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YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

WASTE PACKAGE IMPLEMENTATION PLAN

REVISION 0

FEBRUARY 1993

Prepared for

U.S. Department of Energy
Office of Civilian Radioactive Waste Management

Prepared for the Yucca Mountain Site Characterization Project as part of the Civilian Radioactive Waste Management Program. The Yucca Mountain Site Characterization Project is managed by the Yucca Mountain Site Characterization Project Office of the U.S. Department of Energy. The Yucca Mountain Site Characterization Project work is sponsored by the U.S. Department of Energy Office of Civilian Radioactive Waste Management.

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1.0 INTRODUCTION

1.1 PURPOSE

The purpose of this document is to provide a detailed waste package materials and component testing, modeling, and design implementation plan that supports the Yucca Mountain Site Characterization Project Office (YMPO) Waste Package Plan (WPP) (DOE, 1990a).* The strategy for the implementation of these activities is to use an interactive and iterative approach with performance assessment to determine whether the design meets the requirements with sufficient margin. Thus, the plan provides the bases for the design and performance assessment (PA) of the waste package (WP) and the requirements for the engineered barrier system (EBS) that will demonstrate that they meet or exceed the regulatory requirements. The principal regulatory requirements are the technical requirements for repository operation of the Nuclear Regulatory Commission as given in Title 10 of the Code of Federal Regulations (CFR), Part 60 (NRC) and the environmental standards of the Environmental Protection Agency (EPA) that limit offsite releases as given in 40 CFR 191 (EPA). [40 CFR 191 has been remanded. The repromulgation will include input from the National Academy of Sciences as mandated by the Comprehensive National Energy Policy Act of 1992.]

This plan is a YMPO-controlled document, and changes to it shall be controlled in accordance with applicable YMPO procedures. The plan will be revised as necessary to reflect changes in upper-tier documents from the YMPO, including the WPP, and from the Office of Civilian Radioactive Waste Management, and to reflect requirements of the Engineered Barrier System Design Requirements Document when it is issued. The plan also interfaces with other Yucca Mountain Site Characterization Project (YMP) documents. (These relationships are discussed in Section 2.7.) The plan covers the period of time up to the submission of a repository license application to the Nuclear Regulatory Commission (NRC).

1.2 WASTE PACKAGE/ENGINEERED BARRIER SYSTEM DEFINITIONS

The definitions for the WP and the EBS are taken directly from 10 CFR 60.2. The WP is defined to include "the waste form, and any containers, shielding, packing and other absorbent materials immediately surrounding an individual waste container." The EBS "means the WP and the underground facility" where the underground facility is defined as "the underground structure, including openings and backfill materials, but excluding shafts, boreholes, and their seals."

*References are provided in Appendix A

1.3 OVERVIEW

The WP will be designed as a multi-barrier system that meets the regulatory requirements of 10 CFR 60 and 40 CFR 191 with sufficient margin, using a systems engineering approach. The development of a WP design and the associated performance assessment of the WP/EBS that meets the regulatory and other design requirements will be accomplished by following the process steps shown in the strategy implementation process chart (Figure 1-1). This process will be followed for all designs.

The process begins with the development of the design basis, which consists of inputs from many technical and non-technical areas. This is described in further detail in Section 2. It includes the definition of environmental scenarios and the definition of the performance functions, measures, and parameters for each WP/EBS barrier. The process will permit the design of one or more options of the WP/EBS. This resultant first cut of the design provides the basis for setting performance measure and performance parameter goals needed to refine the first cuts of allocated performance. This in turn defines the test data and models needed to perform an assessment of performance of the WP and EBS. As shown in Figure 1, the process is interactive and iterative, and is repeated until at least one reference and one alternative design are developed that will meet or exceed the regulatory requirements. The final development of the License Application Design (LAD) permits license application to proceed.

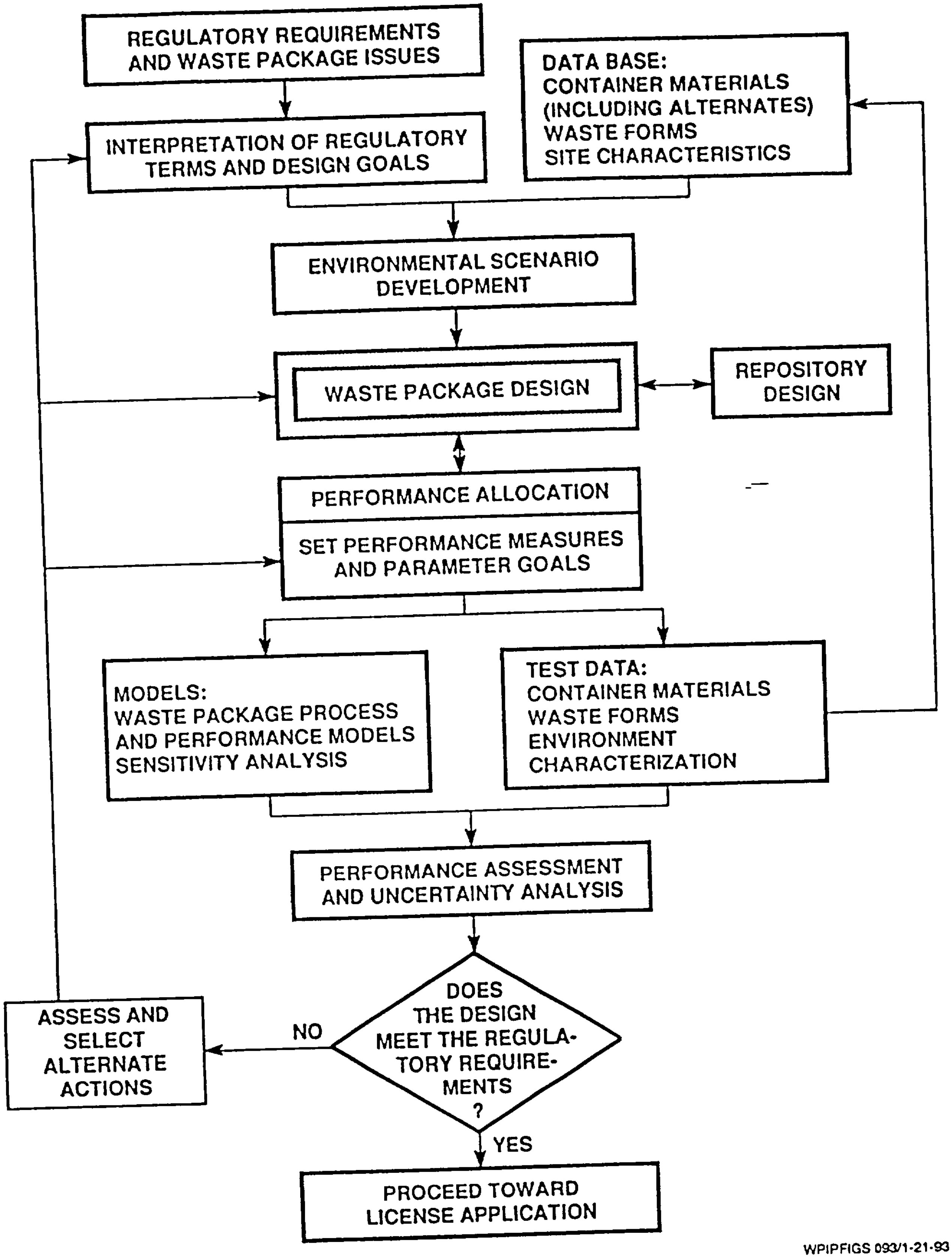

Figure 1-1 Strategy Implementation Process Chart

2.0 WASTE PACKAGE DESIGN DEVELOPMENT BASIS

2.1 INTRODUCTION

The basis for the development of the WP design involves many elements. These include the regulatory requirements, design goals, environmental scenarios, interfaces with other engineered features and the natural barriers, waste form properties, containment barrier properties, and programmatic inputs. These are detailed in the sections below. Note, however, that the major requirements will be covered in the Engineered Barrier Design Requirements Document.

2.2 REGULATORY REQUIREMENTS

The design of the WP and specifications for the EBS will be impacted by regulatory requirements that apply to both the pre-closure and post-closure periods. The regulations that the design must meet include, but are not limited to, the following regulations and applicable sections:

REGULATIONS	APPLICABLE SECTION	
	Preclosure	Post-closure
10 CFR 20	20.101-20.108	N/A
10 CFR 60	60.135 (b),(c), 60.131 (b)(7), 60.137 and Subpart F and 60.111	60.113, 60.135(a), 60.112, and 60.21(c)
10 CFR 960	960 5-1(2), 3 and Appendix II	960.5-1 Appendix I
40 CFR 191	N/A	191.13

The pre-closure requirements taken from the above references are detailed below:

1. Handling--A. The WP must remain intact as a unit, which contains the waste and provides for safe handling of the waste, at least until the end of the period of retrievability. B. The WP must be capable of sustaining normal handling and packaging operational loads without loss of containment, and design bases accidents either without loss of containment or with a limited release of radionuclides as required in 10 CFR 20.

