metrics or measures to use.[29] What will be the real benefits to future generations of expending substantial resources now in an attempt to prevent cancers from occurring 1,000 years from now? (Cancer to future generations is the primary, presumed risk driving radioactive waste disposal standards.) Technology and medical science are advancing at increasing rates. The internal combustion engine was invented in 1862; the Wright brothers first flew an airplane in 1903, a man landed on the moon in 1969. Average life expectancy in ancient Greece was 20 years. When the Declaration of Independence was signed, average life expectancy was still just 23; the median age was 16. In 1900, life expectance was 49 years; in 1997 it was 77 years. As cures are found for diseases we live longer and other diseases become of concern; medical science then finds cures for these diseases. In 1900 the three leading causes of death in the United States were pneumonia, tuberculosis, and diarrhea. Cancer was number eight and heart disease and cerebrovascular diseases were not in the top ten. In 2001 heart disease, cancer, and cerebrovascular disease were the top three causes of death. All of these changes have occurred over the past 100 years or so. It is nearly impossible to try to imagine what changes may occur over the next 1000 years.

These uncertainties make it questionable whether estimated doses provide a reasonable metric for fairly evaluating risks and benefits for a few hundred let alone thousands of years into the future. New technologies may allow people to monitor and remove radiation from food and water easily. In fact EPA's current drinking water standards for radionuclides are set at the levels where it is currently economically practical to treat public water supplies. It is not credible to assume that cancer will be a concern 1,000 years from now. In the event that civilization regresses and medical science is lost, life expectancies would revert to the old low numbers and radiation induced cancers would be the least of mankind's worries. Thus it is not clear that there will be any benefit to future generations from the expenditure of resources to demonstrate long times of compliance.

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[29] Broadly looking at human priorities through time, from about 200,000 to 10,000 years ago man was nomadic and lived in tribal communities. Human priorities were food and shelter – every day was spent hunting and gathering and protecting themselves from animal attacks and weather. The agricultural revolution (10,000 to about 1750 years ago) relieved the stress for finding food and sheltering from animal attacks. Disease (generally infectious disease) and war (others trying to take food and shelter) were of greater concern to the populations. With the industrial revolution, very large population centers, the ability to process and transport food quickly over large distances, the demand for natural resources and scientific and medical improvements again drastically impacted priorities.

THE ROLE OF SCIENCE

Science based analyses should provide factual information which facilitates making good waste management decisions. Although good decisions are those which result it proceeding in the most effective way to achieve benefits to both current and future generations; technical information is most useful in a more narrow sense, making good decisions which result in the most appropriate facility siting and design. It is important that data be of sufficient quality to result in good decisions.

In the 1990 report by the National Research Council, “Rethinking High-Level Radioactive Waste Disposal” [17] the Board on Radioactive Waste Management stated:

> “[A] Scientifically sound objective of geological modeling is learning, over time, how to achieve the long-term isolation of radioactive waste. That is a profoundly different objective from predicting the detailed structure and behavior of a site --- [I]t is the latter use to which models have been put. The Board believes that this is scientifically unsound.”[30]

The above assessment has merit: Particularly when applied to near-surface disposal instead of the deep geologic disposal that was being evaluated by the Board. However, in a more recent National Research Council report [8], a panel charged with making recommendations for standards for the Yucca Mountain site appears to hold an opposite view of the validity of long-term predictions of site behavior, recommending that performance standards and the calculation of risks extend out to one million years.

This National Academy of Science panel concluded that there is no scientific basis for limiting the time period of individual risk standards to any particular time period. They also acknowledged that issues of equity to future generations and of public policy are important in establishing compliance time periods. In reality, these issues are more than important considerations, decisions on actions that can affect the distant future are primarily public policy administration issues of resource allocation and balancing risks and benefits fairly to current and future generations – they are not technical or scientific issues. Thus, it is not clear why the National Academy of Science, after concluding that there was no scientific basis to establish a time of compliance, proceeded to make recommendations on the topic. It is unfortunate the National Academy of Science did not have available the deliberations of the National Academy of Public Administration [16] discussed above.

The comparison of performance assessment results, at a computational time in the future, to a quantitative dose standard does not provide protection to individuals in the future. Protection is provided by disposal facility barriers to water and radionuclide transport, by the surrounding geologic system, by intrusion barriers, and by ongoing institutional controls (such as Federal government ownership or periodic monitoring or inspection). Performance assessments are quite important to the extent that they improve facility siting and design. Comparing these

[30] Ref. 17, pg. 23

calculations to a dose standard at 10,000 years instead of 1,000 years[31] will not result in better decisions on waste disposal. Given the large uncertainties (discussed below) and wholly hypothetical nature of the calculations and the questionable appropriateness of the metrics (dose limits), such a comparison is as likely to drive a wrong decision as a good one. For example, no significant credit may be allocated to protective barriers for which extremely long-term performance is difficult to prove, hence, there will be little incentive to expend resources on them and they may not be used. However extended calculation times may help to evaluate the reasonableness of the models used.

