Cambridge University Press
978-1-107-41112-8 - Scientific Basis for Nuclear Waste Management X: Materials Research Society Symposia Proceedings: Volume 84
Editors: John K. Bates and Waldemar B. Seefeldt
Excerpt
More information

PART I

Plenary Session: Long-Term Projection of Materials Interactions

HIGH-LEVEL WASTE PACKAGE LICENSING CONSIDERATIONS FOR EXTRAPOLATING TEST DATA

T.C. JOHNSON, K.C. CHANG, T.L. JUNGLING, L.S. PERSON, C.H. PETERSON, J.C. VOGLEWEDE, AND E.A. WICK
Division of Waste Management, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

ABSTRACT

Programs intended to provide supporting information for the high-level radioactive waste (HLW) repository program must consider the licensing requirements and the technical issues involved with extrapolation of short-term test data to periods of up to 10,000 years. The licensing requirements of the Nuclear Regulatory Commission (NRC), and the issues the NRC staff considers important for the development of predictive methods, are described. Because performance predictions of the geologic repository and particular components of the waste package must largely be based upon inference, a reasonable assurance, on the basis of the record before the Commission, is the general standard that will be required .

LICENSING REQUIREMENTS

The NRC is charged by the Atomic Energy Act of 1954, as amended, the Energy Reorganization Act of 1974 and the Nuclear Waste Policy Act of 1982 (NWPA) to develop regulations and license the operation of high-level radioactive waste repositories. The NWPA also assigns the responsibility for development, construction and operation of the repository to the Department of Energy (DOE). The environmental standards for the disposal of radioactive wastes have been promulgated by the Environmental Protection Agency (EPA), as specified by the NWPA.

In 1983, NRC promulgated technical regulations for high-level waste repositories, 10 CFR Part 60, "Disposal of High-Level Radioactive Wastes in Geologic Repositories."

These regulations are based on a philosophy that a geologic repository controls the rate of radionuclide release to the accessible environment by means of two major subsystems: (1) the geologic setting; and (2) the engineered system. The geologic setting (site) is selected for its geologic, hydrologic, and geochemical attributes such that radionuclide isolation will be maintained for a long period of time. In order to compensate for uncertainties in predicting the behavior of the geologic system, the NWPA relies on the engineered system. One of the functions of this system is to contain the waste for periods sufficient to allow most of the fission products to decay to very low levels. This action protects the waste from groundwater contact until the temperature and radiation levels have decreased to the point where technically supportable predictions of radionuclide release to the geologic system can be made. This simplifies the repository performance analysis and reduces uncertainty in predicting releases to the environment.

The geologic setting and the engineered system differ in both their contributions to isolation and in the degree of confidence that can be placed on predictions of their long-term performance. During the containment period, the geologic system provides a backup to the engineered system to account for those scenarios which may result in loss of containment. Thereafter, the engineered barriers and the site geology will retard the movement of the long-lived radionuclides to the accessible environment.

Mat. Res. Soc. Symp. Proc. Vol. 84. © 1987 Materials Research Society

The NRC regulation (10 CFR Part 60), which includes specific criteria for waste packages and the engineered barrier system, is discussed below.

Post Closure Requirements (10 CFR Section 60.113)

In Section 60.113 of Subpart E, "Technical Criteria," the performance objectives for waste packages and the engineered barrier system are presented. The first of two basic post-closure requirements for the engineered barrier system deals with containment within the waste packages during a time period shortly after repository closure. The second requirement deals with releases following the containment period. Each of these performance objectives is explained below:

The Containment Criterion

10 CFR Section 60.113(a)(1)(ii)(A) states that

> "Containment of HLW within the waste packages will be substantially complete for a period to be determined by the Commission taking into account the factors specified in § 60.113(b) provided that such period shall not be less than 300 years nor more than 1,000 years after permanent closure of the geologic repository."

A critical phrase in the cited paragraph is "substantially complete." The NRC staff is currently in the process of developing a Generic Technical Position (GTP) on substantially complete containment. The technical position will be issued by the Division of Waste Management.

Considerable flexibility is provided in meeting the containment and other criteria of 10 CFR 60.113. Section 60.113(b) provides that

> "On a case-by-case basis, the Commission may approve or specify some other radionuclide release rate [described below], designed containment period or prewaste-emplacement groundwater travel time, provided that the overall system performance objective, as it relates to anticipated processes and events, is satisfied."