2. Criticality control--The internal waste distribution in waste emplacement packages shall be such that nuclear criticality shall not be possible unless at least two unlikely, independent, and concurrent or sequential changes have occurred in the conditions essential to nuclear criticality safety. The calculated effective multiplication factor k_{eff} must be sufficiently below unity to show at least a 5 percent margin after allowance for the bias in the method of calculation and the uncertainty in the experiments used to validate the method of calculation (10 CFR 60.131).

3. Unique identification--Provide a label or other means of identification for each waste emplacement package. The identification shall not impair the integrity of the waste emplacement 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 emplacement package identification shall be consistent with the waste emplacement package's permanent written records (10 CFR 60.135 (b) (4)).

4. Explosive, pyrophoric, and chemically reactive materials--The waste emplacement package shall not consist of explosive, pyrophoric, or chemically 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 (10 CFR 60.135(b)(1)).

5. Free liquids--The waste emplacement package shall not contain free liquids in an amount that could compromise the ability of the WPs to achieve the performance objectives relating to containment of high-level waste (HLW) (because of chemical interaction or formation of pressurized vapor) or result in spillage and spread of contamination in the event of WP perforation during the period through permanent closure (10 CFR 60 135(b) (2)).

6. The encapsulating or stabilizing matrix associated with spent fuel or used with reprocessed waste shall be designed to limit the availability and generation of particulates in case of an accident occurring during preclosure (10 CFR 60.135(c)(1) and (2)).

7. The repository (and therefore the WPs emplaced therein) shall be demonstrated to be technically feasible on the basis of reasonably available technology and that the associated costs be reasonable (10 CFR 960.5-1(a)(3)).

8. The repository (and therefore the WPs) must be designed to preserve the option of waste retrieval throughout the period during which wastes are being emplaced (10 CFR 60.111(b)(1)).

9. The repository (and therefore the WPs) must be designed to permit implementation of a performance confirmation program (10 CFR 60.137 and Subpart F).

The primary post-closure regulatory requirements are from 10 CFR 60, particularly the engineered barrier performance objectives in 60.113. This section mandates two specific performance objectives for the WP and EBS after the closure period of the repository and divides the post-closure period into two time periods, conventionally referred to as the "containment" and "controlled-release" periods. Containment "within the waste packages will be substantially complete for a period to be determined by the Commission...not less than 300 nor more than 1,000 years after permanent closure of the geologic repository." The controlled-release requirement applies to the EBS, which includes the WPs. The release from the EBS "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."

These two requirements have been addressed, as Issues 1.4 and 1.5, respectively, of an issues hierarchy that has been detailed in the Site Characterization Plan (SCP) (DOE, 1988). These issues address the question of whether the two performance objectives have been met.

The overall system performance objective in 10 CFR 60.112 relates to limits on the releases of radioactive materials to the accessible environment following permanent closure as established by the EPA in 40 CFR 191. Other requirements from 10 CFR 60 also need to be addressed. These include 60 21(c)(1)(ii)(D) on comparative evaluation of alternative designs that would provide longer radionuclide containment and isolation, and 10 CFR 60.137 and 10 CFR 60 Subpart F on performance confirmation data that could impact the long-term prediction of WP/EBS performance.

2.3 INTERPRETATION OF REGULATORY TERMS

Several terms included in the NRC performance regulations are only defined in qualitative terms. These include the "engineered barrier system," "substantially complete containment," "anticipated processes and events," and the "release rate...from the engineered barrier system." The U.S. Department of Energy (DOE) has developed interpretations of these terms which are given in the SCP. Brief versions are given below.

In regard to the EBS, the DOE has assumed that the exclusion of "boreholes" from the underground structure does not apply to emplacement boreholes for WPs, if used. In addition, the DOE has assumed that the boundary of the EBS coincides with the surfaces of the excavations within the underground facility, consistent with the current NRC position, for the purposes of evaluating radionuclide release rates. However, it is recognized that rock properties may be modified as a result of the engineered system and that these properties affect the long-term performance of the WPs as well as the eventual rate of transport of radionuclides into and through the rock, regardless of where the boundary is drawn. Thus, a reassessment of the inclusion of a portion of the host rock within the EBS boundary may be required as the design of the EBS matures.

The DOE understands "substantially complete containment" to mean that the set of waste packages will fully contain the total radionuclide inventory for a period of 300 to 1,000 years following permanent closure, allowing for recognized technological limitations. For design purposes, the DOE has chosen this period to be 1,000 years. However, robust designs may permit containment of radionuclides for much longer periods. Recently, the NRC has recognized, in a staff position paper (SP-60-001) (NRC, 1990), that the DOE can take credit for containment beyond the 1,000 year period.

For "anticipated processes and events," the DOE assumes that they are those naturally occurring processes and events that have a probability equal to or greater than 0.1 of occurring during the period when the intended performance requirement must be achieved. Inadvertent human intrusion is specifically excluded from this category. One hypothesized event was the upwelling of ground water that would cause the repository to become saturated for a prolonged period of time. While this is now considered an unanticipated event, the design of the WP and EBS will consider intermittent flooding scenarios. This is further discussed in Section 2.6.

The requirement for controlled release from the EBS in 10 CFR 60.113 states that the release rate of any radionuclide shall not exceed one part in 100,000 per year of its 1000-year post-closure inventory "....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." The DOE interprets this to mean that radionuclides are to be regulated if they are released at greater than one part in 100 million per year of the 1,000 year inventory. Radionuclides that are released at less than one part in 100 million are not subject to the regulation. The entire inventory of such radionuclides could be released in any year. These radionuclides primarily decay rapidly such that they exist only in insignificant amounts by 1,000 years post-closure.

2.4 DESIGN GOALS

Along with the above federal requirements, there will be system and design goals imposed on the WP/EBS design. These goals will be generated during Advanced Conceptual Design (ACD). These include design limits on performance, material behavior, and basic engineering parameters, for instance:

- Centerline fuel pin temperature limit of (to be determined (TBD)) °C
- Rock wall temperature limit of (TBD) °C
- Thermal loading of the repository (TBD)
- Reliability (TBD)
  - Design
  - Fabrication
- WP/EBS surface radionuclide dose (TBD)
- WP Weight

The maximum temperature of the glass waste forms must be maintained below limits established for them. This limit is about 500°C for West Valley and Defense High-Level Waste glass. The YMP and the glass producers have the responsibility to maintain the peak temperature below the transition temperature.

The period of substantially complete containment within the WPs has been chosen to be 1,000 years; however, in order to meet this requirement with sufficient margin of uncertainty, the design goal is to provide a mean WP lifetime well beyond 1,000 years. Other design goals for the WP are listed in Table 2-1. The design goals for the EBS include rock temperature limits, drift temperature limits, package spacing requirements, and water flow limits.

2.5 DATA BASE INFORMATION

The data base information needed for design includes an understanding of waste form materials, container materials, and the WP environment. This type of information has been collected since the inception of the YMP and is not yet complete. The waste form data have been collected into the Waste Form Characteristics Report [4], while the container material data have been largely collected in the Survey of Degradation Modes of Candidate Materials

Table 2-1 Listing of Design Goals*

- Provide adequate margin above regulatory requirements
- Assure sufficient environmental tolerance+
- Assure performance assessment capability
- Meet temperature limits for components
- Provide for a range of thermal loads+
- Provide capability to adjust repository thermal loading after emplacement+
- Assure safety of repository operations
- Permit safe and efficient WP handling
- Assure that worker dose is As Low As Reasonably Achievable
- Permit retrievability of WPs
- Utilize proven, reliable technology
- Meet corrosion limits
- Provide microstructural stability
- Provide structural rigidity
- Assure subcriticality
- Assure reasonable cost+, including:
  - Total number of packages to be emplaced
  - Number of times each package is handled
  - Cost of manufacturing, loading, sealing, transporting, and emplacing WPs

*The source of the design goals is, for the most part, the Engineered Barrier Design Requirements Document (EBDRD) (DOE, 1993).

+The source of these design goals is engineering judgement.

for High-Level Radioactive Waste Disposal Containers [5,6]. The information on the WP environment has been collected into the Near-Field Environment Report [7]. As shown in Figure 1-1, this information will be updated as new information becomes available from the experimental programs.

2.6 ENVIRONMENTAL SCENARIO DEVELOPMENT

The WPs emplaced within boreholes or drifts will be affected by the atmosphere surrounding them, the water that potentially could come in contact with them, and the movement of rock that could potentially impact upon them. During emplacement and early in the post-closure period, the atmosphere surrounding the WPs is expected to be hot humid air, well below saturation. The host rock surrounding the WPs will dry out and water vapor will be driven out spatially to locations where the temperature is cool enough to permit condensation. As the repository rock cools below the boiling point of water, moisture may be able to condense within the near field. The amount of water that could return to the emplacement openings will be a function of the thermal loading of the repository, the thermal profile around the WPs as a function of time, the imbibition into the rock matrix, and the active, available flow paths. Higher thermal loadings will increase the duration of dryout and increase the time required for water to return to the emplacement openings. Thus, this is a function of WP/EBS design. The water entering the emplacement openings could potentially contact the WPs. This contact will be a function, once again, of the design of the WP/EBS in that the emplacement openings may be backfilled (e.g., tuff and/or clays) to retard the contact of the water with the WPs or to drain the water away from them. If water does contact the WPs, it could occur by the wet-drip or moist continuous scenarios. The EBS design will be influenced by the scenario's possibilities. Lastly, it has been suggested that the repository could be flooded by either the upwelling of water or via a series of surface storms. The former event is deemed to be unlikely; the latter event is considered to be possible, but not long lasting. Hence, the repository horizon may see water via fracture flow for brief episodic periods. However, the repository and EBS design could preclude such waters from entering emplacement locations.

