CNWRA 90-007

"SUBSTANTIALLY COMPLETE CONTAINMENT" FEASIBILITY ASSESSMENT AND ALTERNATIVES REPORT

Prepared for

Nuclear Regulatory Commission
Contract NRC-02-88-005

Prepared by

Center for Nuclear Waste Regulatory Analyses
San Antonio, Texas

September 1990

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TABLE OF CONTENTS

LIST OF FIGURES

1. INTRODUCTION

The Nuclear Regulatory Commission (NRC) contracted with the Center for Nuclear Waste Regulatory Analyses (CNWRA) to undertake an assessment of the feasibility of establishing quantitative criteria for the meaning of "substantially complete containment" (SCC) in 10 CFR 60.113. The purposes of the feasibility study were:

1. To develop an understanding of the technical considerations required for demonstrating long-term waste package performance under anticipated conditions at the selected repository site;

2. To identify a methodology that can assist in classifying the type and nature of uncertainties and provide guidance for quantifying the uncertainties in a systematic manner for evaluating waste package performance;

3. To assess the feasibility of establishing quantitative criteria for "substantially complete containment" in a regulatory framework.

The uncertainty in 10 CFR 60.113 was identified by the NRC document SECY-88-285 [Ref. 1] and confirmed by the Systematic Regulatory Analyses (SRA) in CNWRA 89-003 [Ref. 2] and CNWRA 90-003 [Ref. 3] conducted by the Center. The information on and the assessment of uncertainty are described in three NRC and CNWRA documents. These documents include:

- J. O. Bunting, "Technical Policy Options to Minimize the Regulatory Uncertainty Regarding Substantially Complete Containment," Draft Report, March 20, 1989 [Ref. 4];

- J. O. Bunting, R. A. Weller, C. Peterson, and C. Interrante, "Scoping Paper for Proposed Rulemaking to Minimize Uncertainty Regarding the Regulatory Requirement for Substantially Complete Containment," Draft Report, Revision 1, March 28, 1989 [Ref. 5]; and

- E. Tschoepe, R. L. Wilbur, P. K. Nair, "Program Architecture Baseline, EBS Performance After Permanent Closure - Substantially Complete Containment," Draft Report, October 1989 [Ref. 6].

The scoping paper [Ref. 5] identified a quantitative rulemaking as a potential uncertainty reduction method. Based on the NRC documents [Ref. 4 and 5] and the evaluation of the recommendations in the documents, the NRC elected to conduct the feasibility study at the CNWRA. At the direction of the NRC, the CNWRA developed a strategy for conducting the feasibility study to assess the technical basis for any quantitative criteria that may be appropriate for addressing the SCC issue.

To date, the license applicant, the Department of Energy (DOE), has, in the Consultation Draft Site Characterization Plan and in the subsequent Site Characterization Plan, attempted to define the performance implication of "substantially complete containment." In both cases, the NRC staff found the representations at variance with the intent of the regulations as established in the statement of considerations for the original containment rule and in the supporting document, Staff Analysis of Public Comments on Proposed Rule 10 CFR Part 60, "Disposal of High-Level Radioactive Wastes in Geologic Repositories," NUREG-0804, December 1983 [Ref. 7]. Considerations from NUREG-0804 are discussed in Section 2.1 of this report.

Because of the nature of the uncertainty associated with the Regulatory Requirement for "substantially complete containment," a strategy was established to develop the technical considerations needed for the concept of "substantially complete containment" and then develop recommendations for resolving the regulatory uncertainty (see Figure 1). Towards examining the technical basis, a detailed evaluation of the technical considerations that one may need in evaluating any level of containment was undertaken. Once the technical assessment was complete, potential regulatory uncertainty reduction methods could then be pursued. Based on this strategy, the feasibility study was initiated. The feasibility study consisted of initially developing an understanding of the technical issues involved and the development of guidelines based on quantitative methods to assess the types of uncertainties that could arise from the technical considerations. This part of the study was reported in two technical documents, namely:

- H. K. Manaktala and C. G. Interrante, "Technical Considerations for Evaluating 'Substantially Complete Containment' of HLW Within the Waste Package," Draft Report, CNWRA 90-001, June 1990 [Ref. 8]; and

- Y.-T. Wu, A. G. Journel, L. R. Abramson, and P. K. Nair, "Uncertainty Evaluation Methods for Waste Package Performance Assessment," Draft Report, CNWRA 90-002, July 1990 [Ref. 9].

The approach followed in the development of these two reports is appropriate regardless of how the uncertainty about the meaning of SCC is reduced. First, all of the technical factors to be considered in predicting containment performance are identified along with a rationale for each. The arguments are developed based on the use of a container. However, the higher order technical considerations apply to all containment barriers that may be prescribed to perform the containment function of the waste package. Next, the characterization of the various classes of the technical considerations by the application of structured mathematical principles in the form of probabilistic and statistical methods were developed and presented in Reference 9.

A peer review of the contents of these reports was conducted in a public meeting on April 2-4, 1990, by a committee of nine technical experts. Observers from the NRC staff, Advisory Committee on Nuclear Waste (ACNW), DOE, Technical Review Board (TRB), and State of Nevada attended the public peer review sessions. The comments and suggestions have been appropriately incorporated into the final drafts of the reports.

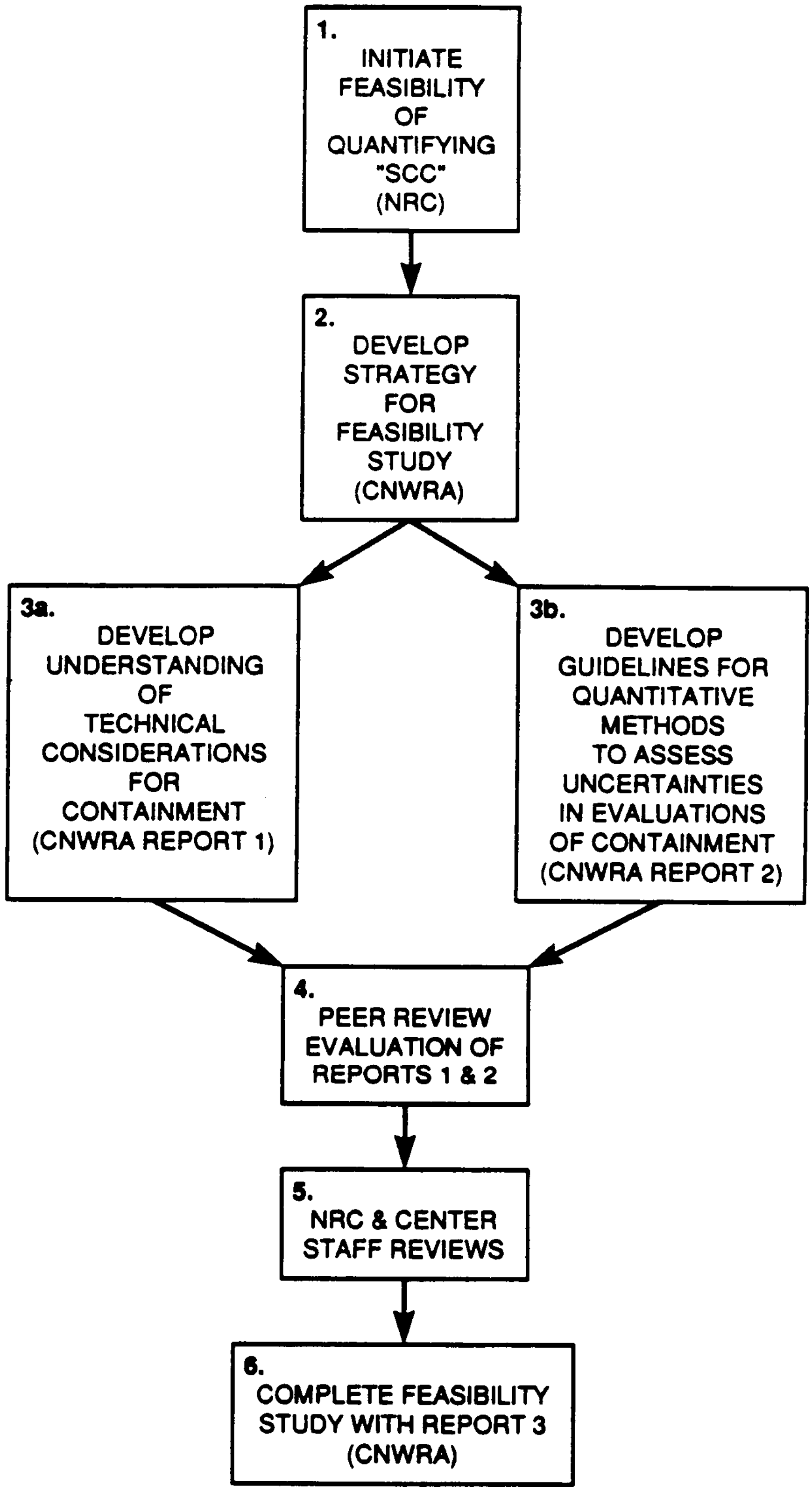

Figure 1. Steps in Development of the Feasibility Study

2. BACKGROUND TO "SUBSTANTIALLY COMPLETE CONTAINMENT" REQUIREMENT

An essential part of the high-level nuclear waste disposal strategy is the concept of the long-term protection of the health and safety of future generations from the long-lived radionuclides. The inventory of radionuclides and the heat thereby generated changes with time; as a result, the conditions under which protection is sought will also change with time. Coupled with the requirements for long-term protection, a reasonable understanding of the assessment methodology of the performance of the repository is required. The choice of a deep geologic repository for the disposal of high-level nuclear waste is an attempt to provide a stable environment for the purpose of long-term isolation.

