89001458

DAVID BAKER

OCT 0 1 1991

Mr. David P. Baker
65 Colbath St.
Las Vegas, NV. 89110

Dear Mr. Baker:

This is in response to your letter requesting information on the Yucca Mountain Project. Enclosed is a copy of the latest "Generic Technical Position on Waste Package Reliability Analysis" (December 23, 1985) and the "Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes (December 1977)."

The other information you requested is being developed by the U.S. Department of Energy. A request for that information can be addressed to:

Ms. Linda Desell
Chief, Regulatory Integration Branch
Office of Systems and Compliance
Office of Civilian Radioactive
Waste Management - RW-331
Department of Energy
1000 Independence Ave., S.W.
Washington, D. C. 20585

In addition to asking for information, your letter raised a concern about the response from Mr. Paul T. Prestholt to your original request. Based on my review of his response, I believe that Mr. Prestholt's willingness to meet with you and discuss your concerns was an appropriate level of response. I would encourage you to schedule a meeting with Mr. Prestholt so that he can discuss that office's function and better identify ways they are able to assist the public.

Sincerely,
(Original Signed by
for John J. Linehan, Acting Director
Repository Licensing and
Quality Assurance Project Directorate
Division of High-Level Waste Management
Office of Nuclear Material Safety
and Safeguards

Enclosure:
As stated

cc: PTPrestholt

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

DEC 2 3 1985

TO: ALL INTERESTED PARTIES

The following document is being distributed for your information:

Generic Technical Position on Waste Package Reliability Analysis

If you have any questions, please contact Hubert J. Miller, Chief, Repository Projects Branch, Division of Waste Management, U. S. Nuclear Regulatory Commission, Mail Stop 623-SS, Washington, DC 20555.

Sincerely,

Hubert J. Miller, Chief
Repository Projects Branch
Division of Waste Management
Office of Nuclear Material Safety
and Safeguards

8604230011 1p.

U. S. NUCLEAR REGULATORY COMMISSION
GENERIC TECHNICAL POSITION

WASTE PACKAGE RELIABILITY ANALYSIS FOR HIGH-LEVEL NUCLEAR WASTE REPOSITORIES

ENGINEERING BRANCH
DIVISION OF WASTE MANAGEMENT

DECEMBER 1985

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1.0 BACKGROUND

10 CFR Part 60, the Nuclear Regulatory Commission's (NRC's) regulations governing the geologic disposal of high-level radioactive waste (HLW) establishes objectives for the performance of the repository after permanent closure. Section 60.113 establishes specific performance objectives for particular barriers of the repository including the engineered barrier system, and Section 60.112 establishes the overall system performance objective for the geologic repository.

The engineered barrier system is defined as the waste packages and the underground facility (60.2). The waste package consists of the waste form and any containers, shielding, packing and other absorbent materials immediately surrounding an individual waste container. Specific design criteria for the waste package are set forth in 10 CFR 60.135. DOE will be required to demonstrate that containment of the waste within the waste package must be substantially complete for a period of 300 to 1000 years.

The purpose of this technical position is to provide guidance for an acceptable method of analysis for demonstrating reasonable assurance that the waste package designs proposed by DOE will meet the performance objectives of Section 60.113 and design criteria of 10 CFR Part 60.135.

One method that is acceptable to the staff is to use the reliability assessment techniques described herein supported by appropriate data from experimental tests. Such an approach is consistent with the steps that will be necessary to show compliance with the overall system performance objective of Section 60.112.

2.0 REGULATORY FRAMEWORK

Appendix A contains definitions and the relevant sections of 10 CFR 60 which specify performance objectives and design criteria for HLW packages; other definitions are contained in footnotes.

Section 60.113(a)(1)(ii) requires that the engineered barrier system be designed assuming anticipated processes and events so that:

(a) Containment of HLW within the waste package 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 be no less than 300 years nor more than 1,000 years after permanent closure of the geologic repository, and

(b) 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 1,000 years of radioactive decay.

In determining the period of time for which containment will be substantially complete under A, above, the commission will take into account the factors specified in Section 60.113(b). In addition, under Section 60.113(b), containment and/or release criteria may be modified by the Commission provided that the overall system performance objective, as it relates to anticipated processes and events, is satisfied.

However, as stated in Section 60.101, "[w]hile 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 ... that the [performance] objectives and criteria will be met is the general standard that is required. For paragraph 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 involved, that the outcome will be in conformance with those objectives and criteria. Demonstration of compliance ... 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."

3.0 REGULATORY POSITION

The staff position on waste package reliability analysis is summarized in this section. Subsections 3.1 and 3.2 expand upon paragraph (5) below.

(1) 10 CFR 60.101(a)(2) does not specify a quantitative level of confidence to support a finding that the standard of performance has been met. Reasonable assurance is the standard. However, in the information to be considered in a licensing proceeding, DOE should include probability distribution functions for the consequences of anticipated processes and events and unanticipated processes and events which may affect the ability of the repository to meet the performance objectives. (Supplementary Information for 10 CFR 60, 48 Federal Register 28204, June 21, 1983).

(2) DOE should gather the data to address uncertainties in the data and models during the site characterization program. Consideration of these uncertainties is a major concern that will need to be addressed in the license application. Testing and data collection must consider in a systematic way all important interactions of the system that affect waste package performance.

(3) To demonstrate reasonable assurance that the waste package designs proposed by DOE will meet the performance objectives of 10 CFR 60, DOE must assess the performance of the waste package system as well as other components in the engineered barrier system in the repository environment over the period from permanent closure to 10,000 years after permanent closure.

(4) An assessment of the performance of the waste package must be submitted at the time DOE applies for a license for the high-level waste repository and must address the following:

(a) identification and screening of failure modes,*

(b) determination of the consequences of failure in containment,

(c) demonstration that for anticipated processes and events, containment of the waste within the waste package for a period of 300 to 1000 years after permanent closure will be substantially complete. If the period of containment to be demonstrated is less than 1,000 years, the analysis should justify the shorter period.

