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A Ten Thousand Year Prediction
For Nuclear Waste Management**

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The Lack of Technical Basis for Requiring a Ten Thousand Year Prediction for Nuclear Waste Management¹

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ABSTRACT

There is no technical basis for setting a time limit of 10,000 years on the regulated performance of a nuclear waste repository. First, accurate prediction of releases for such periods is not possible. Second, there is nothing unique about 10,000 years. Third, equally toxic materials, which never transform to non-toxic substances by radioactive decay, have no long-term requirements. And fourth, over a 10,000 year time frame, social and natural disasters will dwarf the worst possible outcomes of repository placement.

Analyses could be required to extend as long as doses above current radiation protection guidelines are possible (perhaps several million years), but these results should be recognized as qualitative information rather than evidence of quantitative compliance with exact numerical limits. Concern for what will happen over long times can be addressed for the next several hundred years by maintaining waste retrievability. At that time, uncertainty about future performance should have been reduced significantly.

INTRODUCTION

The U.S. Environmental Protection Agency's (EPA) standards for the management and disposal of spent nuclear fuel, high-level and transuranic radioactive wastes set numerical limits for the cumulative release of radionuclides over a 10,000 year period.¹

Although not invoked by EPA, the common technical rationale for requiring a very long time period in regulating radioactive materials is based on the reduction of inventory by radioactive decay. Reduction of inventory reduces the toxicity from

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radioactivity of the emplaced waste. However, it does not necessarily reduce the risk, because the risk is a result of many interacting complex factors (see the APS study² for a discussion of the difference between toxicity and risk). In a curious inversion, the predictable decline in toxicity of nuclear waste with time has been ignored in producing requirements that nuclear waste be regulated for thousands of years, while not requiring long times for persistent toxic materials.³

There is a considerable body of literature comparing high-level repositories with uranium ore bodies.^{2,3,4} The premise is that when a repository inventory decays to below the inventory of a typical ore body, then the repository could be considered to pose no more hazard than the original source of the uranium used in the reactor. If one compares toxicity indices, early studies showed reprocessed waste reaching this level in 400 years and spent fuel in about 7000, whereas later revisions based on International Commission on Radiation Protection revisions raised those values to 20,000 years for reprocessed waste and three million years for spent fuel.³

More than any other materials, radioactive substances have been subjected to the no-threshold, linear-dose hypothesis in considering health effects. That is, a single radiation interaction with the body can produce a cancer, and therefore no amount of radiation is safe. However, if this is the driving force behind long regulatory time-frames, then millions of years—not thousands—would be required. And in fact, analysis to beyond a million years is common in waste management programs worldwide. However, such analyses are not considered predictive, merely heuristic. The attempt to predict compliance with exact numerical limits for 10,000 years is unique to the U.S.

REGULATORY JUSTIFICATION

The published justification by EPA for a time requirement of 10,000 years is qualitative:

“In the course of performing numerous risk assessments of radioactive waste disposal systems, the Agency has concluded that the risks identified over relatively short time spans, such as a few hundred to one thousand years, do not adequately portray important differences between alternative sites or disposal systems... The primary risk assessments carried out in support of this rulemaking have thus been based on a time frame of 10 thousand years. This

³ Recently, non-nuclear material in a few instances has become subject to multi-thousand year requirements. See for example EPA's 40 CFR Part 148.

time frame appears long enough to identify important differences between one site and another, or between other aspects of one disposal system and another.”⁵

Thus it appears that the main purpose of the long time frame is to allow comparison between sites, presumably to aid in site selection. This rationale is further expressed by EPA in response to comments in which they agreed that “more qualitative or comparative assessments beyond 10,000 years might be appropriate.”⁶ They noted DOE's provisions for comparisons of the projected releases from undisturbed performance of alternative repository sites over 100,000 years to be a significant consideration in site selection. They concluded that “this provision should allow for appropriate consideration of longer time periods without requiring the absolute values of these very uncertain calculations to meet a specific quantitative test”.⁶

There is no evaluation of half-lives, inventory concentrations, or toxicity or risk as a function of time. Ten thousand years is simply a convenient reference point for comparison. Unfortunately, in subsequent years, it has become fixed as a goal, both with the technical and lay public with respect to repository performance. A number that has no quantitative basis is now to be applied quantitatively with exactness and rigor.