The Nuclear Waste Policy Act (NWPA) and the subsequent Amendment (NWPAA) [Ref. 10] provide the statutory basis and the fundamental concepts and definitions for the nation's high-level nuclear waste program. The Act recognizes the need for a defense-in-depth approach to ensure safe disposal. This is provided by the concept of having a system of natural (geologic) and engineered barriers. A multibarrier system is an approach to ensure that the uncertainties in overall disposal performance predictions are compensated for by conservative design and that reasonable assurance can be provided that the overall EPA standard can be met.

2.1 ENGINEERED BARRIER SYSTEM

The engineered barriers part of the system accounts for the near-field isolation of the waste within prescribed boundaries. The NWPA/NWPAA have defined the components of the engineered system as follows.

42USC 10101 -- Definitions

"(10) The terms "disposal package" and "package" mean the primary container that holds, and is in contact with, solidified high-level radioactive waste, spent nuclear fuel, or other radioactive materials, and any overpacks that are emplaced at a repository."

"(11) The term "engineered barriers" means manmade components of the disposal system designed to prevent the release of radionuclides into the geologic medium involved. Such term includes the high-level radioactive waste form, high-level radioactive waste canisters, and other materials placed over and around such canisters."

Consistent with NWPA, the NRC's regulation 10 CFR Part 60 [Ref. 11] provides additional definitions and establishes specific performance requirements for the engineered barriers. The definitions appear in 10 CFR 60.2. The definitions relevant to the engineered barrier performance are listed below.

60.2 -- Definitions

"'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."

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

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

"'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."

"'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."

NUREG-0804 [Ref. 7] presents the rationale and the intent of the regulations in 10 CFR Part 60. The definitions of the engineered barriers components in the NWPA and in 10 CFR Part 60, though not identical, tend to describe the functional requirements with some consistency. As part of the comments on the subject, the following text from NUREG-0804, page 38, on the subject of the Definition of Waste Package, is relevant.

"Commenters questioned the clarity of this proposed definition and one commenter suggested an alternative definition. One commenter misinterpreted the proposed definition to require that the outermost component of the waste package be an airtight, watertight, sealed container. The revised definition no longer uses the terms 'discrete backfill' or 'overpack', which were ambiguous. To the extent that absorbent materials or packing are placed around a container to protect it from corrosion by groundwater, or to retard the transport of radioactive material to the host rock, these materials would be considered part of the waste package. However, while the final rule no longer imposes a requirement for an airtight, watertight, sealed container as part of the waste package, the Commission believes it likely that DOE will incorporate such a component into the design of the waste package in order to meet the performance objectives for the engineered barrier system for the period following permanent closure. The related terms 'disposal package' and 'package', as defined at Section 2(10) of the Nuclear Waste Policy Act, include unspecified overpacks; for purposes of the Commission's rules, and specifically in connection with the performance objective set out at Section 60.113(a)(1)(ii)(A), a more precise definition is needed. The differences in the definitions will not, in the judgment of the Commission, result in confusion or conflict."

As indicated above, the definitions relate specifically to performance objectives identified in 10 CFR Part 60. The background of the performance objectives is presented in NUREG-0804. The concepts for the disposal of high-level nuclear waste are based on providing as much reliance as is realistic on engineered barriers in the early postclosure life of the repository and depending on additional contribution by the geologic setting for the longer term isolation requirement. These concepts are consistent with the following understanding of the behavior of a repository system:

1. Early in the postclosure period the waste inventory is dominated by fission products and high decay heat temperatures in the range of 200-250°C. The heat input into the repository is of such magnitude that the hydrological and geochemical environment can be significantly altered. This could include two-phase flow conditions (steam/vapor and liquid) in unsaturated repositories where radionuclide movement is governed by hydrologic transport. The prediction of radionuclide behavior under such conditions is difficult and the uncertainties in the validation of models will be large.

2. The experience base for engineered components for long-term performance is limited. However, engineering principles applied to the relevant data can provide the basis of long-term predictions. There is historic evidence that manmade structures have survived many centuries. This implies that with modern technology it is possible to engineer barriers for successful performance at least during the early life of the repository.

3. During the later part of the life of a repository, the average temperature of the wasteform is lower and the inventory of the radionuclides would decrease. Under such conditions a stable geologic setting by itself could provide the waste isolation function. Here it is assumed that a geologic site is adequately characterized and studied to conclude that the site will perform as anticipated for the period desired.

4. It is recognized that, even with the best technical effort that one may undertake, there will be uncertainties remaining. This aspect of the problem is addressed by having multiple barriers with redundant and conservative performance requirements.

In 10 CFR 60.113, two repository subsystem performance objectives are identified with the engineered barrier system (EBS). The first requires that the engineered barrier system be designed so that containment of high-level waste (HLW) within the waste packages shall be "substantially complete" for a period after closure, to be determined by the Commission, and to be a minimum period of 300 to 1000 years. The second objective is to ensure that the release of radionuclides from the EBS will be gradual after the containment period is over.

On the other hand, an assessment of the " . . . effectiveness of engineered and natural barriers . . . against the release of radioactive material to the environment . . ." must accompany the license application to meet the requirement of 10 CFR 60.21(c)(1)(ii)(D).

The intent of the containment barrier is to preclude the large inventory of radionuclides from interacting with the geologic environment during the thermally dominated condition, particularly, when there are large technical uncertainties in modelling the complicated processes taking place. By providing a containment barrier, the scientific investigations can focus on a much more tractable situation, i.e., the breakdown of the containment barrier. Here, the complications of the near-field geochemistry and thermohydrology will still remain. However, the attention is not directed at radionuclide transport, but on how well the containment barrier performs its function during the period of containment.

The second performance objective is met by the total engineered barrier system. This objective ensures that the release of the radionuclide inventory after the containment period is gradual. The intent of this objective appears to be for providing continuity in the way degradation of the various engineered barriers can contribute to limiting excessive spike releases to the geosphere. There is a close relationship between the "containment" and "gradual release" requirements. The barrier or barriers providing containment will very likely contribute extensively to meeting the gradual-release requirement. As stated on page 52 of NUREG-0804 [Ref. 7], containment and gradual release ". . . are coupled parameters that should not be varied independently, but rather should be viewed as a system to control the release to the geologic setting."

2.2 "SUBSTANTIALLY COMPLETE CONTAINMENT"

The containment objective is described in 10 CFR 60.113. The pertinent section is given below.

> 10 CFR 60.113
>
> "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; . . . ."
>
> "In satisfying the preceding requirements, the engineered barrier system shall be designed, assuming anticipated processes and events, so that: (1) 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 be not less than 300 years nor more than 1,000 years after permanent closure of the geologic repository; . . . ."

The background to this rule and the development history of the final wording of the rule are described in NUREG-0804 [Ref. 7]. The intent of the rule was to ensure the demobilization of all the radionuclides in the waste inventory at all times for a minimum specified period of time. In an early version of the rule, the term "absolute containment" was employed. However, several comments received by the Commission questioned the practical aspects of demonstrating such an absolute rule. In response, the wording of the rule was changed to "substantially complete containment." The objective of "no releases" remains intact as expressed in the basis of design of the EBS in 10 CFR 60.113, but it is not a requirement with which compliance must be demonstrated.

2.2.1 Assumption and Bases for Containment

A key consideration in implementing the containment rule is that the license applicant should design a waste package for containment and not for some partial release of radionuclides. The words "substantially complete" in this context describe 'how well' the demonstration of containment has to be pursued. It captures in it all the uncertainties associated with technology limitations, data inadequacies and the like in the design of a containment barrier. Once the best job of designing for containment is complete, then an analysis of the goodness of the design can be performed. This analysis will evaluate the likelihood and consequence of the designed containment barrier failure.