(d) potential sources of uncertainty and their impact on containment and on release of radionuclides from the waste package. Examples include the environmental and geochemical conditions listed in Subsection 3.2.2.

(5) One method of assessing the performance of the waste package that is acceptable to the staff is to use the reliability assessment techniques described herein. Other approaches may also be found acceptable if, after staff review, it is determined that they fully address points a. through d. above. The approach to an acceptable reliability analysis is described in Subsection 3.1 and the recommended content of a reliability analysis is described in Subsection 3.2.

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*In general, failure implies the inability of a system to perform its intended function and degradation implies a lessening in ability of a system to perform its intended function. The waste package is considered to have failed when a measurable quantity of radionuclides appears or may be calculated to appear outside the outermost boundary of the waste package. Similarly, canister containment is considered to have failed when the canister cannot contain gaseous radionuclides or prevent water and water vapor from contacting the waste form. It should be noted that canister failure can be viewed as a degradation process of the waste package system. Failure modes, as used herein, refer to failure of the waste package. These failure modes are considered to consist of a series of barrier degradation modes which will lead to failure of the individual components of the waste package. The relevant parameters of a failure mode, therefore, are the parameters that influence the degradation of the barriers in the waste package.

(6) The applicant is required under 10 CFR 60.151 and 60.152 to establish a quality assurance (QA) program for the design, construction and operation of the repository. This QA program* should be applied in the development of the reliability analysis described in this generic technical position, or to any other methodology for waste package assessment submitted, as well as to the experimental test programs and field tests to obtain necessary data.

To reach licensing findings, the following will be used: the quantitative estimates of uncertainties in performance and confidence levels in the analysis of reliability of the waste package, developed in a program consistent with that described in this technical position; evaluations of laboratory and field data; qualitative assessments of system performance; and expert judgement. Dealing fully and explicitly with uncertainties is essential to being able to make licensing findings. The staff considers that a quantitative approach, such as described in this technical position, is an acceptable way to assure that uncertainties are treated appropriately.

3.1 Approach

3.1.1 The application for a license should identify the types of potential failure modes for the proposed waste package for the given repository system. These failure modes should be determined based on a comprehensive review of the relevant literature and of an adequate body of experimental results including site-specific tests performed by DOE. Comparisons should be performed between the proposed system and other systems having similar failure modes. The identification process should continue until all pertinent failure modes have been identified. The identification process must be documented and the issue of completeness of the failure mode list must be addressed.

3.1.2 The applicant should conduct a screening evaluation of each potential failure mode to determine whether it is a possible cause of failure in the proposed repository environment. The applicant may dismiss specific failure modes if they are physically implausible under the proposed repository conditions. The reason for the dismissal of failure modes should be documented in sufficient detail to provide technically defensible positions.

3.1.3 The applicant should develop a model for each of the retained failure modes. These models should describe the conditions which could lead to failure, predict when the failures could occur and estimate the impacts of the failure. There may be instances in which the physical understanding of the operative processes is

*This QA program is explained in further detail in Appendix B of 10 CFR Part 50 and in the "NRC Review Plan: Quality Assurance Programs for Site Characterization of High-Level Nuclear Waste Repositories," dated June 1984.

insufficient to develop a quantitative model for a process. In such instances the applicant should develop an acceptable model for predicting or at least bounding the rate of progression of various processes which could lead to containment failure and the level of uncertainty which would be tolerable. The development of models should continue until each of the pertinent failure modes has been evaluated and documented. A discussion of model uncertainties and assumptions should be included. Computer programs based on the models should be used to estimate mean values and distributions of variables, important to waste package failure analysis.

3.1.4 The applicant should determine from experimental testing and analysis of results the ranges of parameters of the proposed repository environment and the other parameters which are relevant to the failure modes. This process should continue until the relevant waste package material properties and environmental parameters for the repository system have been determined and their uncertainties and probability distributions ascertained and documented.*

3.1.5 The applicant should combine the set of waste package materials properties, environmental parameters and models in a scheme that serves to explore all interactions modeled and predict failure probabilities. The computer programs based on this scheme should be validated against an adequate base of test data. Because failures may occur due to a combination of unlikely conditions, a probabilistic simulation should be considered for this evaluation scheme.

3.1.6 The applicant should identify the most important degradation processes and parameters, for example by sensitivity studies using codes based on the best available models and data. Such sensitivity studies must be confirmed by reference to experimental data.

3.2 Content of the Reliability Analysis

The DOE is required to submit a Safety Analysis Report (SAR) as part of the license application for the high-level waste repository. The SAR must contain a performance assessment of the waste package. Section 60.21(c)(1)(ii)(D) requires that the assessment shall include the effectiveness of engineered and natural barriers, including barriers that may be themselves a part of the geologic repository operations area,

* A rigorous statistical distribution may not be necessary for some input data if the results are insensitive to the data. In such cases, a point value or bounding distribution may suffice. For data that are crucial to results, however, a distribution that is at least bounding is necessary. Another approach would be to take a conservative point value such that the probability of exceeding or not exceeding (as the case may be) the point value is negligible. This approach, however, is equivalent to assigning to the value a conservative distribution, in the form of a unit step function.

against the release of radioactive material to the environment. The analysis shall also include a comparative evaluation of alternatives to the major design features that are important to waste isolation, with particular attention to the alternatives that would provide longer radionuclide containment and isolation. If a reliability analysis is used to assess performance of the waste package, the recommended content of the reliability analysis is described below.

3.2.1 Waste Package Design and Materials Specification

The applicant should describe in detail the proposed design and materials specifications for:

a. The waste form including the radioactive waste and any associated encapsulation or stabilization media.

b. The canister including the major sealing enclosure system for the waste form.

c. The overpacks, which consist of any additional vessel receptacle, structure, or shielding which are both within and an integral part of the proposed waste package and which provide additional containment of the waste.

d. The packing material which may control the flow of groundwater, modify the groundwater chemistry, or retard the transport of radionuclides from the waste form following breach of the container.