The source of the water contacting the WPs will influence the chemistry of the water. Water that has evaporated and recondensed may be diluted or concentrated upon its return through the fractured rock. Water that is retarded in its path to the WPs by the tuff backfill may equilibrate with the backfill. Water that enters the emplacement openings as a result of an episodic surface rainfall may either be relatively pure or be modified by its travels through the tuff rock and the backfill.

Rock movement may impart thermal and mechanical loads to the emplaced WPs, particularly during the early post-closure period when the rock temperature is increasing. The rock load could be a result of rock expansion and rock fall or by rock instability caused by a phase transformation in the rock. The transformation of the mineral cristobalite, from the alpha to beta structure at about 225°C, causes a volume expansion. Drift-emplaced waste packages have a greater exposure to rock fall even though the rock is likely to be cooler and go through a slower thermal cycle. However, the wall thickness for drift-emplaced WPs is expected to be much thicker than the reference design so that the impact of rock fall itself is reduced. In addition, drift-emplaced packages can be inspected during the preclosure period and steps can be taken to mitigate further rock fall prior to backfilling.

2.7 OTHER INPUTS TO THE DESIGN DEVELOPMENT BASIS

As shown in Figure 1-1, repository design is an important input into the design of the WP, and surface and subsurface facility design decisions must be interfaced closely with WP design decisions. These include the repository surface facility limitations and devices required for the emplacement operation. The decision on emplacement mode and the separation or commingling of spent fuel and HLW glass packages will be made by the YMPO upon the recommendation of the Mined Geologic Disposal System (MGDS) Development team consisting of the WP/EBS and the repository subsurface design teams.

This document also derives input from the programmatic documents shown in the document hierarchy, Figure 2-1. Relationships with the technical requirements documents are also shown. The WPP sets the tone for the project activities as well as providing the overall strategy for WP design development. The Performance Assessment Management Plan (DOE, 1990b) provides the linkage to the PA activities needed to support the licensing process. The SCP and the Waste Package Design (Basis for Site Characterization Plan Chapter 8) (DOE, 1991) provides details of the technical needs and the originally baselined WP conceptual design. The EBDRD and the other functional design requirements documents (Waste Acceptance, Transportation, MRS, Site, and Repository Design) provide the upper-level system requirements and define the interface requirements.

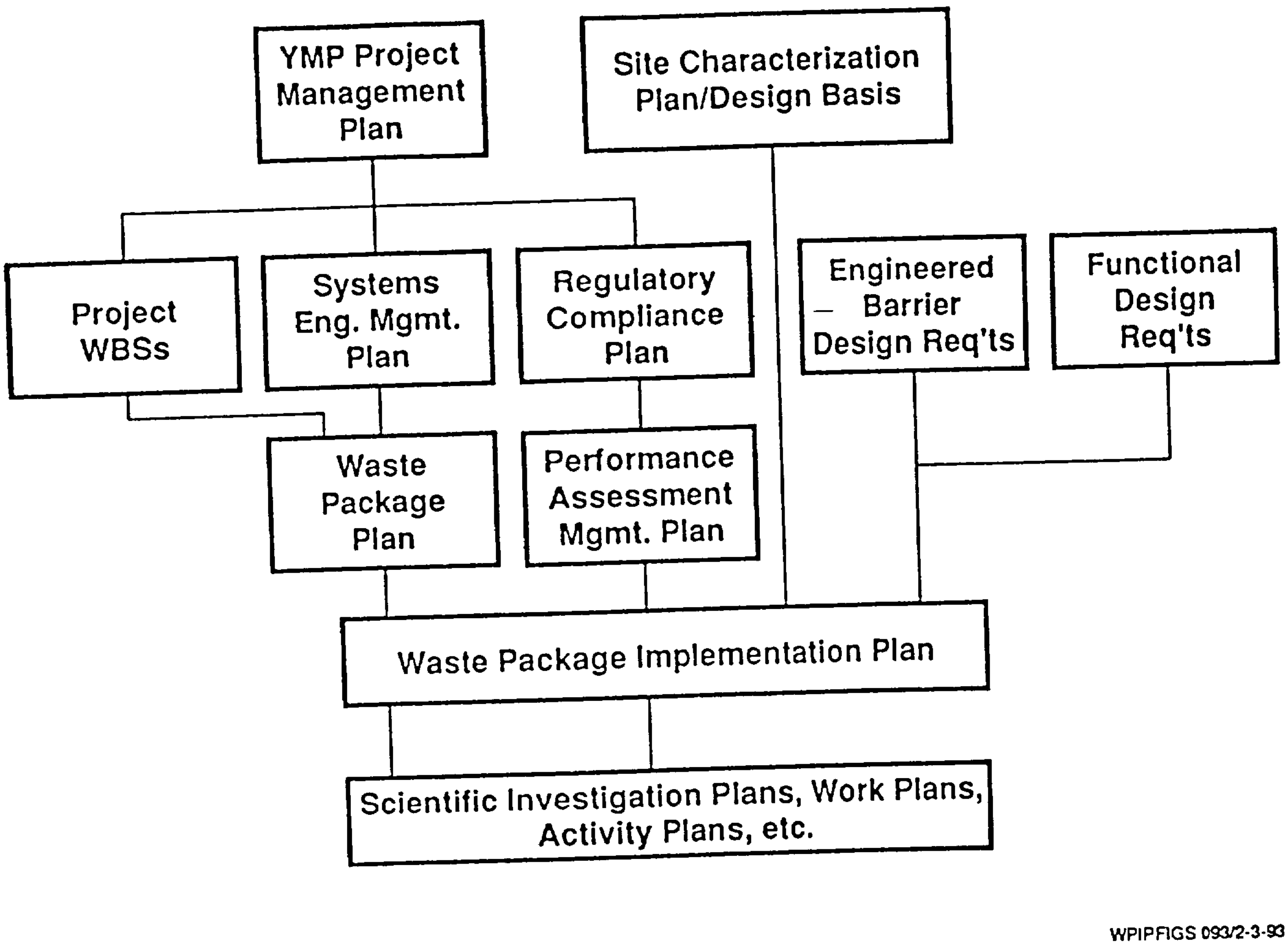

Figure 2-1 Project Document Hierarchy

3.0 REGULATORY COMPLIANCE

3.1 LICENSING GOALS

The principal goal of the development effort is to create a WP/EBS design that will be licensable; i.e., it will meet the regulatory requirements with sufficient margin that the NRC will find that compliance has been achieved with reasonable assurance. The design effort will consider robust, multi-barrier WPs that are tolerant to a range of repository conditions.

Performance will be allocated to each barrier in the system. As shown in Figure 1-1, performance allocation leads to the establishment of performance measure and parameter goals that are re-evaluated as test data and predictive models are developed. The goal of the WP testing program is to develop sufficient understanding of materials and component behavior to guide the design effort, and to provide adequate data to support modeling of the performance parameters, i.e., to provide reliable submodels. The submodels should be deterministic and/or mechanistic to provide confidence in their validity over repository time periods. The submodels provide the basis for the model hierarchy upon which PA is constituted.

3.2 LICENSING APPROACH/ASSUMPTIONS

Regulatory compliance will be demonstrated by means of PA of the WP/EBS design, using mathematical representations of the responses of the WP/EBS to the repository environment. These computational representations of the responses, or models, must be validated to the extent possible.

The approach to licensing recognizes that full model validation is not possible due to the long service life of the WP/EBS. However, the licensing approach will include several activities that support the validation effort. These include: in-situ testing of full or sub-scale prototypes of WP/EBS designs in the Exploratory Studies Facility or another test facility; the evaluation of natural analogues, particularly for corrosion-allowance and ceramic materials; and the use of the American Society for Testing and Materials (ASTM) C1174-91 framework for testing and modeling of material responses. These are described in detail in other sections of this document.

3.3 ENVIRONMENTAL SCENARIOS/CONCEPTUAL MODELS

As noted in Section 3.1, the WP will be designed to be environment tolerant. Thus, variations in temperature, moisture level, and water chemistry will be considered. However, assumptions still need to be made regarding the range of environmental conditions in the repository including the pre-emplacement undisturbed condition, the post-emplacement disturbed condition, and the condition following closure. In addition, the potential modes of water contact with the package for the design concepts being evaluated must be assessed. For most design concepts, the moist-continuous, wet-drip, and steam-air modes must be evaluated. Which of these modes is dominant is dependent on the thermal loading of the repository and the timing and nature of the backfill.