An alternate interpretation of the words "substantially complete containment" has been made by DOE to permit some release. The emphasis of such an interpretation is to control and calculate the amount of release from the time of repository closure. In pursuing this alternate interpretation, a greater emphasis would be placed on the stability of the wasteform in the presence of the geologic environment. Here the wasteform is viewed as a major contributor to the containment barrier. It also assumes a high degree of confidence in developing radionuclide release models during the period when radiation and thermal conditions are dominated by fission product decay. However, as stated in NUREG-0804 [Ref. 7], p. 471, release rate predictions are difficult during the period when radiation and temperatures are high. If release rates in such a high temperature and radiation repository environment could be reasonably predicted, then this hypothetical approach might be pursued. Conditions for which the wasteform by itself might support a containment requirement are discussed in Appendix A under Case 1, a dry repository. Appendix A expounds on the physical nature of the barrier by evaluating the types of geologic repository sites and their unique characteristics relating to the containment issue. Appendix A also includes a discussion of the saturation conditions for two other repository cases: Case 2, a saturated repository, and Case 3, an unsaturated repository. It is important to keep in mind that the containment rule must be generic, and it must, therefore, apply in any case.

2.2.2 Current Structure of the Containment Requirements in 10 CFR Part 60

The containment regulation in 10 CFR Part 60 [Ref. 11] is driven by the engineered barrier subsystem performance objective in 60.113. Containment design requirements to support the performance objectives are addressed in 60.135. Once the design is completed, analysis of the adequacy of the final design is required in 60.21. Critical definitions of the various containment barriers are presented in 60.2. Finally, data acquired during the performance confirmation program should substantiate that the waste packages and the EBS are performing as intended, in accordance with 60.140 and 60.143. Figure 2 presents all the parts of the containment regulation along with other relevant sections from 10 CFR Part 60 in a structured form.

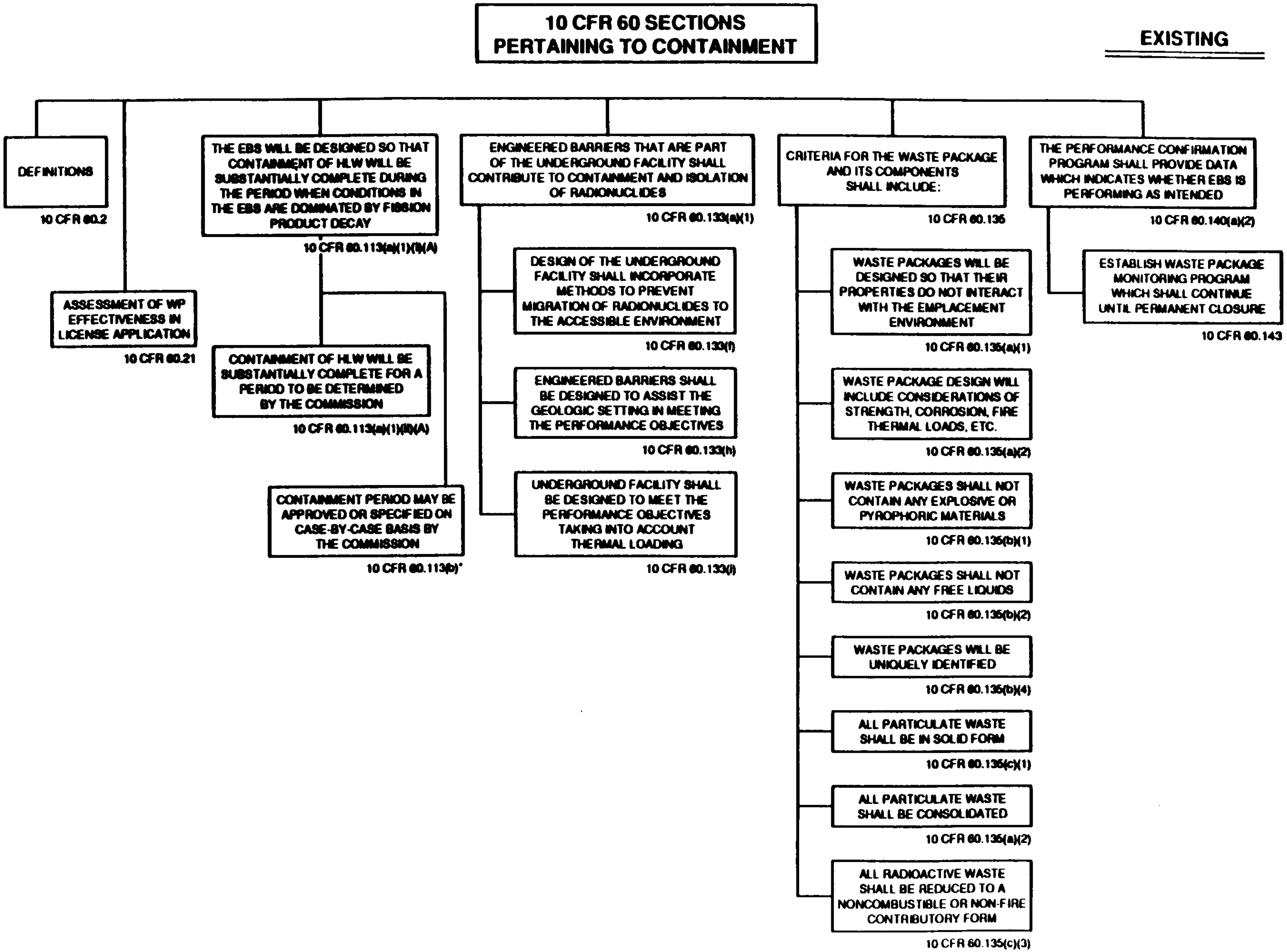

Figure 2. 10 CFR 60 Sections Pertaining to Containment

3. CONCLUSIONS FROM REPORTS 1 AND 2

The uncertainty arising from the "substantially complete containment" requirement in 10 CFR 60.113 requires, first, a degree of understanding of the technical elements that must be considered in a systematic approach to address any containment evaluation, and, second, a logical approach to define "how well" each of the technical elements can be determined. An in-depth look at technical considerations relevant to the prediction of waste package containment performance was provided in the CNWRA 90-001, the Technical Considerations Report [Ref. 8]. The second report, CNWRA 90-002, the Uncertainty Evaluation Methods for Waste Package Performance Assessment Report [Ref. 9], concerned the approach to define "how well" such technical information can be known.

3.1 TECHNICAL CONSIDERATIONS REPORT

The discussion in Reference 8 was centered around technical considerations of the repository environment, materials and fabrication processes for the waste package components, various degradation modes of the materials of construction of the waste packages, and inspection and monitoring of the waste package during the preclosure. Reference 8 was developed with the assumption that a container, as part of the waste package, was the major contributor to the requirement for containment performance. Although the emphasis was on metallic container materials, brief reference was also made to other candidate materials (ceramics, graphite, bonded ceramic-metal systems, and other types of barriers). Comments from an external peer review panel were incorporated following a workshop held at the CNWRA in San Antonio for that purpose. It was recognized in Reference 8 that uncertainties associated with each of the considerations may be significant and that compliance with the containment requirement can be assured only if these uncertainties are understood and minimized. These assurances may be obtained, however, through scientific understanding, to assure that the environment is within the expected range for which waste containers were designed, and through the application of good engineering practices and implementation of quality control procedures that render assurances that the containers and the materials from which they were fabricated are within design specifications. In other words, the state of the technology exists for providing a basis for addressing the technical issues for any containment rule. Since the duration of the required service period is much longer, by orders of magnitude, than the times over which laboratory experiments can be conducted, there is a need for the development of methods for the prediction of service behavior over such long periods.

Although Reference 8 used a container as a baseline for the discussion, the approach is valid regardless of the material and specific design for containment. The higher order considerations presented in this report apply to any engineered containment barrier. It is understood that the technical issues and considerations for the other components and their interactions would follow the same logical pattern as that described in the report.

3.2 UNCERTAINTY EVALUATION REPORT

In Reference 9, four applicable uncertainty evaluation methods based on currently available technologies were described: probability-distribution approach, bounding approach, expert judgment and sensitivity analysis. Such diverse methods will likely be needed to address the diverse nature of the types of technical data or information that can be expected from the technical considerations identified in Reference 8. The second report also identified and characterized associated uncertainties by type and source. Once the pertinent technical data are identified, they can be individually or collectively quantified by the method or mix of methods most feasible and applicable.

3.3 TECHNICAL ASSESSMENT CONCLUSIONS

Based on the knowledge of the types of technical considerations from Reference 8 and the uncertainty evaluation methods available as identified in Reference 9, it is feasible that a probability-based approach can be used in the overall performance evaluation of the waste package for the long-term containment of radionuclides. Also, Reference 9 identified a probabilistic analysis framework by which uncertainties in waste package containment performance assessment can be treated and evaluated.

Based on a predefined design strategy, a process for the design of a containment barrier using the contents of References 5 and 6 would involve the following steps.

- Select all applicable technical considerations important to the design from among those listed in Figure 1 of Reference 8.
- Characterize the technical information on each of the considerations using one of the uncertainty evaluation techniques described in Reference 9.
- Combine the characterized information using probabilistic methods and present the result in the form of the quantitative criteria presented in Reference 9.