TECHNICAL CONSIDERATIONS

Analytical projections of the performance of LLW disposal facilities have many significant uncertainties. These uncertainties include those in the parameters used as input and in the conceptual models assumed to represent future processes and events as well as those introduced by approximations introduced by mathematical techniques used in modeling. Current conditions are theoretically knowable but practicalities of measurement introduce errors. For example stratigraphic and hydrologic conditions must be interpolated between a few measurement points. Actual knowledge would require complete excavation, destroying the site. And the measurements actually made of parameters have error bands.

Other important factors in a performance assessment having to do with future conditions are inherently unknowable. In particular, future biospheric conditions are uncertain. Within some thousands of years climate changes and geologic processes will occur; lakes will dry out and rivers will change their course. Cycles of glaciation occur at around 10,000 years. The sources humans use for food, water, power, heat and shelter will be radically different. Medical science and capabilities will be different than today.

The prediction of long-term performance of a disposal facility's engineered barriers requires many models and assumptions to extrapolate from a relatively short base of actual data. For example, while concrete may provide an intrusion barrier for a much longer period of time, its performance as a barrier to water and radionuclide migration is believed to start deteriorating significantly in several hundred years. The useful lifetime of plastic liners and plastic "High Integrity Containers" must be projected from a short span of actual data. The corrosion rate of metallic components such as waste containers or borehole liners in an underground environment must be extrapolated from short-term test data.

The assumptions used for the type and likelihood of human intrusion have a great impact on the calculated results and are often the controlling factor. However, it is widely acknowledged that there is no scientific basis for predicting human intrusion.

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[31] In their analysis of alternative times of compliance the Department staff recognized the subjective nature of the decision. In general, for low-level radioactive waste surface facilities100 years was too short a period as reasonable estimates can be made several hundred years in the future and estimates beyond 1000 years were too dependent on assumptions and subject to great uncertainty. Rather than trying to pick a specific time in between the two, the 1000 year period was selected as the conservative maximum time period that was reasonable for quantitative comparison to a dose limit.

In the past individual dose limits have been applied to current, ongoing radiation exposures. Compliance has been determined based on data from various types of radiation monitoring systems. LLW disposal performance assessments represent no such reality. They are predictions based on and limited by available scientific knowledge and the imagination of the modeler. The large inherent uncertainties require the use of conservatism in deterministic analyses or the use of probabilistic analysis (also done conservatively). The deterministic approach attempts to show that doses will be less than a standard; but how much less, or whether unknowns could overcome the conservatisms, is unknown. In the probabilistic approach large error bands result and issues arise as to what degree of confidence is appropriate.

An illustration of the large uncertainties involved follows. In 1992 DOE completed a task undertaken to provide technical assistance related to the repromulgation of EPA's standard for disposal of high level and TRU radioactive waste, 40 CFR 191. The task involved the calculation of the standard deviation in the dose calculated at 10,000 years from a deep geologic repository for high-level waste. It assumed undisturbed conditions. That is, geologic, hydrologic, and biospheric conditions remain as they are today. It input the probability distribution functions for five geologic, hydrologic, and leach rate parameters and used constant, fixed values for all other parameters in the analysis. The standard deviation in the calculated individual dose at 10,000 years for one of the nuclides analyzed, neptunium-237, was 1,498 mrem/year.

BASIS FOR 1000 YEARS IN DOE ORDER 435.1

DOE Order 435.1 documentation[32] explains that the 1,000 year timeframe was selected because of the uncertainties and hypothetical nature of long-term projections and after consideration of times used for other requirements such as 40 CFR 191 [7] and 40 CFR 192 [5]. The documents[33] include information on compliance periods for other countries. Canada and Sweden had established a compliance period of 10,000 years. However, France and the United Kingdom had not specified a time of compliance.

The compliance period for demonstrating a reasonable expectation for a site to meet the PA performance objectives of 435.1 was developed within the context of the overall protection system implemented through the order. In implementing its radiation protection responsibilities for LLW DOE opted for a defense-in-depth approach that utilized geologic barriers, engineered barriers, numerous real-time required passive and active institutional controls, and prospective analysis to guide decision-making. The objective of the DOE waste management system is to:

- Develop, design, operate, and close sites so as to provide long-term stability of the sites and wastes
- Monitor and maintain the site to ensure DOE requirements for protection of the public and environment are met. (There is no time limit on this commitment.)