Conceptual design and repository response models will be described to provide a means for preliminary comparison of design concepts and to direct the formulation of the performance parameters and component performance allocations. These conceptual models also serve as an aid in the design of testing programs by identifying key physical and/or chemical processes, thus focussing test methodologies and goals. These conceptual models also feed the development of the mechanistic models/submodels needed for PA.

3.4 PERFORMANCE ALLOCATION

Performance allocation is a tool for developing a design of the WP/EBS which meets applicable performance requirements. Containment and radionuclide release factors are assigned to the materials, components, and barriers of the system. The capability of these elements to meet the allocations will be demonstrated through PA of the system supported by test data obtained in accordance with Scientific Investigation Plans (SIPs).

The SCP lists the system elements as well as the performance measures that have been tentatively established during the containment period (SCP Table 8.3.5.9-1) and the post-containment period (SCP Table 8.3.5.10-2). The performance measures appropriate to the development of the WP/EBS are discussed in Section 4, Technical Approach.

For the containment period, a multibarrier design that is environment tolerant permits the engineered environment restrictions to be relaxed. For example, the quantity and chemical variability of liquid water that is assumed to contact the containers can be expanded, offsetting the performance allocated to the additional barrier. This barrier may be a corrosion-resistant or corrosion-allowance material. Many approaches are being evaluated during the development of the WP/EBS concepts. The concept selected will depend on the range of environmental conditions chosen as a design input. Thermal analyses will be performed to determine the temperature profiles across the drifts for drift emplacement. Thermal analyses will also be refined for the borehole emplacement modes, assuming various package sizes and thermal loadings These analyses will permit the re-evaluation of the goals given in the SCP for performance measures; e.g., the time periods into which the containment period was subdivided. All of the preliminary allocations provided in the SCP will be reviewed. Values will be assigned for each new design concept. These will be confirmed as an interactive result of the scientific investigations, design and PA.

Similarly, the system elements to which performance is allocated during the post-containment period will be reviewed. The performance allocated to the environment and the container will be modified after consideration of the addition of another containment barrier (overpack) and the possible addition of backfill materials, particularly for drift-emplaced WPs. Filler materials, which have not yet been considered in the design of spent fuel WPs, can add mechanical stability during handling, can provide a chemical buffer to condition the interior of the package, can assist in criticality control, and may also provide a diffusional resistance to migration of radionuclides.

Performance parameters are the in-repository responses of the WP/EBS and its components which affect the ability to meet their performance measure allocations. A determination of these parameters has been documented in the SCP and the SIPs. These will be reviewed for consistency with the ACD design concepts. Parameters will be identified and confirmed for PA of the selected reference and alternative designs. These are discussed in detail in Section 4.0.

4.0 TECHNICAL APPROACH

4.1 INTRODUCTION

This section describes the detailed technical approach to development of a WP design and EBS requirements which demonstrates compliance with regulatory and other requirements, involving the integration of design development, materials/component testing, repository response modeling, and PA. Development of the reference and alternative WP designs takes into account the mechanical and other properties of the components and the ability to manufacture and assemble them, and the ability to predict their performance under repository conditions. The design, testing, and PA activities are integrated and iterative. A flow chart of the integrated schedule of activities is shown in Section 5.0.

This implementation plan relates the rationale for test activities to the need to provide WP material/component response models applicable for repository time scales from relatively short-term testing. The required degree of extrapolation makes development of reliable models difficult. Test programs will distinguish between addressing performance parameters, which are responses in the repository environment and which require applicable models, and attributes, which are inherent characteristics independent of environment. One approach to bridge this extrapolation gap was outlined in the ASTM Procedure C1174-91, entitled "Standard Practice for Prediction of the Long-Term Behavior of Waste Package Materials Including Waste Forms Used in the Geologic Disposal of High-Level Nuclear Waste." This approach is used in this implementation plan. The approach addresses the generation, justification, and validation of models, and the minimization of uncertainties in the long-term extrapolation of the models developed from the test data. The approach is detailed in later portions of this section.

The framework for the development of the EBS technical approach is presented in Table 4.1-1. This framework is based on the anticipated combination of EBS components and their respective functions. Component functions have been assigned to each anticipated EBS component on the basis of the need to satisfy regulatory requirements to contain and subsequently limit the release of radionuclides. As the EBS design evolves, components and associated functions may be added or deleted from this table. The design of each component must focus on the particular functions of the component and its interface with other components or functions.

For each identified component function, performance measures are identified. The performance measures are the means by which component performance is measured. The performance measures are used to quantify "how well" the component is anticipated to perform its functions. Quantification is accomplished using component models that will be developed (based on simplified and combined degradation mode models) to predict each performance measure.

For each component performance measure, degradation modes are identified that influence the performance measure. Degradation modes are material behavior forms or processes that can result in an adverse change in the quantitative level of a performance measure. Degradation mode models will be developed based on a fundamental, mechanistic understanding of the processes associated with the degradation. The extent that a mechanistic understanding cannot be developed, a semiempirical model will be developed.

Table 4.1-1 Technical Approach to Waste Package/Engineered Barrier System Development *

EBS COMPONENT	FUNCTION OF COMPONENT	PERFORMANCE MEASURE	DEGRADATION MODE	PERFORMANCE PARAMETER
BACKFILL	Limit Water Contact with WPs	Fraction of WPs Contacted by Water	Water Flow Through the Backfill to the WP	• Hydraulic Conductivity of Backfill • Backfill Heterogeneity
	Distribute Rock Loads Imposed on WPs	Stresses Induced in WP Components by Rock Loading	Load Transmittal Through the Backfill	• Backfill Heterogeneity • Initial Backfill Density • Consolidated Backfill Density • Backfill Settlement (%)
	Limit Radionuclide Egress from EBS	Release Rate of Radionuclides from EBS	Air Pathways	• Permeability of Air in Backfill • Diffusion Coefficients of RNs in Air
			Water Pathways	• Hydraulic Conductivity of Water in Backfill • Diffusion Coefficients of RNs in Water • Retardation Coefficients in Backfill
METALLIC CONTAINER	Contain Radionuclides	Fraction of Containers Breached	Metallugical Instability (incl. weld and HAZ)	• Phase Transformations
			Low-Temperature Oxidation	• Oxidation Rates
			General Aqueous Corrosion	• General Corrosion Rates
			Microbiologically Influenced Corrosion (MIC)	• MIC Rates
			Pitting Corrosion	• E_{crit} for Pitting • E_{prot} for Pitting • Pit Penetration Rates
			Crevice Corrosion	• Penetration Rates

* Table inputs are either taken directly or are derived from the SCP.

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Table 4.1-1 Technical Approach to Waste Package/Engineered Barrier System Development (continued)

EBS COMPONENT	FUNCTION OF COMPONENT	PERFORMANCE MEASURE	DEGRADATION MODE	PERFORMANCE PARAMETER
METALLIC CONTAINER	Contain Radionuclides	Fraction of Containers Breached	Environmentally Assisted Cracking	• Crack Propagation Rates • Threshold Stress Intensity Factors (K_{SCC})
			Mechanical Instability	• Tensile Properties • Creep Properties • Fracture Toughness (J_{1C})
	Limit Radionuclide Egress after Container Breach	Release Rate of Radionuclides from Container	Diffusion Through Corrosion Products	• Diffusion Coefficients of RNs in Corrosion Products
			Transport Through Cracks	• Diffusion Coefficients of RNs in Water and Air • Crack Geometry • Effective Pneumatic and Hydraulic Conductivities of Breached Container
NON-METALLIC CONTAINER	Contain Radionuclides	Fraction of Containers Breached	Chemical Dissolution	• Dissolution Rates
			Mechanical Instability	• Tensile Properties • Creep Properties • Fracture Toughness
			Environmentally Assisted Cracking	• Crack Penetration Rates • Threshold Stress Intensity Factors (K_{SCC})
	Limit Radionuclide Egress after Container Breach	Release Rate of Radionuclides from Container	Transport Through Cracks	• Diffusion Coefficients of RNs in Water and Air
			Gaseous Diffusion	• Carbon(14) Dioxide Diffusion Coefficients in Non-Metallic
SNF BASKET	Prevent Criticality	WP K_{eff}		• Boron Concentration
	Enhance Heat Transfer	WP Temperature Gradient		• Thermal Conductivity

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Table 4.1-1 Technical Approach to Waste Package/Engineered Barrier System Development (continued)

EBS COMPONENT	FUNCTION OF COMPONENT	PERFORMANCE MEASURE	DEGRADATION MODE	PERFORMANCE PARAMETER
SNF CLADDING	Contain Radionuclides	Fraction of Fuel Rods Breached	Low-Temperature Oxidation	• Oxidation Rates
			General Aqueous Corrosion	• General Corrosion Rates
			Pitting Corrosion	• Pit Initiation Rates • Pit Penetration Rates
			Mechanical Instability	• Creep Rupture Properties • Hydride Formation
SPENT FUEL	Limit Radionuclide Release from Spent Fuel	Release Rate of RNs from Spent Fuel	Pellet-Cladding Gap Exposure	• Amount of C-14 Released as a Gas • RN Concentrations in Effluent Water (Solute and Colloid)
			Spent Fuel Oxidation	• Amount of C-14 Released as a Gas
			Spent Fuel Dissolution (Matrix and Grain Boundary)	• Amount of C-14 Released as a Gas • RN Concentrations in Effluent Water (Solute and Colloid)
METALLIC HLW GLASS CANISTER	Contain Radionuclides	Fraction of Canisters Breached	Metallurgical Instability (incl weld and HAZ)	• Grain Boundary Sensitization
			Environmentally Assisted Cracking	• Crack Penetration Rates • Threshold Stress Intensity Factors (K_{ISCC})
			Low-Temperature Oxidation	• Oxidation Rates
			General Aqueous Corrosion	• General Corrosion Rates
			Pitting Corrosion	• Pit Initiation Rates • Pit Penetration Rates
			Crevice Corrosion	• Crevice Corrosion Rates
HLW GLASS	Limit Radionuclide Release from Glass	Release Rate of RNs from Glass	Glass Dissolution	• RN Concentrations in Effluent Water (Solute and Colloid)

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In some instances where assumptions can be justified on a strong scientific basis, it may be judged prudent that an empirical, bounding model approach be used. Degradation mode models will be simplified and combined to develop the component models used to predict the performance measures described above.