Information provided in a probabilistic format provides additional knowledge about such information to a reviewer in the distribution of data and the quantification of reliability of such information, and these might be crucial in decision making. A probabilistic format also structures information, and this can help to show relative value of various data in its proper context. Probability-based quantitative criteria for evaluating waste package performance are discussed in detail in Reference 9.

The quantification of uncertainties, along the lines described in Reference 9, gives the decision-maker the ability to make comparative estimates of the uncertainties involved with the technical considerations of "substantially complete containment." Regardless of which path is followed to present any new guidance on "substantially complete containment," these advantages should be pursued so that the best and most complete information is available to the decision maker.

Thus, References 5 and 6 contribute to a technical basis that could be used in demonstrating compliance with the "substantially complete containment" requirement. This is accomplished by a thorough understanding of the physics, chemistry, geology, and other technical considerations coupled with application of an appropriate choice of approaches to reduction of the uncertainty of "how well" each of the technical considerations must be known. It should be noted that the two reports provide a logical framework for what technical information is needed and how the information should be presented such that the easily quantifiable parts of the compliance strategy can be represented and the other aspects can be managed with specialized techniques.

Based on the analysis summarized above, it is feasible to represent technical information on waste package performance in a quantitative manner. This approach would provide methods for the comparison of alternate interpretations of technical data, models, and other information and can help determine the sensitivity of the important parameters. However, there will remain significant areas of uncertainty in certain conceptual models, scenarios, and in long-term extrapolation of data, where straightforward quantification may not be possible. For such conditions, assessment of risk and consequence analyses will be required along with a plan to acquire the necessary data during the performance confirmation program. The notion of acceptability of any perceived risk may require the incorporation of additional barriers or a demonstration of the degree of the defense-in-depth within the designed repository system.

It is expected that a mechanistic understanding of the interactive behavior of the waste package and its environment will be utilized to develop models to predict the containment performance. These interactive models should be available at the time of license application. It is recognized that deficiencies in the state of information on some technical issues will persist even during the license application period. This is particularly true of the time-dependent interaction models. In the event a satisfactory understanding of the interactions cannot be gained prior to submittal of the license application, the applicant should: 1) explain the current level of understanding and drawbacks of the currently used interactive models, and 2) present plans and procedures to obtain a satisfactory level of knowledge during the performance confirmation program.

Given the shortcomings of predicting long-term performance of a repository system and its components, it becomes imperative that a process of scientific investigation be undertaken such that there is a measurable decrease in technical uncertainties with the gaining of knowledge about the site and engineered components with time. To the degree possible, the quantification of technical information and a structured representation of all such information into cohesive and understandable criteria is a goal that will provide clarity to unambiguously evaluate various containment designs. Criteria based on probabilistic analyses methodologies will enable containment designers to perform comparative analyses of alternate designs and assist in improving performance of any particular barrier without a complete redesign. Also, a probability-based quantitative criteria will facilitate design modifications and/or retrofits during the preclosure period of the repository. In the next section, the various aspects of a quantitative criteria and how such a criterion can be incorporated into different regulatory alternatives are discussed.

4. FEASIBILITY ASSESSMENT OF ALTERNATIVES

In a repository development program, there is an ongoing long-term effort to gather, investigate, and analyze new technical information and data on the site characteristics and engineered components. The nature of these technical information and data are such that they provide an understanding of the type of concern regarding any given phenomenon and/or an assessment of the degree of concern regarding the given phenomenon as it relates to waste isolation. The 'type of concern' can be addressed by qualitative judgments. However, in dealing with the 'degree of concern' questions, there has to be a quantitative basis for exercising judgments.

The subsystem requirement in 10 CFR 60.113 for containment defines the performance expectations for anticipated conditions. In typical engineering practice, designs are developed to meet a quantitative specification for normal (anticipated) operating conditions. The designs are then tested or analyzed to check the component performance under accident (unanticipated) conditions. The standards for accident conditions are usually different. A risk/consequence analysis is then performed to ensure that no catastrophic system failure occurs. There is no one-to-one correspondence with typical engineered systems in practice with the engineered barrier system components of the repository program. However, there are several parallels. The parallels particularly apply where normal or anticipated conditions are involved. It is, therefore, the recommendation of this report to develop and use quantitative criteria in the evaluation of containment regulations for anticipated conditions. Of course, the choice of a quantitative criterion should be made with consideration to avoid adoption of a criterion which is unduly prescriptive or too relaxed. The next two subsections (4.1 and 4.2) discuss some of the aspects of a quantitative criterion. Subsection 4.3 describes recommended alternatives for presenting a quantitative criterion.

4.1 RATIONALE FOR A QUANTITATIVE CRITERION

The use of a quantitative criterion has the following advantages:

- Eliminates or minimizes, to the extent practicable, the necessity for the hearing board to entertain contentions regarding (1) the interpretation of the meaning of SCC; (2) the elements of proof that form the basis for the finding of compliance with the regulatory requirement; or (3) the pass/fail criterion.

- Quantitative criteria would have the major advantage of providing the applicant with a concise description of what is expected to demonstrate compliance with the containment requirement.

- There is less risk that the applicant will adopt a different approach which they feel is appropriate but which may be unacceptable to NRC.

- More time is available for NRC's evaluation/advising, to include the entire period of site characterization (from now to time of licensing) by providing commonly understood criteria at the earliest time.

Disadvantages to changing the current qualitative SCC criteria include the following:

- If the quantitative criteria are overly prescriptive, they may negate options for flexibility to incorporate new technical or probabilistic techniques for uncertainty reduction which may appear prior to licensing.

- Flexibility in alternative approaches may be more appropriate than a strictly quantitative procedure to demonstrate compliance, and such flexibility may be lost with adoption of a quantitative rule.

The following points provide offsetting factors to be considered in light of the disadvantages:

- Quantitative criteria can be designed to leave enough flexibility in the definition of acceptable thresholds to allow for a final decision which is responsive to the latest data available. Just as the containment period is not yet a fixed value, the probability of failure of a proportion of waste packages by the end of the containment period and the value for the proportion of failed waste packages could be constrained to be in an interval to be ultimately decided by the Commission.

- Any guidelines proposed by NRC would be carefully peer-reviewed. In addition, the current process of public comment and debate on any rulemaking or technical position on the subject will adequately expose the pros and cons. Documentation and rationale descriptions can be time-tested over a long period.

From the above discussion, it can be concluded that the advantages of adoption of a quantitative criterion for "substantially complete containment" outweigh the disadvantages.

4.2 ATTRIBUTES OF A QUANTITATIVE CRITERION

In order to maintain flexibility for the NRC, while assisting the license applicant in designing safe waste packages, any quantitative criterion based rule should have the following attributes:

- It should be easy to interpret and unambiguous.

- It should allow for a pass-fail criterion.

- It should reflect the state-of-the-art in both scientific knowledge and uncertainty.

- Its demonstration should be achievable with presently available or easily developed methodology and data, including the use of expert judgement.

- It should allow flexibility to use data up to licensing hearing time and beyond, up until permanent closure of the repository.

- It should allow flexibility for possible later rule modification.

A quantitative criterion developed in Reference 9 and meeting the attributes discussed in this section is described below:

The probability that the proportion K of waste packages failing during the period $(0, T_o)$ does not exceed K_o should be greater than r_o.

Probability $\{K \leq K_o\} > r_o$, where

K_o is the maximum allowable proportion of waste packages failing in time T_o;
r_o is the minimum acceptable probability that $K \leq K_o$; and
T_o is the containment period.

The quantitative criterion expressed above attempts to capture the postclosure performance of the waste packages in a broad yet concise manner. In establishing a robust rule, the above quantitative criterion should also imply that the probability of failure of waste packages, $K > K_o$, is controlled and is very small. This approach will ensure the application of the philosophy of designing for containment. It will also enable the designer to account for a multiple of waste packages in varying environmental and loading conditions.

The definition of a waste package failure plays an important part in evaluating the consequence of the failures. Assuming that the waste package degradation is progressive with time and at some time in the future (say >> 1,000 years) all of the waste package material is ineffective toward performing any containment functions, a reasonable definition can be developed where the credit for a minimum containment period is established such that a significant part of the waste package is intact at the end of the minimum containment period. Regardless of the definition chosen, it should be possible for the applicant to compute partial or fractional releases from the waste package when demonstrating compliance with the post-containment, gradual-release rate requirement. The quantitative approach presented in terms of proportions of waste packages is equally applicable to proportions of radionuclides in a single or multiple waste packages, if failure is defined in terms of the proportion of radionuclides released. The approach facilitates a logical transition from the containment requirement to the gradual-release requirement. It also provides a basis to analyze consequences of premature compromise of the containment function.

4.3 PRESENTATION ALTERNATIVES

There are several presentation alternatives to implementing a quantitative criterion. Three basic approaches to reduction of the uncertainty related to "substantially complete containment" are identified as follows:

- Change the existing regulation by way of a qualitative rule with probabilistic language;
- Change the existing regulation by way of a quantitative rule; and
- Do not change the regulation but provide interpretation of SCC within a regulatory guidance document (Regulatory Guide or Technical Position).