The proposed waste package description should include drawings and schematics which clearly identify the components and materials to be used.

3.2.2 Environmental Conditions

The applicant should identify the range of environmental and geochemical conditions to which the waste package may be subjected. These conditions should address all anticipated conditions and events. Environmental and geochemical conditions should include:

a. The temperature field;
b. The groundwater chemistry (e.g., pH, oxygen and hydrogen fugacities and water composition)
c. The groundwater flow rates;
d. The radiation field;
e. The pressure and stress fields;
f. Groundwater flux and flow mechanisms; and
g. Air composition and flow rate;*

*Since part of any repository will be in the unsaturated condition at closure, the analyses must address, at least by bounding, all performance during which the waste package is under unsaturated conditions.

3.2.3 Material Properties

The applicant should identify for each waste package component the material properties which are relevant to the reliability analysis. These material properties may include the original component composition and the mechanical, chemical and thermal properties and their expected dependence on the repository environmental parameters as the values of those parameters change with time. The applicant should describe how these material properties influenced the waste package design. The applicant should also describe the quality of the materials property data required for model calculations. Table 1 provides an example list of material properties for a generic packing material and the design parameters they affect.

3.2.4 Failure Mode Analysis*

The applicant should list in the SAR all identified potential reasonable failure modes for each waste package component, including common-cause and other non-independent failures, and justify their retention or dismissal for further analysis. The documentation justifying the dismissal of implausible failure modes, i.e., the failure mode analysis, should be included in the SAR. The applicant should consider the natural variability of the repository environment in the dismissal of potential failure modes. The failure modes retained for further analysis become the repository design failure modes.

Table 2 shows an example listing of potential and design failure modes for a waste form canister. The interrelations between design failure modes may also be summarized by event trees and/or fault trees. These trees can be useful qualitatively in promoting a systemic approach to failure analysis. An example of a fault tree is shown in Figure 1.

3.2.5 Assessment

As stated in 10 CFR 60.113, DOE should demonstrate that, taking into account the factors specified in 60.113(b) (See page A-9), for anticipated processes and events containment of the waste within the waste package will be substantially compete for a period of 300 to 1000 years and the annual rate of release of radionuclides from the engineered barrier system thereafter will not exceed the release rate limit in 10 CFR 60.113. One part of the demonstration should address the impact of all significant sources of uncertainty in estimates of waste package performance. The staff considers a quantitative reliability analysis based on an adequate test program to be an acceptable approach in making this demonstration. Basic elements of a rigorous reliability analysis are presented below. More detail is provided in Section 4.

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*Alternatives to a failure mode analysis may be used if the alternatives adequately identify failure mechanisms and adequately describe the failures.

Table 1.
Example List of Generic Packing Materials Properties
Required for Reliability Analysis

Function	Properties
Groundwater Exclusion	Effective Porosity Permeability Hydraulic Conductivity Swelling pressure ≠
Radionuclide Retention or Retardation	Dispersivity Diffusivity Tortuosity Distribution Coefficients Effective Porosity Density of Solids Radionuclide Loading Capacity
Mechanical Stability	Elasticity Moduli Modulus of Resilience Rupture Moduli Atterberg Limits Activity
Heat Transfer	Thermal Conductivity Thermal Diffusivity Emissivity
	Thermal Expansion Coefficient
Resistance to Hydrothermal Alteration	T-V-P Points for Change of Phase Change in Composition with Changing Physical Conditions
Groundwater Conditioning	Redox Conditions Solubility Limits Sorption with Respect to O_2

Table 2

Example Documentation for Failure Modes / of a Waste Package Component

Waste Package Component	General Failure Mode	Identified Failure Modes*	Design Failure Modes**
Waste form container (low carbon steel)	Chemical	Uniform corrosion Pitting " Galvanic " Crevice " Intergranular " Bacterial " Erosion " Stress corrosion cracking Hydrogen damage Selective leaching ***	Uniform corrosion Pitting " Stress corrosion cracking Hydrogen embrittlement
	Mechanical	— — — —	— — —
	etc.		

/List of failure modes not intended to be complete.

* Identified failure modes are all modes identified that could lead to failure.