Additional flexibility in DOE's design of the waste package is permitted by the technical position on containment being developed by the NRC staff. In order to exercise this flexibility, design objectives may be assigned to individual components at DOE's discretion provided that the overall performance objective of the waste package continues to be met. Consider, for example, groundwater contact with the waste form and the subsequent release and migration of radionuclides through the various components of the waste package. Assuming the availability of adequate supporting data, an appropriate period of delay in the flow of groundwater through the packing, penetration of the container, leaching of the waste form and so on, may be assigned. The 300 to 1000 year containment criterion may thus be satisfied through a series of components in sequence, or through the use of a single component (e.g., the waste container). Reliability analysis may then be used to determine the functional variation in individual components. This will result in a probability distribution for the time of containment and rate of radionuclide release.

The 1000 year time period is intended to serve as an upper limit to the engineered containment design goal. It does not imply that the criterion is violated if containment provided by the waste packages exceeds 1000 years.

The Release Rate Criterion

10 CFR Section 60.113(a)(1)(ii)(B) states that

> "The release rate of any radionuclide from the engineered barrier system following the containment period shall not exceed one part in 100,000 per year of the inventory of that radionuclide calculated to be present at 1,000 years following permanent closure, or such other fraction of the inventory as may be approved or specified by the Commission; provided, that this requirement does not apply to any radionuclide which is released at a rate less than 0.1% of the calculated total release rate limit. The calculated total release rate limit shall be taken to be one part in 100,000 per year of the inventory of radioactive waste, originally emplaced in the underground facility, that remains after 1000 years of radioactive decay."

It should be noted that radionuclides present in very small amounts are exempt from the annual release rate limit. The relationship between the waste package and the engineered barrier system (EBS) used in the above cited criterion is discussed in a draft technical position on the EBS boundary being developed by the staff. This second technical position will also be issued by the Division of Waste Management.

Design Criteria for the Waste Package (10 CFR Section 60.135)

Section 60.135 contains the main body of design criteria for the waste package. The first portions of this section, Paragraphs 60.135(a)(1) and 60.135(a)(2), provide general guidance concerning the need for the waste package to have chemical, physical and nuclear properties that do not compromise the function of the waste package. A list of required design considerations is provided and includes the following: solubility, oxidation/reduction reactions, corrosion, hydriding, gas generation, thermal effects, mechanical strength, mechanical stress, radiolysis, radiation damage, radionuclide retardation, leaching, fire and explosion hazards, thermal loads and synergistic interactions.

Section (b) of Part 60.135 contains the specific criteria for HLW package design. There are four basic areas of consideration: (1) explosive, pyrophoric, and chemically reactive materials; (2) free liquids; (3) handling, and (4) unique identification. The specified criteria are based upon engineering considerations that contribute toward meeting the performance objectives for containment and controlled release.

Section (c) of Part 60.135 deals with waste form criteria. There are three considerations:

(1) Solidification: "All such radioactive wastes [emplaced in the underground facility] shall be in solid form and placed in sealed containers."

(2) Consolidation: "Particulate waste shall be consolidated (for example, by incorporation into an encapsulated matrix) to limit the availability and generation of particulates."

(3) Combustibles: "All combustible radioactive wastes shall be reduced to a noncombustible form..."

As in the case for the waste package criteria, the design criteria for the waste form are intended to contribute toward meeting the performance objectives for the waste package and the EBS.

Monitoring and Testing Waste Packages (10 CFR Section 60.143)

Subpart F, the Performance Confirmation Program, addresses both geotechnical and waste package performance confirmation requirements. In the case of the waste package it is intended that the monitoring program will continue up to the time of permanent closure of the repository. The waste package monitoring program is also intended to include laboratory experiments that focus on the internal condition of the package. The laboratory experiments must, to the extent practical, duplicate the environmental conditions experienced by the waste packages in the underground facility.