These three approaches provide the basis for a broad scope of alternatives that could be pursued to accomplish the task of expressing the technical details needed to clarify the SCC issue. For each of the cases described above, complementary Technical Position (TP) (or Regulatory Guide) reports are recommended. For each case, the content and scope of the associated TP will be different. The purpose of the TPs is to provide guidance on the implementation of the defined approach.

The choice of which alternative is pursued will determine where explanatory text will reside. The alternatives that involve changing the existing regulation, either with a qualitative or a quantitative rule, would require that some text in 10 CFR Part 60 be replaced and/or supplemented with new text. Under the current rule, the following portions of 10 CFR Part 60 [Ref. 11] contain text relevant to the issue of "substantially complete containment," as illustrated by Figure 2:

- 10 CFR 60.2 "Definitions"
- 10 CFR 60.21 "License Applications"
- 10 CFR 60.113 "Performance of Particular Barriers after Permanent Closure"
- 10 CFR 60.133 "Additional Design Criteria for the Underground Facility"
- 10 CFR 60.135 Design "Criteria for the Waste Package and Its Components"
- 10 CFR 60.140(a)(2) Performance Confirmation Program "General Requirements"
- 10 CFR 60.143 "Monitoring and Testing Waste Packages"

4.3.1 Areas of Change

4.3.1.1 Definitions - 10 CFR 60.2

There is a need for precise definitions for containment and failure of containment in order to adequately pursue an assessment of compliance with a rule on "substantially complete containment." If any change to 10 CFR Part 60 is contemplated to aid in the understanding of SCC, the change in such definitions is the minimum required. Refer to Appendix B for further discussion.

4.3.1.2 Additional Factors

The approaches involving changing the existing regulation would introduce new definitions in 10 CFR 60.2, and they may involve a probabilistic assessment as part of the analyses of barrier performance in the license application under 10 CFR 60.21. Changing the existing regulation might be done either in 10 CFR 60.113 (which is under the general heading of "Performance Objectives") or in 10 CFR 60.135 (which is under the general heading of "Design Criteria for the Waste Package"). In these two cases there are certain implications associated with the choice of where new language would appear in 10 CFR Part 60 [Ref. 11] as well as with the Regulatory Guidance choice of simply interpreting SCC outside the structure of 10 CFR Part 60. The implications and rationale for the various alternatives are discussed below.

4.3.2 Qualitative Rule - Alternative 1

The potential changes to the various sections of 10 CFR Part 60 [Ref. 11] to support clarification of 60.113 with a qualitative rule are identified in Figure 3. For a qualitative rule, a change in language would most appropriately appear in 10 CFR 60.113, since the issue of SCC is most accurately categorized as performance of the engineered barrier after permanent closure. Also needed would be a clear definition of containment failure in 10 CFR 60.2 so that the license applicant could demonstrate compliance for a particular design for containment. Any proof of compliance with a probabilistic methodology in the case of a qualitative rule would require additional guidance outside 10 CFR Part 60, and that is indicated by presentation of an acceptable methodology and a worked example in a Technical Position (TP) Report.

Presentation in a qualitative rule has the following advantage:

- It does not constrain the requirement to specific probability numbers, even in a generic sense. This allows for regulatory flexibility in light of anticipated advances in technical state of the art in both the ability to produce improved containment and the ability to predict such containment performance.

There are, however, disadvantages associated with the adoption of a qualitative rule.

- It does not provide a quantitative basis to indicate how one is to judge the adequacy of the predicted performance with respect to a standard for containment.

- With the probabilistic approach in a TP, there is a risk that the applicant may adopt a different approach which they feel is appropriate but which may be unacceptable to NRC.

Note that, even with the qualitative rule, the probabilistic approach could be presented in some other format than strictly in a TP. For example, the probabilistic approach could be included in a revision to 10 CFR 60.21 as a requirement in the assessment of performance for the license application.

4.3.3 Quantitative Rule - Alternatives 2 & 3

For the quantitative rule change, two alternatives are considered as shown in Figures 4 and 5. For these alternatives, it is important to consider the location of the modified or additional text within 10 CFR Part 60 [Ref. 11]. For Alternative 2 (Figure 4), probability-based quantitative language would be added to 10 CFR 60.113, whose subject deals with performance objectives. Also, assessment of waste package effectiveness required in 10 CFR 60.21 would be expanded to require that the assessment be made in terms of probabilities. In contrast, Alternative 3 (Figure 5) recommends the inclusion of the probability-based quantitative language in 10 CFR 60.135, whose subject is the waste package design criteria. With this second alternative, the quantification would be treated as a design criterion and not as a performance requirement. The rationale for incorporating a quantified rule in 10 CFR 60.113 (Alternative 2) is that the Commission can prescribe a more flexible performance requirement in terms of a specified number of waste package failures, i.e., nonzero values. If the NRC determines that a nonzero value for K_o would be appropriate, particularly for unanticipated conditions as part of the system