** Design failure modes are the modes considered likely to lead to failure under repository conditions.

*** Leaching here is used in the broad sense of chemical attack leading to dissolution.

Example Fault Tree

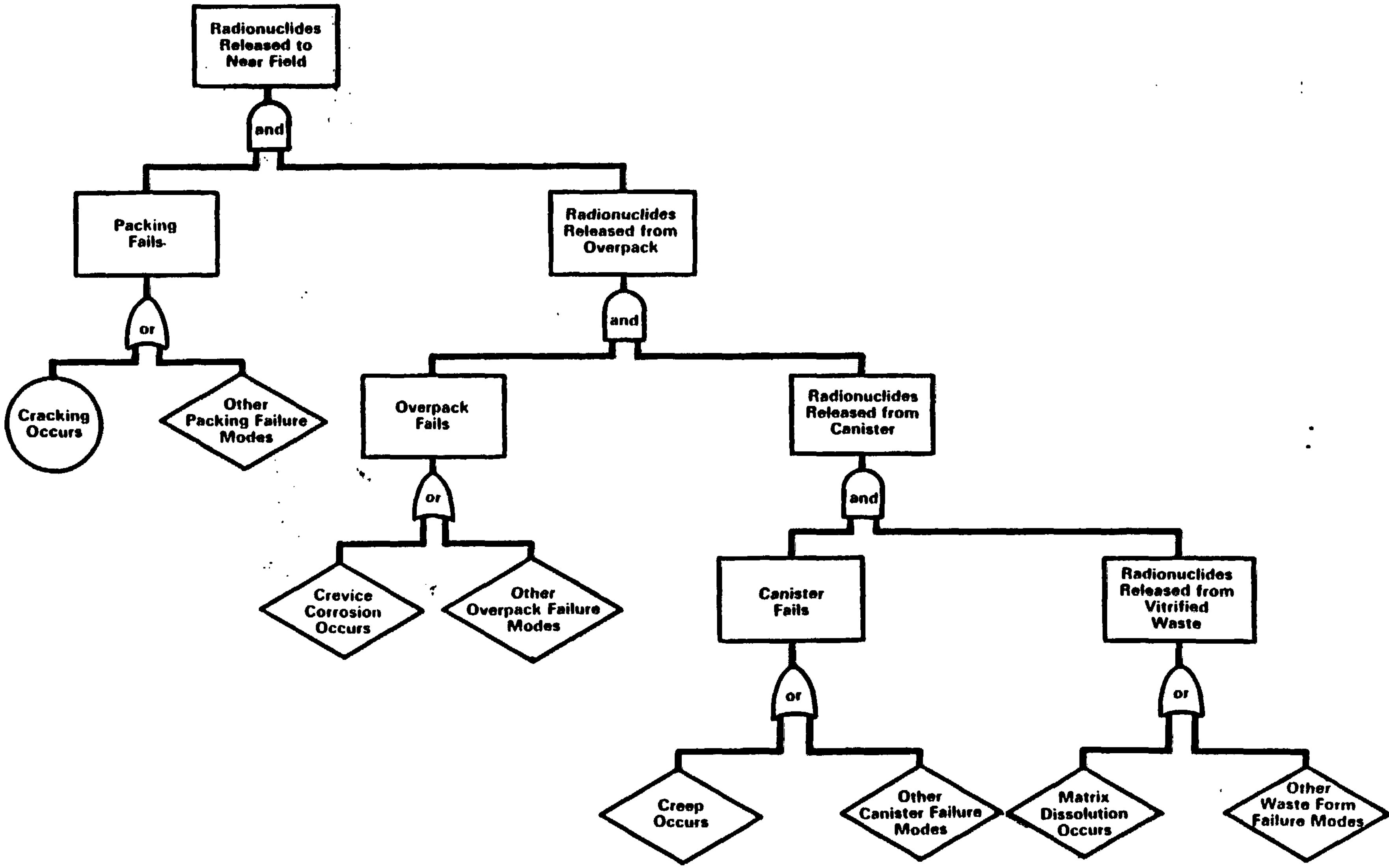

Figure 1

The staff recognizes the limitations inherent in attempting to apply a traditional reliability analysis to assessment of the performance of the waste package. These limitations result from the uncertainties inherent in the components of a reliability analysis (items a. through d. in Section 3.2.6 below). These uncertainties are expected to be higher in this analysis than in a traditional analysis. The reason for the higher uncertainty is that the type of data base used for a traditional reliability analysis (i.e., results of testing many components over their full design lifetime under well-characterized environmental conditions) is not available for the waste package. Nevertheless, the staff considers that even with these uncertainties a reliability analysis supported by appropriate testing is a rigorous assessment of waste package performance and, therefore, is an acceptable approach.

In assessing the consequences of significant failure modes, the applicant should provide predictive or bounding equations for failure rates by each of those modes and for the physical processes affecting the repository environmental conditions and material properties. For each of the predictive equations, the applicant should provide the theoretical basis, the experimental or other verification, and an analysis of the uncertainties associated with each equation. To the extent practicable, the uncertainty in numerical results obtained from an equation because of scatter in quantities entering it should be established through a statistical evaluation of the scatter of the reference data. Also, wherever practical, the applicant should provide statistical distributions for all the data used to support the predictive equations. In cases for which this is not practical, a conservative point value or bounding statistical distribution may be used (see footnote for Section 3.1.4). Based on these data, the applicant should perform a quantitative reliability analysis of the proposed waste package design. The quantitative reliability analysis would combine the various models for the design failure modes, the material property changes and changes in the repository environmental conditions into a composite or performance model validated by appropriate tests. By use of the performance model and the statistical data sampled from distributions derived from adequate tests, the analysis would produce the statistical distribution for the times of containment and the rate of release of radionuclides thereafter. Monte Carlo sampling techniques applied to these calculations may be used as an approach for the derivation of failure probabilities. An outline of this approach is contained in Reference 1. Other probabilistic approaches may also be used.*

*It is not NRC's intent to claim that only one methodology is suitable for calculating probabilities of failure of the waste package to meet the performance objectives. The intent here is to point out that at least one method exists. Alternative methods that account for uncertainties in the basic data about the processes involved in the identified failure modes and that also account for uncertainties in the models used for prediction may be used. DOE must demonstrate rigorously that all assumptions associated with any alternative method are met or that the results of the analysis are not sensitive to the assumptions.

3.2.6 Validity of the Reliability Analysis

The SAR should discuss the validity of the reliability analysis that is conducted. Expert opinion surveys that are completely documented may be used to support the validity of the analysis. The discussion of validity should demonstrate that the estimates of the containment period and the rate of release of radionuclides from the the waste package thereafter have addressed the following potential sources of uncertainty:

(a) uncertainty in understanding of relevant physical and chemical processes.

This refers to uncertainties in the following:

- Initiating events: Is the list of initiating events complete and exhaustive?
- System failure: Are all of the significant contributors to system failure properly identified?
- System interactions: Are all dependent failures and system interactions properly accounted for?
- Human errors: Are human actions properly accounted for in the models?

(b) uncertainty in constitutive relationships that approximate the relevant phenomena and processes

This refers to uncertainties in the ability of the constitutive relationships to describe accurately the system over the range of environmental parameters.

(c) uncertainty in the mathematical models that are used to describe constitutive relationships and conceptual models, and

Uncertainity in the mathematical models refers to uncertainties associated with translating a and b into a mathematical framework for predicting repository behavior. These uncertainties also include errors in solution of the mathematical codes, for example, numerical errors.

(d) uncertainty in the data used to characterize the parameters and variables in the mathematical models.

4.0 DISCUSSION

4.1 Failure Mode Analysis

The failure mode analysis consists of a description of the mechanisms and processes that are likely to lead to a failure of the system to perform its intended function under the anticipated repository conditions. It contains in narrative form the modes of failure considered in the analyses and the ones selected as design failure modes. The interrelations between component failures may be summarized by means of fault trees.