For each degradation mode, performance parameters have been identified. The performance parameters are either intrinsic or extrinsic properties or attributes of the EBS materials that combine to result in the respective degradation modes. It is important to develop, to the extent practical, a mechanistic understanding of the processes associated with the performance parameters to aid in the development of defensible degradation mode models.

The materials testing effort must focus on the generation of these performance parameters or on the data that can be used to establish the parameters. The performance parameters need to be understood over the range of environmental conditions expected throughout the component's service lifetime. The model development effort must focus on the particular performance measures identified for each component. Models must be developed that will permit calculation of the performance measures for PA purposes.

The next three sections of this plan, WP Design, Materials Testing, and PA detail the integrated technical approach to development of a WP/EBS design that demonstrates compliance with the requirements.

4.2 WASTE PACKAGE DESIGN

This section includes guidance on the methodology and criteria for the selection and prioritization of WP and alternative WP conceptual designs. This section describes the WP design process, Pre-ACD, ACD, and the LAD specified by the DOE. It also describes WP design tools, including codes and standards requirements, data sources, and quality requirements, the design analyses that will be performed in support of the concepts, the engineering development tasks, and engineering and manufacturing prototypes.

The system design process will relate design parameters (such as materials selections and design configurations) to performance allocation, thereby integrating design with the testing and modeling activities. It will link conceptual candidate waste container fabrication processes with design, performance parameters, and performance allocation requirements (in terms of predictive models and the testing required to support the models).

The principal goal of the WP development effort is to create WP designs that will be licensable; that is, will meet the regulatory requirements with sufficient margin that the NRC will find that compliance has been achieved with reasonable assurance. This goal drives the design effort to the consideration of robust, multi-barrier WPs that are tolerant of a range of repository conditions.

4.2.1 SELECTION CRITERIA

Each design concept includes a number of options that are driven by the requirements and the functional needs. The matrix of options, shown in Table 4.2-1, is a list of options that can be used in combination to define various WP concepts. For example, an emplacement mode may be selected and then a given set of barrier options could be chosen, then material options can be selected.

The selected WP concepts that are derived from the matrix will then be evaluated during ACD. Detailed engineering design activities, including thermal, structural, neutronic, and fabrication activities, will be performed. Materials will be evaluated and selected and analytical models will be developed to assess the design concepts. At the start of the LAD, one primary and one alternative conceptual design will be selected. During LAD, full size prototypes will be fabricated and fabrication processes will be finalized along with final engineering and performance analyses. At the end of LAD the engineering and performance analyses will be compiled and issued as part of the license application document.

The WP/EBS selection-criteria are a composite of how the design concept performs within the system and to what extent the concepts meet/exceed the regulatory requirements. General selection criteria are:

1. Does the concept meet the federal regulations?
2. Does the concept meet the WP design requirements?
3. Does the concept meet the system interface requirements?
4. Does the concept meet the design goals?

For each design concept, a review of the WP system will be performed including how each component functions within the system. A decision tree will be constructed that will include:

1. The controls (design and system requirements, federal regulations);
2. The inputs (what is needed to perform the design activity),
3. Resources/mechanisms (references, test data, etc.); and
4. Output (what will be the result of the task/design and where does it lead.)

The preclosure WP functional requirements are specified as follows:

1. To contain waste during handling, storage, emplacement, and retrieval, if necessary (10 CFR 60.135(b)(3));
2. To prevent criticality within the WPs; and
3. To provide a means of unique identification.

4.2.2 CONCEPT DEVELOPMENT

The number of conceptual designs is narrowed during the Pre-ACD and ACD phases, with final selection early in the LAD phase. Each phase is described in the following sections.

Table 4.2-1 Waste Package Design Options

1.0 Container Type
- 1.1 Single Purpose
- 1.2 Dual Purpose
- 1.3 Multi-Purpose

2.0 Emplacement Modes
- 2.1 Vertical Borehole
- 2.2 Horizontal Borehole
- 2.3 Drift Emplacement

3.0 Barrier Types
- 3.1 Backfill
- 3.2 Packing
- 3.3 Overpack
- 3.4 Containers
- 3.5 Fillers
- 3.6 Waste Forms

4.0 Material Options
- 4.1 Corrosion Allowance Materials
- 4.2 Corrosion Resistant Materials
- 4.3 Metallic Particulates
- 4.4 Ceramic Particulates
- 4.5 Ceramic Monoliths
- 4.6 Composites
- 4.7 Earthen Materials (Tuff, Clay, Sand, etc.)
- 4.8 Cementitious Materials

5.0 WP Capacity/Size
- 5.1 Three Pressurized-Water Reactor (PWR) Assemblies or less
- 5.2 Four to Ten PWRs
- 5.3 More than Ten PWRs
- 5.4 Equivalent Boiling Water Reactor (BWR) Packages
- 5.5 Hybrid Package
- 5.6 Number of Glass Canisters
- 5.7 Degree of Self Shielding

4.2.2.1 PRE-ADVANCED CONCEPTUAL DESIGN

The Pre-ACD phase, and the earlier conceptual design phase, centered around the use of borehole emplacement. The SCP and SCP-Conceptual Design Report designs reviewed vertical and horizontal borehole emplacement. The Pre-ACD reference WPs are designed as thin-walled, right circular cylinders with end closures and a lifting fixture on one end. The metal containers are 71 cm (28 in.) in diameter with a nominal wall thickness of about 1 cm (0.39 in.). The diameter was determined on the basis of the geometry of the waste forms and their thermal limitations. The wall thickness is based on structural and handling considerations. The total package weights will range from 2.7 to 6.4 metric tons, depending on the type of WP.

The design concepts presented in the SCP are based on the technical data generated in the early 1980s. The MGDS has matured over the past ten years. Additional data have become available that can be applied to the design of the WP. This has led to the consideration of a large matrix of options as described in Table 4.2-1. Thus, an important activity during the Pre-ACD phase was the identification of a reduced set of conceptual designs for detailed evaluation during ACD. This short list of concepts given in Table 4.2-2 was derived from the design options identified in Table 4.2-1.

4.2.2.2 ADVANCED CONCEPTUAL DESIGN

Candidate WP concepts and the SCP WP concept will be evaluated in detail. The ACD activities will include detailed engineering evaluations to determine the viability of one or more concepts for the spent nuclear fuel (SNF) and the HLW streams. Each concept evaluation is directly dependent on the system needs. To minimize divergent requirements, a careful review of the system-imposed needs should be completed in the early part (the first six months) of ACD.

The principal goal of the ACD phase is to develop a set of WP designs that will be licensable. Each design must satisfy the regulatory requirements with sufficient design and performance margin that the NRC will find that compliance has been demonstrated with reasonable assurance.

This goal drives the design effort to consider robust, multi-barrier WP design candidate concepts that are tolerant of a range of repository conditions. The multi-barrier candidate design concept corresponds to a defense-in-depth approach to design and licensing, which is typically accepted by the NRC. Robust WP designs should provide greater than 1000 years containment as the nominal performance life.

The WP manufacturing processes will be determined under the engineering development tasks. These tasks will develop and prove component fabrication and closure methods, in-service inspection/nondestructive examination (ISI/NDE) methods, handling capabilities, and reduced stress fabrication. In each of these engineering tasks, full or reduced scale sections of the WP/EBS will be tested and evaluated. The approach is the systems engineering method of design, using a decision tree to evaluate the many conceptual designs during each step in design, material selection, fabrication, and performance analyses.

Table 4.2-2 Waste Package ACD Concepts

- Large Metallic Multi-Barrier
- Metallic Totally Shielded
- Small Metallic Multi-Barrier (Borehole)
- Non-Metallic Multi-Barrier
- Overpacked Multi-Purpose Canisters
- Universal Cask Waste Package
- Site Characterization Plan Design (Single Container)

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Another tool that may be applied to the design is a PA probabilistic approach that takes into account that breaches are likely to be distributed over time. The time distribution for breach occurrence may be a bell curve. Other distributions, such as a Weibull distribution, will be included in the evaluation. One goal of the WP design is to shift the predicted bell curve for breach further out in time. In addition to a greater mean containment life of the WP, design features will be incorporated to flatten the bell curve, which reduces the number of breach events that occur annually. By more broadly distributing WP breaches, any annual releases would be reduced, facilitating compliance with the release regulations of 10 CFR 60.