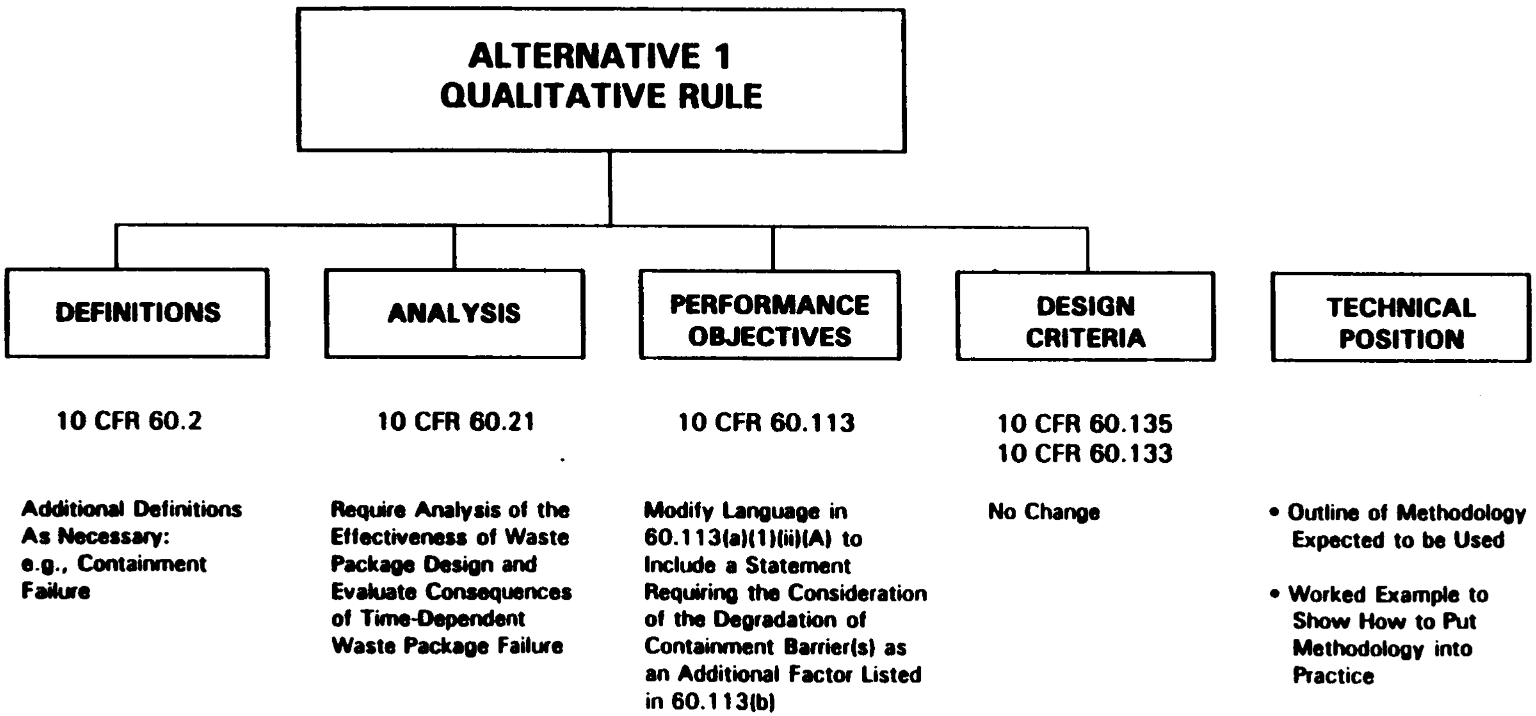

Figure 3. Presentation Alternative 1 - Qualitative Rule

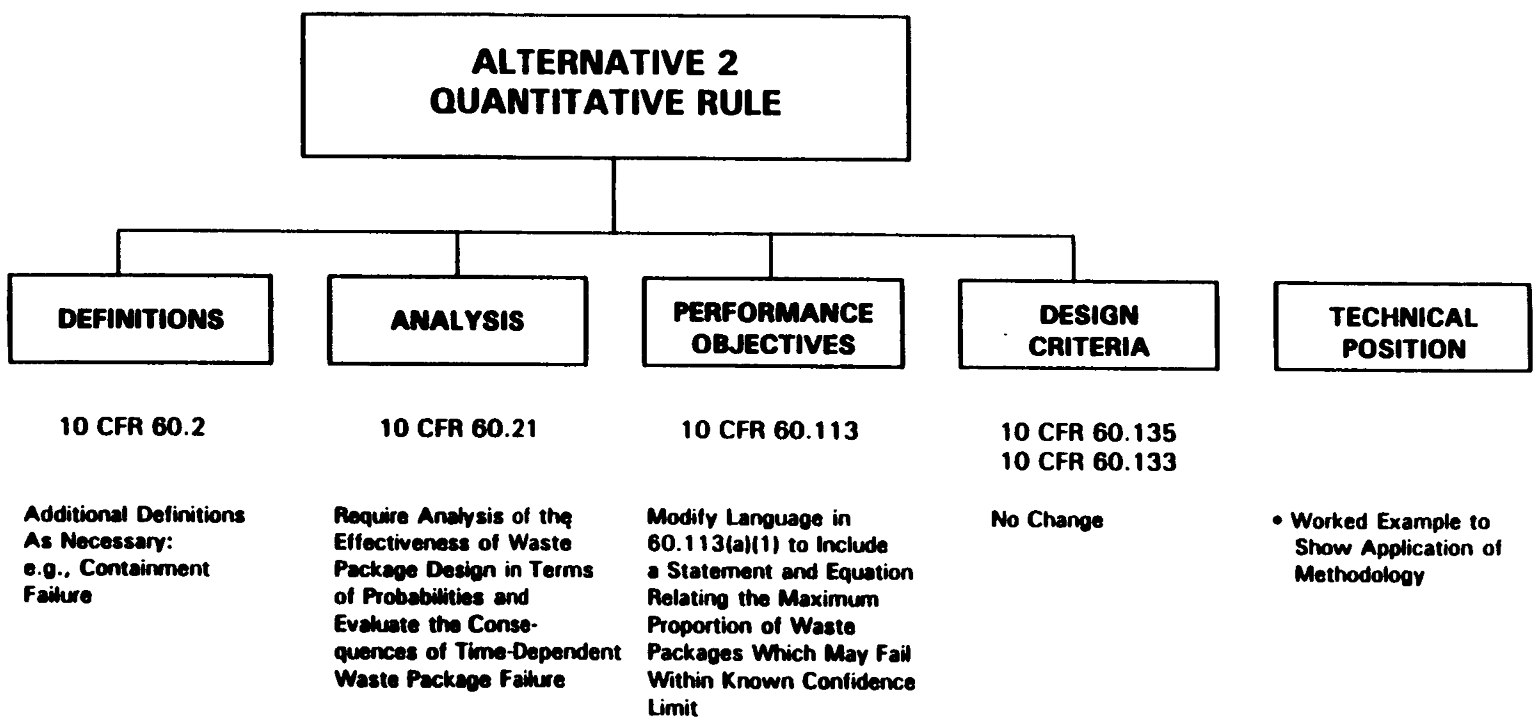

Figure 4. Presentation Alternative 2 - Quantitative Rule

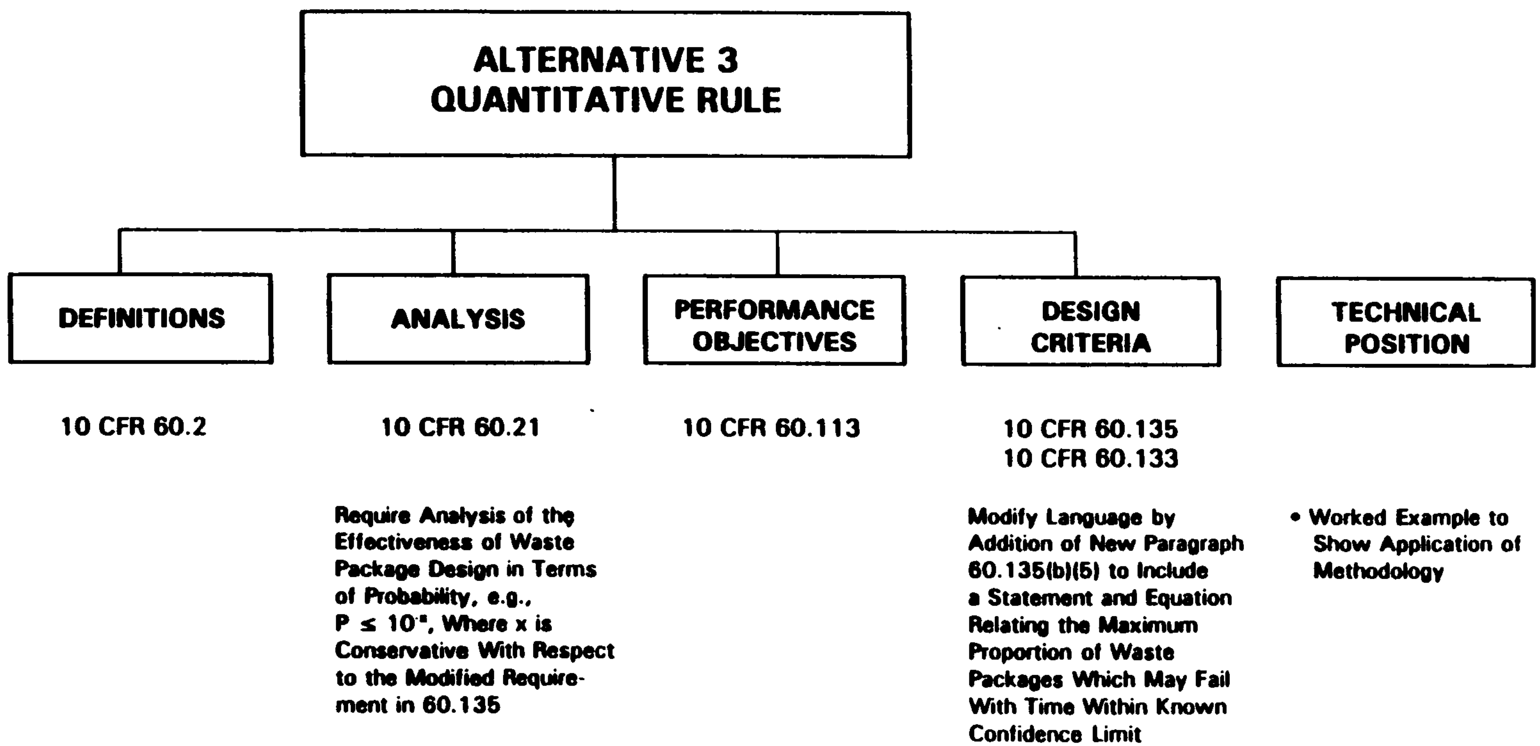

Figure 5. Presentation Alternative 3 - Quantitative Rule

requirement in 10 CFR 60.112, it would have the flexibility to do so. Technological advances and site characterization could, in the future, justify such a Commission decision. The current rule does not allow such flexibility.

In making changes to 10 CFR 60.135 (Alternative 3) a tacit assumption of a performance requirement of zero waste package failures during containment is made and the focus in the quantitative language in 10 CFR 60.135 would be to ensure less than one failure with a high level of confidence. Changes and additions to the definitions in 10 CFR 60.2 and clarification of analyses needs in 10 CFR 60.21 would be required. In either of the two quantitative alternatives, the implication will be to design a robust waste package, such that the containment of radionuclides during the containment period can be attained at a prescribed level of confidence. For both the quantitative alternatives, Technical Position reports would be prepared with an example to clearly show how the methodology is intended to be applied.

Advantage of a Quantitative Rule

The quantitative rule has the following advantages:

- With the probabilistic approach in the rule, there is less risk that DOE will adopt a different approach which they feel is appropriate but which may be unacceptable to NRC.

Disadvantages of a Quantitative Rule

A quantitative rule has the following disadvantages:

- Greatest change in rule probably means greatest expenditure of resources/effort and time to implement it.

- Reduces freedom of license applicant in choice of how to comply with the requirement.

- May reduce flexibility to adopt options available in the future.

A comparison between the two quantitative Alternatives 2 and 3 is outlined below.

Advantages of Alternative 2

- There may be a distinct advantage of putting the specific probability language in 60.113, which is under the heading of "Performance of Particular Barriers after Permanent Closure" (instead of 10 CFR 60.135, which is located in the section of 10 CFR Part 60 entitled Design "Criteria for the Waste Package and Its Components"). While both passages carry the force of law, the Performance Objectives have been considered by some to be overriding in any case of apparent conflict or inconsistency with Design Criteria. With the language located in 60.135, it might be viewed by DOE only as a design requirement and not as a performance requirement.