The acceptability of the failure mode analysis depends on the completeness of the consideration of phenomena that need to be accounted for in its formulation. There are no practical methods to prove such completeness other than a documented record of search and analysis of alternative failure modes such that repeated detailed review by competent technical personnel fails to produce new credible failure modes. Such review should be conducted at a pace that will allow the reviewers to explore alternatives suggested by the review, and should result in documentation of the alternatives considered and dismissed.

4.2 Quantitative Reliability Analysis

In order to calculate the reliability of a waste package design in a geologic repository, a Monte Carlo* method of sensitivity and uncertainty analysis can be useful and is considered acceptable by the staff.

In this method one views the parameters of the waste package performance model as random variables with given distribution functions taken from appropriate tests, samples among the parameters with an appropriate random selection technique and determines performance. Features of a waste package Monte Carlo reliability calculation are presented in Figure 2.

Acceptability of a reliability calculation depends on the proper selection of a performance model, data from tests and associated statistical distribution functions, random sampling technique, and algorithms and computer programs.** It is essential that the physical model considered be realistic; thus careful use must be made of available experimental data.

There are basic uncertainties as to how well models are able to represent the actual conditions associated with the design and degradation of the waste package. There are limitations in the ability to represent faithfully the real world by mathematical models. Model uncertainties,

* The term 'Monte Carlo' here refers not only to traditional Monte Carlo schemes but also to related techniques such as Latin Hypercube which permits one to deal with variables which are not truly independent.

**Because not all Monte Carlo schemes converge, some attention must be devoted to methods of ensuring that the Monte Carlo scheme employed provides useful information.

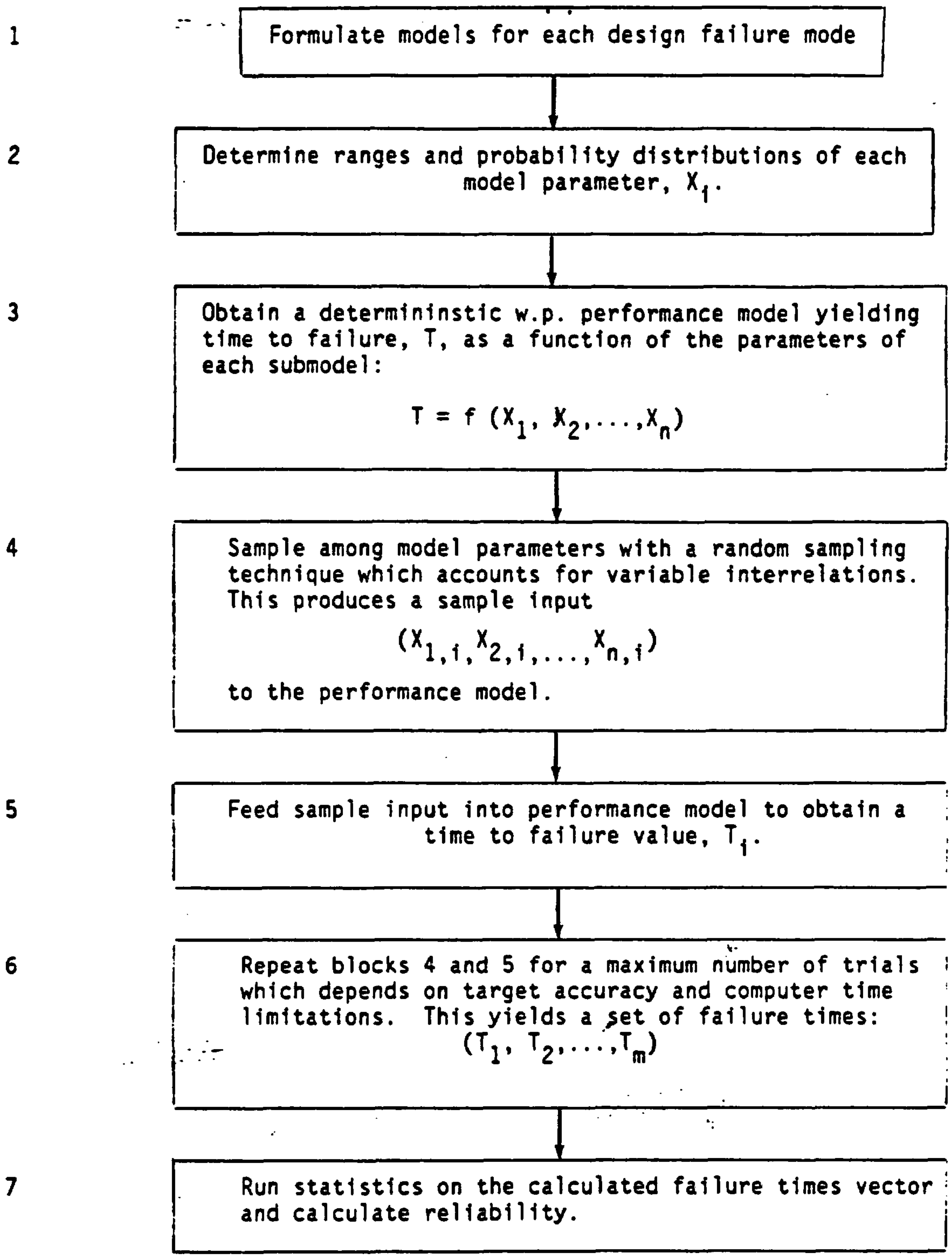

Figure 2. Monte Carlo simulation principles for waste package reliability analysis.

therefore, should be acknowledged and addressed by efforts to make models as realistic as possible with compensating assumptions and modeling constraints. These uncertainties must be minimized by model validation whenever possible. To address uncertainties that still remain in the models (e.g., whether all significant contributors to system failure have been properly identified and modeled), a multiplicative modeling uncertainty factor could be applied during the reliability analysis. This model uncertainty factor is thus a "safety factor" on model applicability because the model may be based on a theory whose applicability or comprehensiveness may be uncertain or because the model is extrapolated from data of uncertain applicability. This uncertainty factor could be based on an expert opinion method, i.e, polling professionals who have extensive experience in the area where the model should be applied. This process of determining model uncertainty is not rigorous and it is not clear whether model uncertainty should be expressed as a point value or as a random variable with its own statistical distribution. The recognition of the uncertainty factor, however, would add credence in the applicability of the model to the situation at hand by addressing a basic problem in model uncertainty.*

4.2.1 Performance Model

A waste package performance model will be composed of component models addressing basic functions or processes within the waste package system. The validity of the performance model depends on the completeness with which the individual component models describe all phenomena of importance, and, in final analysis, on their success in predicting experimental results.