There are three basic material options for the WP: metallic-based, ceramic-based, and combined. In the early phase of ACD, the design concepts that will be further evaluated will be selected. Since metallic-based designs possess relatively standard fabrication methods and mechanical stability, it is planned that a number of metallic based WP designs will be carried into ACD. In addition, an alternative WP design that incorporates ceramic-based or combined materials will be evaluated. Each design will go through a series of analytical and manufacturing development steps, which are described in detail in subsequent sections. WP selection criteria will be developed to support the selection of the WP design. For each design the following will be performed:

1. Analytical report(s)
2. Design drawings
3. Design specifications
4. Material specifications
5. Fabrication drawings
6. Fabrication specifications
7. Engineering development report(s) concerning the fabrication studies

4.2.2.3 LICENSE APPLICATION DESIGN

The LAD phase of the program completes the evaluation of concepts developed during ACD and selects the final two (primary and alternative) Spent Nuclear Fuel (SNF) designs and the final HLW glass design. Each design will be investigated in detail from the performance and manufacturing points of view. The LAD designs will be based on the sum of the data gathered or generated. The evaluations will build from the ACD engineering concepts and will incorporate any comments that have been received from the other system elements. Design and fabrication studies will continue. Fabrication studies will include full-scale models that will be subjected to realistic system-imposed conditions. The results of the LAD evaluation will include, for each design:

1. Analytical design and manufacturing report(s)
2. Design drawings
3. Design specifications
4. Material specifications
5. Fabrication drawings
6. Fabrication specifications
7. Manufacturing development report(s)
8. License Application Section on WP/EBS designs and fabrication.

4.2.3 DESIGN TOOLS

The design process will use industrial and nuclear design, material and fabrication standards. The list of design standards include:

1. American Society of Mechanical Engineers (ASME) Code for Pressure Piping, B31, An American National Standard, "Chemical Plant and Petroleum Refinery Piping", ASME/American National Standards Institute, Inc. (ANSI) B31.3-1987 or latest edition.

2. The applicable material and testing specifications issued by ASTM.

3. AISC, American Institute of Steel Construction, "Manual of Steel Construction".

4. Appropriate non-metallic specifications (TBD).

5. Materials used in the fabrication of the WP barriers should be a "Code Material".

Additional industrial standards listed below will be used as guides. Only those sections that are directly applicable to the WP/EBS will be used.

1. ASME Boiler and Pressure Vessel Code Sections:

   1.1. III -Subsection NSA- General Requirements for Division 1 and Division 2

   1.2. V -Nondestructive Examination

   1.3. VIII -Pressure Vessels, Division 1 and Division 2

   1.4. XI -Rules for In Service Inspection of Nuclear Power Plant Components

2. ASTM, specifications for materials.

3. AMS, Aerospace Material Specifications.

4.2.4 DESIGN ANALYSES

Design products include design calculations, material selections, performance analyses, and design specifications and drawings. These are described in the following sections.

4.2.4.1 DESIGN CALCULATIONS

Design calculations will be performed for each WP concept in sufficient detail to provide a comprehensive comparison base. A comprehensive list outlining the proposed calculations will be compiled for each design option. The calculation outline will be based on the regulatory and system requirements, as well as the WP design goals. The design calculations for the LAD will be compiled into an NRC licensing report that is similar to the transportation and monitored retrievable storage system design reports. Details are provided in Section 5.1.

4.2.4.2 MATERIAL SELECTION

The design concepts will be strongly coupled to the selection of the materials for each component in the design. Properties will be provided from the available literature to assist in the screening of concepts. Corrosion and mechanical measurements will be performed on candidate materials so that short-term and some long-term data under repository conditions will be available to support performance modeling and final selection based on performance analysis. Testing will be performed for those materials and conditions under consideration for which data are either insufficient or unavailable. (The testing program is detailed in Section 4.3.) Where possible, advantage will be taken of ASME code-case data bases.

4.2.4.3 PERFORMANCE ANALYSIS

The design concepts will be evaluated using PA at various stages of the design development process. Initially, the candidate designs will be evaluated using available information or bounding values to provide a basis for screening concepts early in the ACD phase. More detailed assessments will be performed as data become available from the material testing and design activities. The assessments will be performed at least once during ACD and again during LAD. The framework, inputs, model development and compliance determination are described in detail in Section 4.4. The PA activities are described in Section 5.3.

4.2.4.4 DESIGN SPECIFICATIONS AND DRAWINGS

For each of the SNF and HLW glass design concepts, detailed design, fabrication and interface drawings will be created. The drawings will comply with the appropriate Civilian Radioactive Waste Management System (CRWMS) Management and Operating (M&O) Contractor drawing standards, based on ANSI and U.S. Department of Defense standards. The drawing packages will include a parts list that will contain:

1. Drawing number
2. Related design specification
3. Related material specification
4. Related fabrication specification, and
5. Related interface specification (if applicable).

4.2.5 ENGINEERING DEVELOPMENT TASKS

As one of the selection criteria, the required fabrication processes will influence the choice of the final two WP concepts that will be evaluated early in the LAD phase of the program. The technical feasibility and cost effectiveness of the fabrication processes will be evaluated for each ACD concept.

Engineering development tasks will parallel the design activities. The development tasks will determine the needed fabrication and manufacturing processes. The tasks will be focused on key fabrication uncertainties specific to each WP concept. The design and licensing needs will guide the selection of the required development tasks. At the present time there are five identified development programs:

1. Manufacturing stress minimization (induce the lowest tensile stress)

2. Closure methods and processes (low heat input to the WP closure area and WP body remote closure methods)

3. In-service Inspection/Nondestructive Examination

4. Handling methods

5. Fabrication methods for multi-barrier WPs

The above list will be reviewed periodically to verify that it still meets the design needs. Additions and/or deletions will be made as the need arises. The review will be performed by the M&O WP Development Group.

The development tasks will use a quality assurance process that will support NRC licensing documentation. The quality assurance process will include these basic steps:

1. The generation of a Technical Requirements Document (TRD), prepared by the design staff;

2. The preparation of a Task Plan (TP) that directly responds to the TRD, prepared by the responsible organizations;

3. The acceptance of the TP by the design staff and the YMPO;

4. Progress reports and a final report by the responsible organizations; and

5. Design staff incorporation of data into the design and into the license application.

4.2.5.1 MANUFACTURING STRESS MINIMIZATION

The objective of this development task will be to minimize the fabrication tensile stresses that are induced during the manufacturing process. The WP design life, and hence the containment time, is intended to be in excess of 1000 years. To extend the WP containment time, the components should be in a stable and low tensile stress state after manufacturing and closure.

This task will develop a stress mitigation approach that can be applied during manufacturing to produce a compressive residual stress or minimize the residual tensile stresses. The three development approaches and associated objectives are:

1. Closure and fabrication optimization. The objective is to provide guidance in the development of closure and fabrication technology. The task will include the evaluation of low stress fabrication technologies, closure methods and parameters, closure joint configuration, and computer models to support the design and licensing activities.

2. Stress measurement. The objective is to develop a method that can be used to measure the residual stress level of the WP/EBS components and assembly. The system developed shall be portable and nondestructive and should require no special environment.

3. Stress reduction. The objective is to develop a technique that can be applied to the closure and fabrication of the components to further reduce the induced tensile stresses.

4.2.5.2 CLOSURE DEVELOPMENT

The objective of this development task is to provide a process that can close the WPs remotely in a high radioactive field for each of the design concepts. The closure method must be compatible with other development tasks noted in this section such as stress minimization, ISI/NDE, and handling processes, and should not degrade containment barriers, unless justified by a trade study.

Standard and remote closures processes will be investigated for each of the WP design concepts. The processes will focus on metallic materials; however, preliminary evaluations for non-metallic materials will be performed. The areas of interest include the joint configuration, time involved in making the closure, closure equipment, and quality of closure that is made.

4.2.5.3 IN-SERVICE INSPECTION/NONDESTRUCTIVE EXAMINATION DEVELOPMENT

The objective of this task is to ensure that an adequate NDE technology is available for the prototype WP and component fabrication tests and fabrication process inspection and acceptance. Included in this task will be the development of remote ISI techniques that will be used to monitor the WP performance. The performance of the WP, as specified by 10 CFR 60, requires a performance verification period. This task will also develop the remote NDE methods that will be used in radiation fields or contaminated areas.

4.2.5.4 HANDLING METHODS EVALUATION

The objective of this task is to evaluate handling methods that will ensure that the integrity of the WP is maintained throughout the repository system. The Surface Facilities Staff has the responsibility for designing waste handling in the Waste Handling Buildings, including Hot Cells. This task will also encompass any monitored retrievable storage or utility handling of the WP, if required.

The evaluation of the surface facility will include the hot cell area in which the WP is moved to the loading stand, the loading stand, the closure process, loading onto/into the WP transporter, and the potential operations required for retrieval. For each of the system steps, a detailed evaluation will be performed to ensure integrity of the WP.