Advantages of Alternative 3

- The containment provision, since it deals specifically with the waste package, would logically seem more appropriately located in a section dealing more specifically with the waste package. By this logic, it would appear to be more appropriate to locate a quantitative rule for containment under Design Criteria (10 CFR 60.135) than under Performance Objectives (10 CFR 60.113).

4.3.4 Regulatory Guidance - Alternative 4

For the case in which regulatory guidance is chosen as the presentation option, no probabilistic or quantitative language would be introduced in 10 CFR Part 60. Options to consider if regulatory guidance is chosen as the method of presentation include changes or additions to certain definitions (such as containment failure) and providing a worked example along with a discussion of preferred methodology in a comprehensive guidance document (see Figure 6). The guidance document in this case would capture the development of a quantifiable methodology along the lines described in the other alternatives.

Advantages of the Regulatory Guidance Alternative

Use of regulatory guidance as the vehicle to present a quantitative containment criterion has the following advantages:

- Since a rulemaking would not be undertaken, this alternative requires minimal resources (effort, time, expenditures) to implement.
- No new regulatory uncertainties are introduced.
- Guidance to applicant is consolidated into a single reference.
- The applicant retains maximum freedom of how compliance with containment requirements is to be demonstrated, with maximum flexibility for choosing any future options.

The regulatory guidance alternative has the following disadvantages:

- Since regulatory guidance does not have the same force of law as a regulation in 10 CFR Part 60, greater resources may be spent by NRC to determine compliance if DOE chooses an alternative different than that presented in the regulatory guidance.
- Does least to reduce regulatory uncertainty and thus retains possibility of litigation.
- May not allow early consensus of technical community on approach.
- May not meet three-year time period for decision on construction authorization, if appropriateness of methods not adjudicated previously.

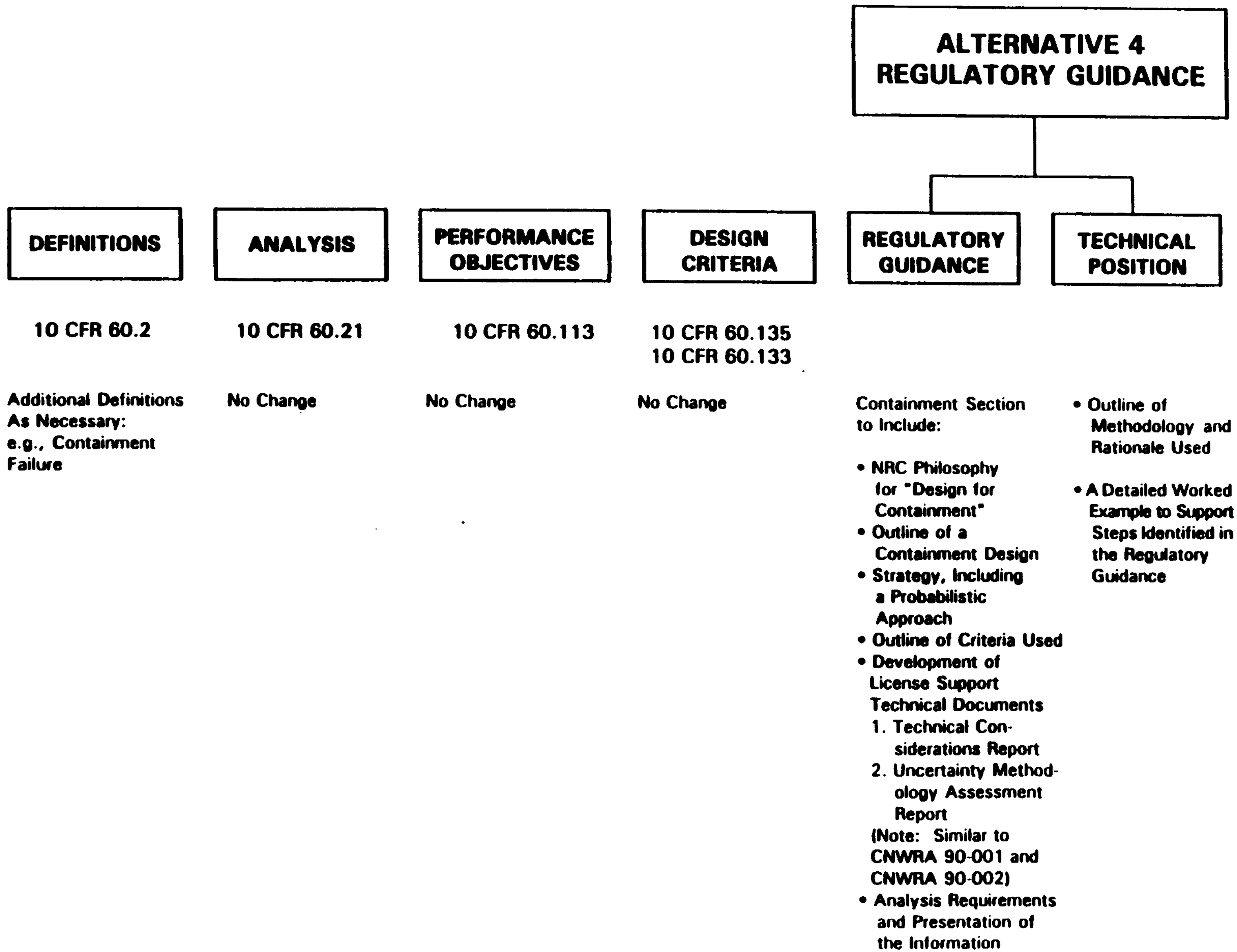

Figure 6. Presentation Alternative 4 - Regulatory Guidance

- The applicant's presentation of data substantiating compliance with containment requirements may not include all information pertinent to make a licensing decision (such as exposition of confidence limits on predictions, etc.).

5. CONCLUSIONS

As a result of the feasibility assessment, two general conclusions can be made.

1. For all the technical data and information developed and analyses performed along the lines described in Reference 8, and using methodologies similar to those identified in Reference 9, a quantitative approach based on probabilistic methods is a viable strategy toward the demonstration of compliance with the requirement for "substantially complete containment."

2. For the exposition of a quantitative criterion in a regulatory context, there are several alternatives available to the NRC. These are, in general, captured in four alternatives presented in this report.

Aspects related to the first of the conclusions above have been discussed at length in Section 3 of this report.

Decisions made by the NRC concerning the detail of how to present a quantitative criterion will depend on the disposition of various attributes associated with the alternatives. There are a number of attributes that would be important to consider. A different combination of desirable attributes can be associated with each of the Alternatives 1 through 4. The choice of a particular alternative will depend on the selection of the pertinent attributes with a logical prioritization process and the implementation of a structured decision methodology by the NRC staff. Preliminary guidelines for the conduct of a prioritization and decision analysis are described in References 12 and 13. It is recommended that a streamlined procedure be adopted for assisting the NRC staff for evaluating the alternatives in a formal and systematic manner.

The two technical reports [Refs. 5 and 6] suggest that strong technical bases can be developed to establish numerical criteria for containment. The second report also provides an example which shows how a framework for a quantitative probability-based criterion can be developed, taking the uncertainties into account.

In this report, the assumptions and rationale for the containment requirement and potential regulatory uncertainty reduction methods are identified and discussed. As part of the approach, the intent of the original containment rule, as discussed in NUREG-0804, remains unchanged. Implementability of the alternatives is also considered a factor. It is important to recognize at the outset that in dealing with time frames of several hundreds to thousands of years, uncertainties will continue to exist. These uncertainties will have to be addressed when the question of reasonable assurance is considered. As part of the determination of reasonable assurance, a technically sound framework for the presentation and the evaluation of all the technical information generated for demonstrating containment at any given time will be required.

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APPENDIX A

Containment in Context of Three Repository Types

To evaluate how a containment barrier performs, it is important to have a concept of the physical nature of the barrier. This is best done by evaluating the types of geologic repository sites and their unique characteristics relating to the containment issue. For the purposes of this discussion the geologic repositories will be classified according to the propensity for radionuclide transport under steady-state undisturbed conditions. To further simplify the discussion only solid waste releases will be considered. Any unacceptable gaseous releases may require leak tight barriers.

Consider three types of repository sites, each described by its saturation conditions. It is important to keep in mind that the containment rule must be generic, and it must, therefore, apply in any case.

Case 1 - Dry Repository

In this case, the undisturbed condition of the geologic repository site for a period far beyond the containment period is expected to remain dry. Here the movement of groundwater is not reasonably likely to occur such that the radionuclide transport by hydrologic conditions is not considered important to the high-level nuclear waste disposal program. Under such circumstances the containment and isolation function for nongaseous radionuclides could be carried out by a conditioned wasteform without other engineered barriers. The primary function of the geologic repository becomes one of shielding and protection against disruptive events such as tectonics, volcanism, and human intrusion.

The ability to meet the performance objectives without having a physical barrier over and beyond the wasteform by itself to support a containment requirement would be supported by satisfying the following three conditions.

a. No unacceptable gaseous releases are predicted.

b. Groundwater saturation levels are such that hydrologic transport is not a predicted mechanism for the entire waste isolation period.

c. The associated uncertainties with respect to conditions a and b above are small and sufficiently well understood to support a finding of "reasonable assurance."