Environmental Protection Agency Regulations (40 CFR Part 191)

The EPA environmental standard for the management and disposal of spent nuclear fuel and high-level and transuranic wastes sets radiation exposure and release limits for a repository. Performance assessments used to show compliance with these requirements may result in more limiting waste package design requirements than the performance objectives in 10 CFR 60.113. That is, the containment and release rate criteria of 10 CFR 60.113 do not guarantee compliance with the exposure and release limits of 40 CFR 191. Depending upon ground water classification and other site-specific conditions, more stringent requirements may be placed on the design of the engineered system than those contained in 10 CFR 60.113. Testing programs, therefore, will need to consider the data needs that also demonstrate compliance with EPA environmental standards as incorporated in 10 CFR 60.112.

REASONABLE ASSURANCE

The regulatory basis for data used to support the repository license application is found in 10 CFR Section 60.21(c)(1)(ii)(F):

> "[The license application must contain] an explanation of measures used to support the models used to perform the assessments required in paragraphs (A) through (D) [of 10 CFR 60.21(c)(1)(ii)]. Analysis and models that will be used to predict future conditions and changes in the geologic setting shall be supported by using an appropriate combination of such methods as field tests, in situ tests, laboratory tests which are representative of field conditions, monitoring data, and natural analog studies."

Although supporting data are required, it is recognized that uncertainties in the data and the difficulties inherent in the predictive process will necessarily prevent complete assurance in the conclusions drawn. In this regard, Subpart E, Technical Criteria (10 CFR 60.101(a)(2)), states that:

> "While these performance objectives and criteria are generally stated in unqualified terms, it is not expected that complete assurance that they will be met can be presented. A reasonable assurance, on the basis of the record before the Commission, that the objectives and criteria will be met is the general standard that is required. For § 60.112, and other portions of this subpart that impose objectives and criteria for repository performance over long times into the future, there will inevitably be greater uncertainties. Proof of the future performance of engineered barrier systems and the geologic setting over time periods of many hundreds or many thousands of years is not to be had in the ordinary sense of the word. For such long-term objectives and criteria, what is required is reasonable assurance, making allowance for the time period, hazards, and uncertainties allowed, that the outcome will be in conformance with those objectives and criteria.

Demonstration of compliance with such objectives and criteria will involve the use of data from accelerated tests and predictive models that are supported by such measures as field and laboratory tests, monitoring data and natural analog studies."

The concept of "reasonable assurance" is further described in the staff response to public comments on the rule [1]:

"Expressing a requisite level of confidence in quantitative terms is far more problematical [than a standard of performance]. To be sure, measurement uncertainties are amenable to statistical analyses. Even though there may be practical limitations on the accuracy and precision of measurements of relevant properties, it is possible to make some quantitative statement as to how well these values are known. The licensing decisions which the Commission will be called upon to make involve additional uncertainties - those pertaining to the correctness of the models being used to describe the physical systems - which are not quantifiable by statistical methods. Conclusions as to the performance of the geologic repository and particular barriers over long periods of time must largely be based upon inference; there will be no opportunity to carry out test programs that simulate the full range of relevant conditions over the periods for which waste isolation must be maintained.

The validity of the necessary inferences cannot be reduced, by statistical methods, to quantitative expressions of the level of confidence in predictions of long-term repository performance. Similarly, the Commission will not be able to rigorously determine the probability of occurrence of an outcome that fails to satisfy the performance standards. It must use some other language, such as "reasonable assurance," to characterize the required confidence that the performance objectives are met. In practice, this means that modeling uncertainties will be reduced by projecting behavior from well understood but simpler systems which conservatively approximate the systems in question. Available data must be evaluated in the light of acceptable physical principles; but, having done so, the Commission must make a judgement whether it has reasonable assurance that the actual performance will conform to the standards the Commission has specified in this rule. "

On the basis of this discussion it may be seen that, of all those uncertainties that affect confidence in geologic disposal of HLW, the most easily accounted for is measurement uncertainty in a laboratory experiments. The level of uncertainty in a laboratory measurement may be statistically determined. However, the level of uncertainty associated with an in situ measurement, where the measurement itself may disturb the environment, is difficult to determine. It is even more difficult to quantify the level of uncertainty in predictions of the site environment at some future time. The potential difficulties in achieving reasonable assurance in the predictive process through the application of statistical methods alone (i.e., without consideration of the mechanisms of the degradation process or the scientific principles upon which they are based) are discussed by Thomas [2].

It is recognized that the geologic sciences are far from being precisely predictive and, as a result, the models and most of the geological data upon which they rely are subject to sizeable uncertainties. These uncertainties could make repository licensing difficult.