The evaluation of the subsurface facility will include the transporter and emplacement and relocation/retrieval of the WP. For each of the system steps, a detailed evaluation will be performed to ensure WP/EBS integrity. These evaluations will be performed jointly with the surface facilities staff.

4.2.5.5 WASTE PACKAGE FABRICATION

The objective of this task is to define a manufacturing method for metallic, non-metallic, and combination WP design concepts. The specific objective is to assess various manufacturing alternatives, relative to the performance requirements, and then demonstrate a primary and perhaps an alternative manufacturing method for making a prototype WP. The process will be completed in three phases. Phase 1 involves an engineering study to identify and assess candidate fabrication processes for the ACD design concepts. Phase 2 will involve sub-scale prototypes fabricated using the materials and other development task items listed in this section. Phase 3, which will be performed during LAD, will include the fabrication of full-scale prototypes. These prototypes will not only validate the fabrication process but will be used in the engineering licensing tests (i.e., drop tests, closure tests, handling tests, etc).

4.2.6 MATERIAL INVESTIGATIONS

The objective of these investigations will be to define the material properties of proposed WP/EBS materials. Technical justification will be established and documented for the WP/EBS materials. Whenever possible, specifications for candidate materials will be developed so that the chemical and metallurgical requirements are consistent with code-approved materials. Material selections, whenever possible, will be based on alloys which have demonstrated successful service in relevant environments. New and/or experimental alloys will be used only if they possess significant advantages over existing materials.

4.2.7 ENGINEERING PROTOTYPES

The engineering prototypes will be developed in the fabrication development task discussed above. The prototypes will be used in the selection process of the final WP design concept that will be carried forward into LAD and licensing. The prototypes will be subjected to regulatory and design tests. The design concepts will be ranked to identify the best concepts. The selection criteria shall include how well the concept meets the design goals, system goals, and the regulatory requirements.

4.2.8 MANUFACTURING PROCESS DEVELOPMENT

During ACD, the development of the process specifications and fabrication drawings will be generated for each WP concept. Process specifications and fabrication drawings will be developed as processes are evaluated and selected and the results of the prototype testing are available.

4.3 MATERIALS TESTING

WP/EBS materials testing shall be conducted for two primary purposes:

1. Materials testing provides the data base required by the modeling activity for developing and validating the material degradation mode (Performance Parameter) submodels and component behavior (Performance Measure) models. These material degradation mode submodels and component behavior models are used as the base of the model hierarchy to help demonstrate WP/EBS regulatory compliance.

2. Materials testing provides the attribute data that are not already available from the literature. These data are required by the WP design activity to perform design analyses, including WP structural, criticality, and thermal analyses.

The technical approach to materials testing is derived directly from the performance parameters identified in Table 4.1-1. The performance parameters are either properties or attributes of the EBS components that are needed to evaluate WP/EBS component performance in accordance with the performance measures.

The materials testing program is organized in accordance with the WP Work Breakdown Structure (WBS). The testing includes Waste Forms, Metal Barriers, Other Materials, Integrated Testing, and Non-Metallic Barriers. The following subsections discuss the testing that is planned in each of the WBS elements to help support development of the detailed, performance parameter submodels.

4.3.1 WASTE FORMS

There are two types of waste forms to be disposed of in a deep geologic repository: SNF and HLW glass. Each of these waste forms consists of two "components" for which functions, performance measures, and performance parameters have been assigned. In the case of SNF, the components are spent fuel pellets and cladding. For the HLW glass, the components are the HLW glass itself and the metallic pour canister. These components and the corresponding performance parameters that need to be measured (and modeled) were identified in the WP/EBS technical approach (Table 4.1-1). The performance parameters associated with the four waste form components from Table 4-1.1 have been consolidated and grouped in Table 4.3-1.

Tests are identified in Table 4.3-1 that will lead to the determination of each performance parameter. There has been no attempt to prioritize these tests or to identify the environmental variables and their ranges that need to be investigated. As WP environment information is developed, this knowledge will be incorporated into Scientific Investigation Plans in the form of specific, environmental scenarios including parameters and ranges. The intent is to develop an understanding, to the extent possible, of each performance parameter's dependence on the WP environment.

<u>Cladding</u>

The key SNF cladding performance parameters are:

- Oxidation Rates
- General Corrosion Rates
- Pit Penetration Rates
- Pit Propagation Rates
- Creep Rupture Properties (includes hydride effects)

These spent fuel cladding performance parameters (also listed in Table 4-3.1) are sensitive to temperature, water flow rate and composition, Eh, pH, and mechanical stress in the cladding. The performance parameter response to these environmental variables is affected by

Table 4.3-1 Waste Form Testing Program Summary

Component	Performance Parameter	Test
SNF Cladding	• Oxidation Rates	Air/Steam
	• General Corrosion Rates	Aqueous Bath
	• Pit Penetration Rates	Potentiostatic
	• Pit Propagation Rates	Potentiostatic
	• Creep Rupture Properties (includes hydride formation effects)	Creep
Spent Fuel Pellets	• Amount of Carbon-14 Released as a Gas	Inventory Measurements C-14(CO_2) Diffusion
	• Radionuclide Concentrations in Contacting Water	Dissolution Oxidation
HLW Glass Canister	• Grain Boundary Sensitization	Time/Temp Exposures
	• Environmentally Assisted Cracking	Crack Propagation
	• Oxidation Rates	Air/Steam
	• General Corrosion Rates	Aqueous Bath
	• Pit Penetration Rates	Potentiostatic
	• Crevice Corrosion Rates	Potentiostatic
HLW Glass	• Radionuclide Concentrations in Contacting Water	Dissolution Air/Steam

variations in cladding alloy chemistry, thermomechanical history during fabrication, in-reactor environment history, as well as post-discharge thermal and mechanical loading histories.

Because of the many anticipated historical and environmental dependencies of spent fuel cladding performance, the intent of the spent fuel cladding testing effort is to determine the conservative bounds of the performance parameters. This will require testing the particular cladding that according to engineering judgement will respond most rapidly to the environmental conditions of the test. In some cases, scoping tests will be needed to identify conservatively bounding environmental conditions.

Spent Fuel

The key spent fuel pellet performance parameters are:

- Amount of Carbon-14 Released as a Gas
- Radionuclide Concentrations in Contacting Water

These spent fuel pellet performance parameters are sensitive to temperature, water flow rate and chemistry, Eh, and pH. The amount of Carbon-14 released as a gas can be related conservatively to the Carbon-14 inventory in the fuel-cladding gap, the spent fuel grain boundaries, and the UO_2 matrix. Therefore, determination of these inventories by a combination of measurements and calculation is needed.

An understanding of the radionuclide concentrations in effluent water is an important step in calculating radionuclide release. A knowledge of radionuclide inventory and spent fuel dissolution rate will provide the necessary basis for determining radionuclide concentrations. Thus, it is important that spent fuel dissolution behavior be investigated. The release of radionuclides is directly affected by the spent fuel pellet surface area available for dissolution. Therefore, spent fuel oxidation tests are needed because the oxidation state influences the surface area available to the groundwater for dissolution. Spent fuel burn up and fission gas release are also key variables that need to be incorporated into the spent fuel performance testing effort.

HLW Glass

The key HLW glass canister (anticipated to be American Iron and Steel Institute 304L stainless steel) performance parameters are:

- Grain Boundary Sensitization
- Environmentally Assisted Cracking
- Oxidation Rates
- General Corrosion Rates
- Pit Penetration Rates
- Crevice Corrosion Rates

These stainless steel canister performance parameters (also listed in Table 4.3-1) are sensitive to temperature, water flow rate and composition, Eh, and pH. These stainless steel canister performance parameters (also listed in Table 4.3-1) are sensitive to temperature, water flow rate and composition, Eh, and pH. Because of the many anticipated environmental dependencies of the stainless steel performance, the intent of the canister testing effort is to determine the conservative bounds of the performance parameters. In some cases, scoping tests will be needed to identify conservatively bounding environmental conditions.

The key HLW glass performance parameter is:

- Radionuclide Concentrations in Contacting Water

Borosilicate glass performance is sensitive to temperature, water flow rate and composition, Eh, and pH. An understanding of the radionuclide concentrations in effluent water is important for use in calculating radionuclide release. A knowledge of radionuclide inventory and glass dissolution rate will provide the necessary basis for determining radionuclide concentrations. Thus, it is important that HLW glass dissolution behavior be investigated. An understanding of the glass dissolution behavior both with and without prior exposure to an air-steam environment is needed.

4.3.2 METAL BARRIERS

Metal barriers may be used to contain the radionuclides within the WP. The metallic container component and corresponding performance parameters that need to be measured (and modeled) were identified in the WP technical approach (Table 4.1-1). The performance parameters associated with this component from Table 4.1-1 have been listed in Table 4.3-2 along with the appropriate tests that will lead to the determination of each performance parameter. There has been no attempt to prioritize these tests or to identify the environmental variables and their ranges that need to be investigated. As WP environment information is developed, this knowledge will be incorporated into SIPs in the form of specific environmental scenarios including parameters and ranges. The intent is to develop an understanding, to the extent possible, of each performance parameter's dependence on the WP environment.