Case 2 - Saturated Repository

The geologic repository is assumed to be saturated and the hydrologic transport of radionuclides can be expected. It is reasonable in this case to assume the need for having a physical barrier over and beyond the wasteform to provide the major containment function of the waste package. Groundwater is prevented from contacting the radionuclide inventory by the physical barrier during the thermally dominated period in the repository performance life.

Case 3 - Unsaturated Repository

The repository is unsaturated and hydrologic transport is deemed to be a mode of radionuclide transport during the repository performance period. During the early postclosure period, the heat input to the repository system is such that the near-field thermohydrologic conditions are complicated and the uncertainty for adequately modeling this behavior is significant. Two important considerations affecting the containment requirement for this case are (a) definition of the near-field hydrogeologic environment, and (b) the concept of multiple barriers to compensate for inherent uncertainties.

It is important to note that in an unsaturated medium there is an expectation for the rock in the vicinity of the waste packages to remain dry during the period the wasteform temperatures remain above the boiling point of water. This assumes heating of all the distributed waste packages in the repository horizon. Also, a simplified heat transfer model for the site is assumed. These assumptions have been shown to be incorrect in many instances. They also have the effect of erring on the nonconservative side of ensuring adequate waste isolation in a repository. Therefore, in designing for containment under unsaturated conditions, a physical barrier over and beyond the wasteform barrier should be considered for providing the major part of the minimum containment requirement. The possibility that the repository may be dry during the containment period should be treated as a favorable condition when unanticipated conditions are evaluated.

APPENDIX B

Example Texts for Various SCC Presentation Alternatives

Several presentation alternatives for the implementation of more quantifiable criteria for reduction of the uncertainty related to "substantially complete containment" were presented in Section 4. Language which might be used to replace or supplement that already in relevant sections of 10 CFR Part 60 [Ref. 11] is given below. Variations in language reflect variations which are possible. By considering different ways in which a concept may be presented, appropriate language for a new rule can more readily be chosen.

B.1 Definitions

Regardless of whether the approach taken is quantitative or qualitative, the following example definition would appropriately be added to those existing in 10 CFR 60.2.

> "10 CFR 60.2 -- Definitions
>
> "Containment Failure" of an engineered barrier means that the containment barrier predicted to remain at the end of the period of interest has been reduced in its capacity to contain radionuclides to less than 1/10 of its original capacity (e.g., wall thickness for a container, unpenetrated thickness for a permeable boundary, etc.), although no radionuclides have been released."

This definition adds defense-in-depth to ensure containment. It also accounts for model uncertainties which typically become large toward the last part of the containment barrier life. There are two reasons why model uncertainties become large toward the last part of the containment barrier life: 1) extrapolation of short-term data for such long-term predictions becomes increasingly uncertain, and 2) the behavior of the failure mechanism near the end of barrier life becomes increasingly uncertain. Insight on the intent of containment failure may be found in the following excerpt from NUREG-0804 [Ref. 7], p. 471:

> "One means by which waste-groundwater contact can be limited is by containment. In this context, containment means confining the wastes within a sealed boundary, such as a metal or ceramic container or canister, to protect the waste form from groundwater and to delay the onset of leaching and migration until the containment boundary is breached. Such a container can protect the waste form from water during the period when radiation and temperatures are high and release rate predictions are difficult."

B.2 Qualitative Rule (Alternative 1)

Language for such a rule is as follows as it would appear in context with existing text from 60.113. Revised or additional language is underlined, while text which would be deleted is shown with a horizontal strikeover (e.g., ~~and~~).

"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 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 analysed 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 packages will be substantially complete for a period to be determined by the Commission taking into account the factors specified in 10 CFR 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. To satisfy this requirement, the failure of the containment barrier should be predicted, taking into account *(1)* waste package degradation factors such as environment, materials, materials/environment interactions, specifications and inspections, and service life predictions; *(2)* internal degradation factors; *(3)* the need to maintain minimal mechanical strength to withstand expected external loads; and *(4)* technical uncertainties."

In support of modified language in 10 CFR Part 60 [Ref. 11] concerning a qualitative approach to "substantially complete containment," a change in the language of 10 CFR 60.21(c)(1)(ii)(D) should be considered (added text underlined):

Change to 10 CFR 60.21:

"LICENSE APPLICATIONS
"10 CFR 60.21 Content of Application
"10 CFR 60.21(c) The Safety Analysis Report shall include:

"(1) A description and assessment of the site at which the proposed geologic repository operations area is to be located . . .

"(ii) The assessment shall contain:

"(D) The effectiveness of the engineered and natural barriers, including barriers that may not be themselves a part of the geologic repository operations area, against the release of radioactive material to the environment. The effectiveness of the waste package at the end of the containment period shall be analyzed, taking into account the containment barrier degradation factors listed in 10 CFR 60.113(a)(1)(ii)(A). 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."

It is expected that a Technical Position Report would be required for the applicant to clearly understand the technical details of conforming with such a qualitative rule. It is in the Technical Position Report that the quantitative aspects would be discussed in detail.

B.3 Quantitative Rule (Alternatives 2 and 3)

The definition of containment failure, as described above for a qualitative rule, would also appropriately be added for any quantitative rule. In support of modified language in 10 CFR Part 60 [Ref. 11] concerning a quantitative approach to "substantially complete containment," a change in the language of 10 CFR 60.21(c)(1)(ii)(D) should be considered (added text underlined):

Change to 10 CFR 60.21:

"LICENSE APPLICATIONS
"10 CFR 60.21 Content of Application
"10 CFR 60.21(c) The Safety Analysis Report shall include:

"(1) A description and assessment of the site at which the proposed geologic repository operations area is to be located . . .

"(ii) The assessment shall contain:

"(D) The effectiveness of the engineered and natural barriers, including barriers that may not be themselves a part of the geologic repository operations area, against the release of radioactive material to the environment. <u>The effectiveness of the waste package at the end of the containment period shall be analyzed, taking into account the containment barrier degradation factors listed in 10 CFR 60.113(a)(1)(ii)(A). The reliability of this prediction shall be expressed in quantitative form.</u> 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."

B.3.1 Alternative 2 -- Quantitative Text in 60.113

"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 thermal conditions in the engineered barrier system are dominated by fission product decay; <u>and the probability that the proportion K of waste packages failing during the period $(0,T_o)$ does not exceed K_o should be greater than r_o</u>.

<u>Probability $\{K \leq K_o\} > r_o$, where</u>

<u>K_o is the maximum allowable proportion of waste packages failing in time T_o, to be determined by the Commission;</u>
<u>r_o is the minimum acceptable probability that $K \leq K_o$, to be determined by the Commission; and</u>

T_c is the containment period, chosen by the Commission; 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 analysed 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 packages will be substantially complete for a period to be determined by the Commission taking into account the factors specified in 10 CFR 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. To satisfy this requirement, the containment barrier predicted to remain in the waste package at the end of the containment period shall be analyzed and presented in probabilistic terms, taking into account (*1*) waste package degradation factors such as environment, materials, materials/environment interactions, specifications and inspections, and service life predictions; (*2*) internal degradation factors; (*3*) the need to maintain minimal mechanical strength to withstand expected external loads; and (*4*) technical uncertainties; and

"(B) The release rate etc."

B.3.2 Alternative 3 -- Quantitative Text in 60.135(b)(5)

Following is an example of revised regulation language as it might appear in context with other text from 60.113 and 60.135. Revised or additional language is underlined, while text which has been deleted is shown with a horizontal strikeover (e.g., ~~and~~).

Quantitative Text -- Alternative 3:

"60.113 Performance of particular barriers after permanent closure.

(No change.)

The following new language complements existing 60.113(a)(1)(ii) for Quantitative Alternative 3:

"DESIGN CRITERIA FOR THE WASTE PACKAGE

"10 CFR 60.135 Criteria for the waste package and its components.

"(b) Specific criteria for HLW package design

"(5) To satisfy the containment requirement in 10 CFR 60.113(a)(1)(ii)(A),

"(i) the containment barrier predicted to remain in the waste package at the end of the containment period shall be analyzed and presented in probabilistic terms, taking into account (A) waste package degradation factors such as environment, materials, materials/environment interactions, specifications and inspections, and service life predictions; (B) internal degradation factors; (C) the need to maintain minimal mechanical strength to withstand expected external loads; and (D) technical uncertainties; and "(ii) The containment barrier shall be designed so that assuming anticipated processes and events, the probability that the proportion K of waste packages failing during the period $(0,T_o)$ does not exceed K_o should be greater than r_o.

Probability $\{K \leq K_o\} > r_o$, where

K_o is the maximum allowable proportion of waste packages failing in time T_o, to be determined by the Commission;
r_o is the minimum acceptable probability that $K \leq K_o$, to be determined by the Commission;
and T_o is the containment period, chosen by the Commission."