In order to ensure completeness of the review, the derivation of predictive equations should be described in sufficient detail to allow independent verification and reconstruction of the predictive equation by qualified experts. For widely used predictive equations in the public domain, e.g., conventional heat transfer correlations, identification of sources and reference to publications is sufficient. For predictive equations developed specifically for evaluation of waste package performance and used in the reliability assessment, the logic and any supporting data bases used for the derivation of the equation should be provided in tabular form either originally or by reference to published reports. Any analysis of the data should include an analysis of correlations between the independent variables, measures of goodness of fit of the regression in the form of significance levels of the estimate of the regression coefficients, and an analysis of residuals to defend the choice of the form of the distribution function of the expected errors.

Models to be used for estimating uncertainties will be based on, for practical reasons, relatively simple relationships. For example,

*Analytical treatment of model uncertainties is an acceptable alternative. This method entails developing an equation or model to describe and test components of the overall model.

temperature calculations may be reduced to one-dimensional models to keep computer time within practical limits.

In cases where such simplifications are used, the models will require further validation of the simplifying assumptions by comparisons against detailed calculations accepted to serve as benchmarks, as well as against experimental data whenever practical.

The design of HLW packages is not sufficiently defined now to permit a complete specification of the performance model. The following considerations, therefore, should serve only as a guideline. It is expected that a performance model should be composed of the following component models:

- A temperature model able to predict the temperature at important points in the waste package as a function of time.
- A heat source model able to predict the rate of heat generation in the waste as a function of time.
- A radiation model able to predict gamma dose rates in the packing material as a function of time.
- A water flow model able to predict groundwater flow near the waste as a function of time and temperature.
- A water chemistry model able to predict the parameters of interest as a function of flow rate, temperature, radiation and time.
- A corrosion model able to predict rates of release as a function of temperature, water chemistry and radiation dose rates.
- A mechanical failure model able to predict damage to the canister due to stresses.
- A leach model able to predict rates of release of radionculides from the waste form as a function of time, temperature and water chemistry.
- A packing material transport model able to predict concentrations of nuclides as a function of time, water flow, temperature, water chemistry, and radiation field.

4.2.2 Numerical Data and Constants

The basic criterion for acceptance of numerical data to be used in models or correlations is accuracy as demonstrated by reproducibility in tests. The conditions of each experiment from which such data are obtained should be stated or referenced such that the results can be reproduced within stated experimental error by a qualified practitioner. Calculated or deduced results from data reductions and analyses should also be reproducible.

All data from experimental measurements which are used in the analysis of performance or reliability of the waste package should be presented with estimates of their associated errors or confidence intervals. In the case of experimental data having uncertainties larger than a few percent, estimates of the expected distribution of errors should be provided. All basic experimental data used for the development and validation of models should be provided in a form, such as tables or references to available publications of numerical data, that will permit any derived correlation or predictive model used in the analysis of reliability to be reconstructed as the need arises during the review. Data in the form of plots are not acceptable for the justification of models unless accompanied by tabulations of the numerical values. References to data in draft reports are not acceptable unless such reports are made publicly available.

4.2.3 Random Sampling Technique

Reliability calculations based on sensitivity and uncertainty analyses necessitate the repetitive use of the waste package performance model with different values of required parameters selected randomly from data of good quality. Confidence in the results of reliability analyses improves as more cases are analyzed. For these reasons a conflict exists between economy and confidence in reliability calculations. This conflict is expected to be resolved by selecting an appropriate analytical technique which samples efficiently among the input parameters of the model so that a wide range of cases is covered with an optimal number of calculations. The results of sensitivity analyses also may justify the use of some single-valued "bounding" data rather than statistical distributions, thereby simplifying the reliability calculations.

DOE should show that the chosen random sampling technique correctly selects parameter values which reflect the original probability distributions, and that parameters selected independently are in fact uncorrelated. In a reliability calculation, some parameters may be correlated with each other and such correlations should be taken into account in the calculation. For example, the thermal properties of waste package materials and the host rock depend on temperature. As another example, there is a strong correlation between permeability and porosity in packing materials.

A sample calculation was performed (Reference 1, Appendix A) using a technique known as "Latin Hypercube Sampling" (Reference 2) which selects efficiently and randomly among given statistical distributions of para-meter data with rather uniform coverage and controlled correlation. Latin Hypercube Sampling has been used by the NRC in previous risk studies for nuclear waste repositories (References 3 and 4). Other sampling techniques may be acceptable as well, provided proper justification is given with reference to the open scientific literature, or, if originally developed, by providing analyses of actual test runs.

4.2.4 Analyses and Computer Programs

The basic criterion for acceptance of results obtained through the use of analyses is reproducibility by a qualified practitioner working independently. Reproducibility requires disclosure of the method, computer program listings and details of computation sufficient to perform a completely independent analysis, including validation of the model(s) and verification of the associated computer programs. This disclosure can be provided by DOE in the SAR or by citation in the SAR of fully documented information in the open literature. In either case, the method chosen must be capable of reproducing the desired results within the necessary accuracy by using the same data. NRC guidance for the content of documentation on computer programs to be used in support of a license application for high-level waste disposal is given in Reference 6.