The EPA standard 40 CFR 191 was remanded by the court in 1987. This was in part based on the discrepancy between the main containment requirement that set cumulative limits on releases of radionuclides to the environment for the first 10,000 years following disposal and two ground water protection requirements that were applicable for 1000 years. The court found that EPA has not sufficiently justified the difference between the two time frames.⁷

DISCUSSION

The thesis of this paper is that exact numerical standards for specific time limits such as 10,000 years based on analysis of repository performance are unprecedented and unwise, based on four main points: 1) exact prediction for 10,000 years cannot be done, 2) lack of technical justification, 3) non-radioactive toxic materials are not regulated to the same time-frames, and 4) natural events of far greater consequences will overwhelm effects from a repository over such time-frames.

It should be emphasized that 10,000 years is not the issue in itself, nor would 1,000 or 100,000 years if they were adopted. The problem is the expectations that have arisen as to the numerical predictions, either deterministic or probabilistic, that are called for in both the Nuclear Regulatory Commission (NRC) and EPA regulations over a very long time period. Use of qualifying phrases such as "reasonable expectation" or "reasonable assurance" — though intended as an alleviation — opens the door to endless debate about the methodology and limits of science. As pointed out by the National Academy: "a scientifically sound objective of geophysical 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 before, or even after, it is probed in detail. Yet, in the face of public concerns about safety, it is the latter use to which models have been put. The Board believes that this is scientifically unsound."⁸

Impossibility

Exact prediction of the effects of disposing of high-level radioactive waste for 10,000 years as required by regulation in the U.S. is not possible. This is clearly stated by the Board on Radioactive Waste Management (BRWM): "to predict accurately the response of a complex mass of rock and groundwater as it reacts over thousands of years to the insertion of highly radioactive materials is not possible".⁸

There are a variety of reasons why this is the case. For probabilistic (statistical) numerical analyses, uncertainty can grow to unmanageable proportions for such extended calculations. The BRWM devotes considerable attention to uncertainty and modeling limitations for the site, listing numerous sources of uncertainty.⁸ Probability analyses for the engineered barriers use exponential functions.⁹ For both site and engineered barriers, uncertainty grows with time.

It is important to consider unpredictable discrete events. Even without using probabilistic analysis, simply for causal arguments and deterministic analytic solutions, there is a high probability of scientific paradigm shifts that might affect the conclusions within even a few centuries. The public is perhaps more aware of this aspect of science than any other because of the fame accorded to the discovery of radioactivity, Einstein and relativity, plate tectonics in geosciences, and other scientific discoveries that profoundly affect the way we view the world. Therefore, much of the public will intuitively reject predictions for 10,000 years.

Even with a design based on conservative engineering, fundamental scientific principles, and well-established physical laws to the greatest possible extent, uncertainty will remain.

Lack of technical justification

The value 10,000 is not supported by a technical rationale, and might just as well be 1000 or 100,000 years, or even a million years. The numerous analyses reviewed below reveal no discrete time after which a significant decrease of risk occurs. The NRCs justification for their containment requirement is that "uncertainties introduced by the heat generation rate and the fission product contributions to hazard can be compensated for by containment times in the range of several hundred to 1,000 years",^{4, p 519} A technically based rationale is not given for the 1000 year ground water travel time requirement, the rationale being merely to increase confidence that the EPA standard can be met.

It is commonly asserted that ten half-lives is sufficient to eliminate negative consequences from radionuclides in waste or as contamination.² This is frequently then cited to justify 250,000 years (ten half-lives of Pu-239). There is no radionuclide of safety significance with a half-life of 1000 years, so there is no justification based on half-life supporting a 10,000 year time requirement.

The degree of safety afforded by radionuclide decay is really based on concentration in the waste. With a very low concentration, ten half-lives may not be needed, and with a very high concentration, it may not be enough. Pigford¹⁰ points out that in borosilicate glass containing commercial reactor waste, the actinide concentration would have to be reduced by about 10^5 before the glass dissolution rate replaces actinide solubility as the controlling factor for actinide concentration in ground water. Until this 10^5 concentration reduction is achieved, the amount of radioactivity entering the ground water is controlled by the solubility product of the actinide species considered.

Ten half-lives reduces the level of radioactivity by 1024, or very close to 10^3 reduction factor; thus, ten half-lives decay would not affect the rate at which actinides entered ground water. A 10^5 reduction would require 16 half-lives, after which further reduction in concentration would affect the availability to ground water. It would only affect, not control, because at this point, the dissolution rate of the waste form itself would become the controlling factor. In this example, to get an additional thousand-fold reduction to 10^8 would require 26 half-lives.