The staff has, in the case of waste form leaching, suggested [1] how a degree of reasonable assurance may be achieved, that is, under what conditions a leach resistant waste form is shown (with reasonable assurance) to serve as a major barrier to waste release:

"1) The influence of significant parameters (e.g., temperature, groundwater chemistry) must be thoroughly investigated. An understanding of the influence of these parameters may require that the waste form be contained to prevent the initiation of leaching until temperature and radiation levels are low enough that a greater degree of confidence can be placed on the long term behavior.

2) Predictions of the repository environment far into the future must be bounded, including changes in the environment between closure and resaturation of the underground facility. Such predictions need not be precise, but the bounds must lie within the range of conditions for which the waste form has been experimentally tested.

3) Manufacturing quality control must be adequate to assure that the properties of 'production line' waste forms do not deviate significantly from the properties of the waste forms evaluated in the laboratory."

If these conditions are met, leach rates may be extrapolated with less uncertainty. Furthermore, the staff noted that long-term leach rates can probably be predicted with more confidence than can near-term leach rates because of the reduction in the elevated temperature conditions present shortly after waste emplacement.

As a second example, one may consider the problem of uniform corrosion of the waste package container. It may be difficult to ascertain the actual corrosion rate under repository conditions. However, the rate at which material is lost from a clean, freshly prepared metal surface can be determined in a laboratory under conditions representing the repository environment. Initially, there is no buildup of corrosion products on the surface of the sample or in the solution. Therefore, the resulting rate at which material is lost will, in general, represent the bounding rate of material loss due to uniform corrosion under the test conditions. If the uniform corrosion rate under repository conditions cannot be reliably determined, the bounding value may be used. If the actual corrosion rate can be reliably determined, less conservative analyses may be applied.

It should be noted that the use of bounding analysis is not a requirement for the assessment of repository performance. It is, however, a useful tool in the absence of information that would permit a more precise determination of the predictive uncertainties involved.

EXTRAPOLATION OF SHORT-TERM TEST DATA

Based on these examples, it is possible to identify some of the conditions under which short-term test data can be extrapolated with reasonable assurance. Primarily, extrapolations should be supported by:

1. Short-term testing under experimental conditions that not only reflect the best-estimate of the repository environment, but also consider how those environmental conditions vary in time and space.

2. A fundamental understanding of the physical and chemical process involved.

3. Knowledge of the significant parameters affecting the process and (in the case of accelerated testing) the relationship of those parameters to process rates.

Cambridge University Press
978-1-107-41112-8 - Scientific Basis for Nuclear Waste Management X: Materials Research Society Symposia Proceedings: Volume 84
Editors: John K. Bates and Waldemar B. Seefeldt
Excerpt
More information

4. Bounding predictions of the process based on conservative application of physical models.

5. Manufacturing, testing, and analytical quality control to assure that the short-term experimental conditions do not deviate significantly from those present under repository conditions.

6. Plans for appropriate performance confirmation testing at the repository during the time of repository operation until the time of permanent closure.

7. Validation of models using natural analogs or historical artifacts.

8. Independent peer review of programs, models and methods. Although peer review cannot be used to validate models and methods, it can be used to point out data that can be used for this purpose.

The short-term testing program should use conservative test methods to obtain quantitative data on waste package degradation and waste form leach rates. It is expected that these tests will be performed under conservative test conditions that bound the anticipated repository environment (e.g., temperature, Eh, pH, radiation, chemistry). The program should include tests of several years duration and would yield data necessary for long-term extrapolation of waste package degradation and degradation rates.

The short-term testing must be supported by a fundamental understanding of the potential degradation modes as they relate to the repository environment. As an example, Figure 1 shows hypothetical waste package degradation as a function of time in a high-level waste repository. Laboratory data, taken under representative conditions, suggest that uniform corrosion of the waste package container may be the dominant degradation mechanism. However, development of localized corrosion (e.g., pitting) and