5.0 REFERENCES

1. NUREG-CR-2808, "Waste Package Reliability," C. Sastre, C. Pescatore and T. Sullivan, Brookhaven National Laboratory, December 1985.

2. SAND 79-1473, "Latin Hypercube Sampling (Program Users Guide)," Iman, R. L., et.al., 1980.

3. NUREG/CR-1636, Vol. 3 (SAND 79-1393), "Risk Methodology of Geologic Disposal of Radioactive Waste; Sensitivity Analysis of Environmental Transport Model," Helton, J. C., Iman, R. L., 1980.

4. NUREG/CR 2402 (SAND 81-2409), "Risk Analysis Methodology for Spent Fuel Repositories in Bedded Salt: Final Report," Pepping, R. E., et.al., 1983.

5. NUREG-0960, "Draft Site Characterization Analysis of the Site Characterization Report for the Basalt Waste Isolation Project," Section 9.3.10, 1983.

6. NUREG-0856, "Final Technical Position on Documentation of Computer Codes for High-Level Waste Management," June 1983 (draft dated 12/81).

APPENDIX A

SECTIONS OF 10 CFR 60 RELEVANT TO ASSESSING PERFORMANCE OF THE WASTE PACKAGE

Sections of 10 CFR 60 Relevant to Assessing Performance of the Waste Package

§60.2 Definitions

As used in this part:

"Anticipated processes and events" means those natural processes and events that are reasonably likely to occur during the period the intended performance objective must be achieved. To the extent reasonable in the light of the geologic record, it shall be assumed that those processes operating in the geologic setting during the Quaternary Period continue to operate but with the perturbations caused by the presence of emplaced radioactive waste superimposed thereon.

"Barrier" means any material or structure that prevents or substantially delays movement of water or radionuclides.

"Commission" mean the Nuclear Regulatory Commission or its duly authorized representatives.

"Containment" means the confinement of radioactive waste within a designated boundary.

"Controlled area" means a surface location, to be marked by suitable monuments, extending horizontally no more than 10 kilometers in any direction from the outer boundary of the underground facility, and the underlying subsurface, which area has been committed to use as a geologic repository and from which incompatible activities would be restricted following permanent closure.

"Disposal" means the isolation of radioactive waste from the accessible environment.

"Disturbed zone" means that portion of the controlled area the physical or chemical properties of which have changed as a result of underground facility construction or as a result of heat generated by the emplaced radioactive wastes such that the resultant change of properties may have a significant effect on the performance of the geologic repository.

"DOE" means the U.S. Department of Energy of its duly authorized representatives.

"Engineered barrier system" means the waste packages and the underground facility.

"Geologic repository" means a system which is intended to be used for, or may be used for, the disposal of radioactive wastes in excavated geologic media. A geologic repository includes: (1) The geologic repository operations area, and (2) the portion of the geologic setting that provides isolation of the radioactive waste.

"Geologic repository operations area" means a high-level radioactive waste facility that is part of a geologic repository, including both surface and subsurface areas, where waste handling activities are conducted.

"Geologic setting" means the geologic, hydrologic, and geochemical systems of the region in which a geologic repository operations area is or may be located.

"High-level radioactive waste" or "HLW" means: (1) Irradiated reactor fuel, (2) liquid wastes resulting from the operation of the first cycle solvent extraction system, or equivalent, and the concentrated wastes from subsequent extraction cycles, or equivalent, in a facility for reprocessing irradiated reactor fuel, and (3) solids into which such liquid wastes have been converted.

"Host Rock" means the geologic medium in which the waste is emplaced.

"Important to safety," with reference to structures, systems, and components means those engineered structures, systems, and components essential to the prevention or mitigation of an accident that could result in a radiation dose to the whole body, or any organ, of 0.5 rem or greater at or beyond the nearest boundary of the unrestricted area at any time until the completion of permanent closure.

"Isolation" means inhibiting the transport of radioactive material so that amounts and concentrations of this material entering the accessible environment will be kept within prescribed limits.

"Permanent closure" means final backfilling of the underground facility and the sealing of shafts and boreholes.

"Performance confirmation" means the program of tests, experiments, and analyses which is conducted to evaluate the accuracy and adequacy of the information used to determine with reasonable assurance that the performance objectives for the period after permanent closure will be met.

"Radioactive waste" or "waste" means HLW and other radioactive materials other than HLW that are received for emplacement in a geologic repository.

"Restricted area" means any area access to which is controlled by the licensee for purposes of protection of individuals from exposure to radiation and radioactive materials. "Restricted area" shall not include any areas used as residential quarters, although a separate room or rooms in a residential building may be set apart as a restricted area.

"Retrieval" means the act of intentionally removing radioactive waste from the underground location at which the waste had been previously emplaced for disposal.

"Saturated zone" means that part of the earth's crust beneath the deepest water table in which all voids, large and small, are ideally filled with water under pressure greater than atmospheric.

"Site" means the location of the controlled area.

"Site characterization" means the program of exploration and research, both in the laboratory and in the field, undertaken to establish the geologic conditions and the ranges of those parameters of a particular site relevant to the procedures under this part. Site characterization includes borings, surface excavations, excavation of exploratory shafts, limited subsurface lateral excavations and borings, and in situ testing at depth needed to determine the suitability of the site for a geologic repository, but does not include preliminary borings and geophysical testing needed to decide whether site characterization should be undertaken.

"Unanticipated processes and events" means those processes and events affecting the geologic setting that are judged not to be reasonably likely to occur during the period the intended performance objective must be achieved, but which are nevertheless sufficiently credible to warrant consideration. Unanticipated processes and events may be either natural processes or events or processes and events initiated by human activities other than those activities licensed under this part. Processes and events initiated by human activities may only be found to be sufficiently credible to warrant consideration if it is assumed that: (1) The monuments provided for by this part are sufficiently permanent to serve their intended purpose; (2) the value to future generations of potential resources within the site can be assessed adequately under the applicable provisions of this part; (3) an understanding of the nature of radioactivity, and an appreciation of its hazards, have been retained in some functioning institutions; (4) institutions are able to assess risk and to take remedial action at a level of social organization and technological competence equivalent to, or superior to, that which was applied in initiating the processes or events concerned; and (5) relevant records are preserved, and remain accessible, for several hundred years after permanent closure.