<u>DOE's Defense-in –Depth Approach</u>

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[32] Ref. 14 Chapter IV; Ref. 15 Appendix A, Technical Basis and Considerations; Ref. 15 Chapter I
[33] Ref. 14 Appendix A, Technical Basis and Considerations, page 211

The multi-faceted DOE approach for assuring protection of the public health, safety, and the environment at low-level waste disposal facilities utilizes:

- Site characteristics which provide geologic and hydrologic barriers to radionuclide transport
- Facility design
- Waste acceptance requirements tailored to each specific site
- A rigorous waste generator certification program
- Federal ownership of the site and necessary buffer zones until no unacceptable hazard is presented by release of the site
- Barriers to intrusion
- Analyses projecting hypothetical performance of the facility (performance assessments (PA) and composite analyses (CA))
- Siting and design to minimize requirements for future maintenance
- A commitment to provide any future maintenance necessary
- Continued monitoring of facility performance
- Permanent maintenance of records

A performance assessment and the comparison of the results of that assessment to an individual dose limit play an important role in this process, but, it is only one element of the process that is based on a defense in depth approach. Because of the large and irreducible uncertainties, performance assessments are not predictions of actual future circumstances. They are hypothetical projections based on many assumptions and simplifications. The DOE protection system does use conservative assumptions and parameters in the PA – resulting in conservative designs and waste acceptance criteria - to provide a reasonable expectation that the actual doses will not exceed the performance objectives for 1,000 years. But, the real value in these analytical projections is that they facilitate better facility designs: For example, by providing insights as to which features and parameters most affect performance. Thus, the PA is a tool to help assure stability, performance, and effectiveness of the design. In the DOE protection system the PA analysis time is extended beyond the time at which the comparison to a dose-based performance objective is made (1,000 years) to help evaluate the reasonableness of the conceptual and mathematical models used. The DOE process also requires a composite analysis (CA), which evaluates any addition to potential disposal facility doses from all nearby facilities that could contribute additional doses at receptor locations. The CA is a tool to support management decisions that provide information to help establish environmental protection priorities. DOE facilities are required to demonstrate annually that they meet all radiation protection requirements. The CA provides insights to management to determine if multiple sources of dose could potentially threaten to exceed dose limits in the future. DOE would then take actions to mitigate or avert such an event before it could happen.

Thus, the PA is only one part of the protection system and supports decision-making on the facility design. The protection provided by all of the above listed protective measures does not end at the time at which the projected hypothetical results of the PA are compared to an individual dose limit. After assessing the uncertainties involved, DOE has concluded that it is not useful to compare the quantitative results to a limit beyond 1,000 years. Comparing these calculations to a dose standard at 10,000 years instead of 1,000 years will not result in better decisions on waste disposal. Given the large uncertainties, the wholly hypothetical nature of the calculations, and the questionable appropriateness of dose as a metric for health detriment over such long periods, such a comparison is as likely to drive a wrong decision as a good one.

CONCLUSION

The length of time into the future for which radioactive waste disposal facility performance assessments are required to demonstrate compliance with individual dose limits has evolved – ratcheted upward – over the last twenty five years from unspecified to a few hundred years to as much as one million years, i.e., forever. This ratcheting has been propelled by an unfortunate combination of factors including court decisions; the responses thereto, and overly simplified notions of the duty to future generations applied by technical experts. These extended time of compliance periods require analytical projections which have great inherent uncertainties, must be based on arbitrary assumptions about a hypothetical future, and thus do not represent reality. Consequently, resulting waste management decisions may not benefit either future or the current generation.

A comprehensive consideration of equitable principles indicates that demonstrating such long-term compliance with dose limits is not required to fairly balance risks, costs, and benefits across generations.

For example, extending the time of compliance with individual dose limits for LLW disposal facilities from 500 or 1,000 years to 10,000 years to be “consistent” with HLW standards, and requiring that disposal facilities be sited and constructed such that is would be possible to “prove” compliance with such a standard in a court of law, is not a wise use of resources. Such an endeavor would quite costly and would provide no significant health, safety, or environmental benefit. Future generations would be benefited far more by expending those resources on medical research, or in numerous other areas, or even for maintenance and monitoring of the disposal facility.

In summation, the results of prospective analyses should be used within the overall context of the waste management system and its objectives and the associated time-of-compliance should be such that it supports, not burdens, the process. The objective is that waste disposal facilities be designed, constructed, maintained and closed in a manner that provides long-term stability and minimizes the need for active maintenance. To accomplish this:

- Institutional controls (including monitoring and maintenance) should be in place and implemented for as long as necessary and the need for the controls documented and periodically reevaluated (This is required by DOE policy [18]).
- Prospective analyses should be conducted to support design and closure decisions.
  - -the comparison of the results of such analyses to quantitative dose limits should be limited to that time (a few hundred to one thousand years) over which the comparisons can aid in evaluating design, closure, or mitigation options.
  - -over longer time periods the analyses may be useful in assessing the performance of the models or identifying critical problems but not for comparison to quantitative dose limits.

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