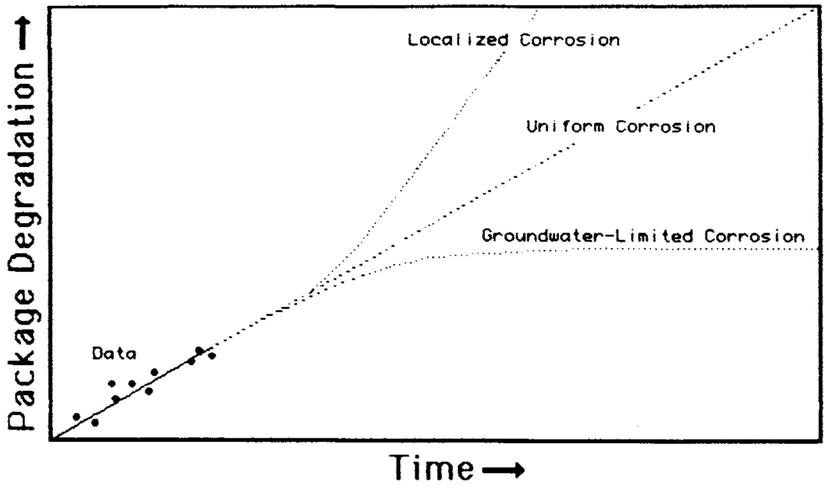

Fig. 1 Hypothetical Waste Package Degradation as a Function of Time in a High-Level Waste Repository.

groundwater-limited corrosion (i.e., all available groundwater is consumed by the corrosion process and no further degradation occurs), are both hypothesized to exist on the basis of non-prototypic tests or corrosion theory. Due to the delayed nature of the alternative degradation mechanisms, it is not possible to establish (based on the data shown) which process is effective after waste emplacement. A determination that localized corrosion has a negligible impact on waste package performance must include data showing that the fundamental mechanisms for this corrosion process do not, and will not, exist under the bounding environmental conditions assumed. If localized corrosion cannot be dismissed, it must be accounted for in the analysis as shown in Figure 2. To some extent, all three of these degradation mechanisms have been considered in the DOE's Final Environmental Assessment Report [3].

Knowledge of the process involved must include a basic understanding of how variations in assumed repository conditions will affect the waste package degradation, waste form leaching, and radionuclide transport. The understanding should include the relationship between process parameters and process rates to confirm the applicability of accelerated tests.

Bounding predictions of the process and process rates should be based on conservative application of physically based models. Because there will be no opportunity to observe actual repository performance prior to licensing, the staff also recognizes that physically based models must figure prominently into the predictive process. However, modeling studies are not, in themselves, sufficient to provide accurate predictions. The reliability of the predictions of these models is limited by the reliability of the input data to the models and by the reliability of the models themselves. It is clearly possible to model without insight into the physical processes involved (curve fitting or empirical modeling). In general, such models cannot be relied on outside of the range of variables upon which they are based. On the other hand, it is possible to assume a fundamental understanding that is not supported by data (conjecture). Like curve fitting models, conjecture is also an unreliable predictive tool.

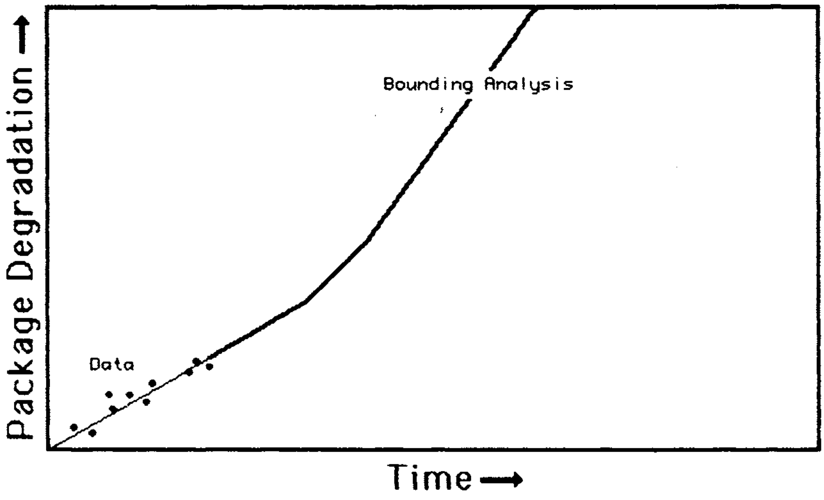

Fig. 2 Bounding Analysis of Hypothetical Waste Package Degradation as a Function of Time in a High-Level Waste Repository.