"Underground facility" means the underground structure, including openings and backfill materials, but excluding shafts, boreholes, and their seals.

"Waste form" means the radioactive waste materials and any encapsulating or stabilizing matrix.

"Waste package" means the waste form and any containers, shielding, packing and other absorbent materials immediately surrounding an individual waste container.

"Water table" means that surface in a groundwater body at which the water pressure is atmospheric.

10 CFR §60.101(a)(2):

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 allowances for the time period, hazards, and uncertainties involved, 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.

10 CFR § 60.102(e) Isolation of Waste

(1) During the first several hundred years following permanent closure of a geologic repository, when radiation and thermal levels are high and the uncertainties in assessing repository performance are large, special emphasis is placed upon the ability to contain the wastes by waste packages within an engineered barrier system. This is known as the containment period. The engineered barrier system includes the waste packages and the underground facility. A waste package is composed of the waste form and any containers, shielding, packing, and absorbent materials immediately surrounding an individual waste container. The underground facility means the underground structure, including openings and backfill materials, but excluding, shafts, boreholes, and their seals.

10 CFR §60.113

Performance of Particular Barriers After Permanent Closure

(a) General provisions

(1) Engineered barrier system

(i) The engineered barrier system shall be designed so that assuming anticipated processes and events:

(A) Containment of HLW will be substantially complete during the period when radiation and thermal conditions in the engineered barrier system are dominated by fission product decay; and

(B) any release of radionuclides from the engineered barrier system shall be a gradual process which results in small fractional releases to the geologic setting over long times. For disposal in the saturated zone, both the partial and complete filling with groundwater of available void spaces in the underground facility shall be appropriately considered and analyzed among the anticipated processes and events in designing the engineered barrier system.

(ii) In satisfying the preceding requirement, the engineered barrier system shall be designed, assuming anticipated processes and events, so that:

(A) Containment of HLW within the waste package 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 be not less than

300 years nor more than 1,000 years after permanent closure of the geologic repository; and

(B) 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 1,000 years of radioactive decay.

(2) <u>Geologic setting</u>

The geologic repository shall be located so that prewaste-emplacement groundwater travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment shall be at least 1,000 years or such other travel time as may be approved or specified by the Commission.

(b) On a case-by-case basis, the Commission may approve or specify some other radionuclide release rate, 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. Among the factors that the Commission may take into account are:

(1) Any generally applicable environmental standard for radioactivity established by the Environmental Protection Agency;

(2) The age and nature of the waste, and the design of the underground facility, particularly as these factors bear upon the time during which the thermal pulse is dominated by the decay heat from the fission products;

(3) The geochemical characteristics of the host rock, surrounding strata and groundwater, and

(4) Particular sources of uncertainty in predicting the performance of the geologic repository.

(c) Additional requirements may be found to be necessary to satisfy the overall system performance objective as it relates to unanticipated processes and events.

10 CFR §60.135

Criteria for the waste package and its components

(a) High-level waste package design in general.

(1) Packages for HLW shall be designed so that the in situ chemical, physical, and nuclear properties of the waste package and its interactions with the emplacement environment do not compromise the function of the waste packages or the performance of the underground facility or the geologic setting.

(2) The design shall include but not be limited to consideration of the following factors: 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.

(b) Specific criteria for HLW package design

(1) Explosive, pyrophoric, and chemically reactive materials

The waste package shall not contain explosive or pyrophoric materials or chemical reactive materials in an amount that could compromise the ability of the underground facility to contribute to waste isolation or the ability of the geologic repository to satisfy the performance objectives.

(2) Free liquids

The waste package shall not contain free liquids in an amount that could compromise the ability of the waste packages to achieve the performance objectives relating to containment of HLW (because of chemical interactions or formation of pressurized vapor) or result in spillage and spread of contamination in the event of waste package perforation during the period through permanent closure.

(3) Handling

Waste packages shall be designed to maintain waste containment during transportation, emplacement and retrieval.

(4) Unique identification

A label or other means of identification shall be provided for each waste package. The identification shall not impair the integrity of the waste package and shall be applied in such a way that the information shall be legible at least to the end of the period of retrievability. Each waste package identification shall be consistent with the waste package's permanent written record.

(c) Waste form criteria for HLW.

High-level radioactive waste that is emplaced in the underground facility shall be designed to meet the following criteria:

(1) Solidification.

All such radioactive wastes shall be in solid form and placed in sealed containers.

(2) Consolidation.

Particulate waste forms shall be consolidated (for example, by incorporation into an encapsulating matrix) to limit the availability and generation of particulates.

(3) Combustibles.

All combustible radioactive wastes shall be reduced to a noncombustible form unless it can be demonstrated that a fire involving the waste package containing combustibles will not compromise the integrity of other waste packages, adversely affect any structures, systems, or components important to safety, or compromise the ability of the underground facility to contribute to waste isolation.

(d) Design criteria for other radioactive wastes.

Design criteria for waste types other than HLW will be addressed on an individual basis if and when they are proposed for disposal in a geologic repository.

10 CFR § 60.143 Monitoring and Testing Waste Packages

(a) A program shall be established at the geologic repository operations area for monitoring the conditions of the waste packages. Waste packages chosen for the program shall be representative of those to be emplaced in the underground facility.

(b) Consistent with safe operation at the geologic repository operations area, the environment of the waste packages selected for the waste package monitoring program shall be representative of the environment in which the wastes are to be emplaced.

(c) The waste package monitoring program shall include laboratory experiments which focus on the internal condition of the waste packages. To the extent practical, the environment experienced by the emplaced waste packages within the underground facility during the waste package monitoring program shall be duplicated in the laboratory experiments.

(d) The waste package monitoring program shall continue as long as practical up to the time of permanent closure.