The only radionuclides for which radioactive decay offers a potential reduction in risk are the soluble fission products. Their solubility is high enough so that the controlling factor is the dissolution rate of the waste form. For these, decay for 10 half-lives leading to a thousand-fold reduction in inventory could be significant. As an example, Sr-90 and Cs-137 make up 36% of the repository Curie inventory at 10 years, but less than 4% at 300 years. Sr-90 and Cs-137 constitute 59% of the hazard index at 10 years, but have decayed to negligible levels by 1000 years.⁴ On the other hand, Tc-99 (half-life 212,000 years) and I-129 (half-life 1.7×10^7 years) are highly soluble fission products unlikely to be affected by radioactive decay. For these nuclides, their low concentration in the waste is a primary safety factor.

Another way of approaching the justification for a 10,000 year regulatory period is to look at performance assessment results. Many early calculations were run out to 10 million years with a variety of assumptions. They generally showed that doses persisted to well beyond one million years and that the only effective way to reduce the dose was to have a very insoluble waste form — in essence slow enough release to promote dilution.^{11,12,13} Although there is a general tendency for dose levels to decline with time, there is nothing significant at 10,000 years (or at 10^2 , 10^3 , 10^5 , or 10^6 years).

Long regulatory time-frames unique to radioactive waste

Equally or more toxic materials such as heavy metals, which never transform to non-toxic substances by radioactive decay, have no long-term requirements comparable to nuclear waste. A striking example is provided by U-238, which has greater ingestion toxicity as a heavy metal than it does as a radionuclide. Yet it is regulated as a radionuclide, and to much stricter requirements than it would be as a heavy metal.

Organic and inorganic toxic and hazardous wastes may degrade to harmless substances, but little is known about their persistence in the environment. Yet they also generally have no long-term requirements. In the cases where they do, the nature of the requirement and the burden of proof is significantly less than for radioactive material.

Low-level waste, which contains the same radionuclides as high-level waste, is regulated by NRC only to 300, 400, and 500 years, depending on the classification.

Over 10,000 years, natural disasters dwarf repository effects

The underlying basis of the EPA standard for a repository is 1000 health effects in 10,000 years. Ignoring war and pestilence, regularly recurring natural disasters such as earthquakes, seismic sea waves, and explosive volcanic eruptions kill thousands of people per year. Such losses seem to be accepted as a normal and unavoidable part of life. However, over a 10,000 year time-frame, many critical events will happen that threaten local or world-wide civilization far more than these "normal" disasters or the worst imagined consequences of a repository. There is a growing acceptance among geologists that rare, but episodic and rapid, "catastrophic" events may be significant in the geologic record. With return periods of hundreds, thousands, or even hundreds of thousands of years, very large volcanic eruptions, earthquakes, and very large meteors can have catastrophic effects on human life. There is a serious prediction of a meteor that is supposed to destroy up to 95% of life on earth in the year 2116.¹⁴

The above remarks should not be interpreted to mean that what we do at present does not matter. We should do the best job of preserving the environment that is justifiable when all risks and benefits are evaluated. In doing this we should attempt to predict the effects of our actions in the present and the immediate future. However, it is arrogant to claim to exactly forecast conditions and effects in a very distant future.

An alternative approach

If not 10,000 years, then what? The answer is to do an analysis of the present ability of the site and engineered barriers to contain the radionuclides — and make this the focus of regulatory concern. A heuristic analysis of the projected performance of the repository system should be required for as long as doses above a specified limit can be expected. Such an approach to time-limits was adopted by a National Academy panel.¹¹ This heuristic analysis might be for several million years, but would be advisory, not prescriptive.

Concern for what will happen over long-times can be addressed for the next several hundred years by maintaining retrievability. The facility would be designed to be safe if an early default to a closed repository were forced by a societal breakdown. Before emplacing any waste, performance would be analyzed using present conditions. Then the retrievability period would be used to monitor and analyze performance. As a result, there will be a several hundred year data-base to

use in extrapolation when the repository is closed. There likely will be enormous increases in scientific knowledge over the next few hundred years, which can be applied both to better methods of handling the waste and to understanding and mitigating the effects of radioactivity on the human body. Together with the data base from two hundred years of monitoring, this knowledge could be used to decrease uncertainty of future performance. However even then, the effects over very long time-frames should be handled qualitatively — analyses should be done, but not presented as more than general indications.

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