The metallic container materials that are to be studied as part of the WP development effort have been categorized in accordance with corrosion characteristics, specifically, corrosion resistant metals and corrosion allowance metals. The corrosion resistant metals recently recommended by Lawrence Livermore National Laboratory (LLNL) for the SCP-Consultation Draft WP container are Titanium Alloy - Grade 12, Hastalloy C-4, and Incoloy 825 [8].

These alloys will continue to be investigated through the Advanced Conceptual Design phase. Also, iron-base and copper-base alloys will be evaluated as potential corrosion allowance container materials.

The grain structure and metallurgical phases within the grains, including precipitates that may be in grains or along grain boundaries, will be characterized for each candidate metallic container material in the as-fabricated condition. Characterization includes the metallurgical structure and precipitates in the base material, in welds, and in the regions near the welds that may have been affected by heat from the welding process (heat-affected zones). The stability of this as-fabricated metallurgical structure needs to be understood as a function of time and temperature. The performance parameter "Phase Transformations" encompasses the characterization of metallurgical phase and precipitate behavior, for each candidate material

Table 4.3-2 Metal Barriers Testing Program Summary

Component	Performance Parameter	Test
Metallic Container	• Phase Transformations	Aging/Metallographic
	• Oxidation Rates	Air/Steam
	• General Corrosion Rates	Aqueous Bath
	• Microbiologically Influenced Corrosion (MIC) Rates	Aqueous Bath
	• E_{crit} for Pitting	Potentiodynamic
	• E_{prot} for Pitting	Potentiodynamic
	• Crevice Corrosion Rates	Potentiostatic
	• Pit Penetration Rates	Potentiostatic
	• Crack Propagation Rates	Constant/Cyclic Load
	• Threshold Stress Intensity Factors	Cyclic Load
	• Tensile Properties	Tension
	• Creep Properties	Creep (uniaxial)
	• Fracture Toughness	J-Integral Fracture

as a function of time and temperature, sufficient to provide a basis for predictive model development.

Low-temperature oxidation of metallic container materials at temperatures of ambient to 250°C will probably be the dominant degradation mode of containers not contacted by water. Chemical affinity of metals for oxygen in a vapor or non-condensing environment as a function of humidity, results in the formation of metallic oxides which remain on the surface as a film. In some cases, the oxide film is very adherent and protective in nature, inhibiting further oxidation of the underlying metal by limiting oxygen access to the metal substrate. In other cases, the oxide film is less adherent and non-protective in nature thus allowing continuing access of oxygen to the metal and continued oxidation.

General aqueous corrosion will probably be the dominant degradation mode of corrosion-allowance container materials in contact with water. General aqueous corrosion will be active for corrosion resistant materials also, although its importance is much less for these materials due to the very adherent, protective (passivating) nature of their corrosion product films which result in extremely low rates of general corrosion.

MIC is a form of localized corrosion which is induced by local-action cells in an aqueous environment that are created by the accumulation of microbes or microbe by-products on the surface of a metal. If it can be demonstrated that a particular candidate metal is not susceptible to this form of corrosion or that the rates associated with other forms of localized corrosion are higher than MIC, then decreased emphasis can be placed on fully characterizing and modeling MIC.

Pitting (and crevice corrosion) of metals occurs in aqueous environments. The rate of pit growth is rapid relative to general corrosion rates. If the corrosion product film is not passivating in nature, such as with corrosion allowance materials, then the tendency to degrade by pitting is dominated by general aqueous corrosion processes, and general corrosion will prevail over a broad range of environmental parameters.

The performance parameters of interest in modeling pitting corrosion behavior are:

- E_{crit} - Electrochemical potential above which pitting will initiate on the surface of the metal
- E_{prot} - Electrochemical potential below which a propagating pit will stop growing
- E_{corr} - Open circuit (no applied potential) electrochemical potential that exists on the surface of a metal in an aqueous environment in its freely corroding state
- Pit Penetration Rate - The rate of penetration of a pit into the metal.

To develop these pitting performance parameters, potentiodynamic scanning as well as potentiostatic/pit depth tests will be required to understand the mechanisms, initiation behavior and rates of pitting corrosion to support predictive model development. Testing shall be done on each candidate container material to understand the initiation and propagation rates of localized corrosion in crevices and, if possible, to demonstrate that localized corrosion rates in crevices are bounded by pitting corrosion rates. This would minimize the amount of work required to understand crevice corrosion behavior.

Environmentally assisted (stress corrosion) cracking is a degradation mode that occurs by the synergistic interaction of mechanical stress and corrosion processes in that component. Simultaneous exposure to these factors leads to very rapid propagation of cracks, far in excess of that which would occur by stress acting alone.

The performance parameters of interest in modeling environmentally assisted cracking behavior are:

- Crack Propagation Rates - Crack penetration rate as a function of time, stress, and other environmental factors such as temperature and water composition

- Threshold Stress Intensity Factors - Stress intensity factor below which the crack propagation rate approaches zero. This needs to be established as a function of all important environmental factors.

The mechanical instability of candidate container materials is associated with the application of a mechanical stress to the component in the absence of chemical effects. Deformation and failure occur differently depending on the metal and its processing and fabrication history.

The performance parameters or attributes of interest in modeling mechanical instability behavior are:

- Tensile Properties - Modulus of Elasticity, Proportional Elastic Limit, Yield Strength, Ultimate Tensile Strength, Poisson's Ratio, Uniform Elongation, Total Elongation, Reduction of Area

- Creep Properties - Deformation (strain) as a function of stress and time

- Fracture Toughness - The ability of a material, with a crack, to absorb energy.

To determine these performance parameters, appropriate testing of each candidate material will be required to understand the mechanical behavior as a function of temperature and strain rate.

4.3.3 OTHER MATERIALS

The "Other Materials" WBS element is confined presently to the backfill component of the EBS. Filler materials, particularly as chemical buffers, will be addressed when their functions, as well as performance parameters, are defined. The backfill functions and performance parameters were identified in the WP/EBS technical approach (Table 4.1-1). The performance parameters associated with the backfill are listed in Table 4.3-3 along with the appropriate tests that will lead to the determination of each performance parameter. There has been no attempt to prioritize these tests or to identify the environmental variables and their ranges that need to be investigated. As WP environment information is developed, this knowledge will be incorporated into SIPs in the form of specific, environmental scenarios including parameters and ranges. The intent is to develop an adequate understanding of each performance parameter's response to the repository environment.

4.3.4 INTEGRATED TESTING

The objectives of this effort are to determine the transport properties of radionuclides in the EBS and near-field and to develop and validate a model to describe the rate of release of radionuclides from the near-field. The focus of the experimental program is the determination of elemental profiles in rocks, minerals, and glasses and the interaction of actinide-bearing solutions with rock core samples. Data from the experimental programs including those shown in Table 4.3-4 will be utilized to model the radionuclide release from the EBS.

The transport of radionuclides, either in solution or as colloids, through the corrosion products which exist on the surface of the base metal is a diffusion process. The diffusion of radionuclides through these corrosion products is important in understanding release rates of radionuclides from the containers. The performance parameter of "Diffusion Coefficients of Radionuclides in Corrosion Products" will provide the diffusion characteristics needed to assess this aspect of radionuclide transport.

The transport of radionuclides through cracks which exist in the base metal when breach of a container occurs by a cracking mode (environmentally assisted cracking) is in part a diffusion process and is important in understanding release rates of radionuclides from the containers. The performance parameter of "Diffusion Coefficients of Radionuclides in Water" will provide the diffusion characteristics needed to help assess this aspect of radionuclide transport. Also needed for this purpose is the "Crack Geometry." Knowledge of the likely crack geometries (and effective hydraulic conductivity of a breached container) along with the radionuclide diffusion coefficients in water will allow calculation of radionuclide transport through cracks.

4.3.5 NON-METALLIC BARRIERS

Non-metallic barriers may be used to contain the radionuclides within the WP. It is expected that the non-metallic materials will provide the increased degree of radionuclide isolation identified in 10 CFR 60.21(c)(1)(ii)(D) dealing with the consideration of alternative designs and barriers. The non-metallic container component and corresponding performance parameters that need to be measured (and modeled) were identified in the WP technical approach (Table 4.1-1). The performance parameters associated with these components from Table 4.1-1 are listed in Table 4.3-5 along with the appropriate tests that will lead to the determination of each performance parameter. There has been no attempt to prioritize these tests or to identify the environmental variables and their ranges that need to be investigated. As WP environment information is developed, this knowledge will be incorporated into SIPs in the form of specific environmental scenarios including parameters and ranges. The intent is to develop an understanding, to the extent practicable, of each performance parameter's dependence on the WP environment, so that a judgment can be made during LAD as to whether the alternative approach should be further explored.

Table 4.3-3 Backfill Testing Program Summary

Component	Performance Parameter	Test
Backfill	• Backfill Consolidation	Density
	• Permeability of Air in Backfill	Permeability
	• Hydraulic Conductivity of Water in Backfill	Hydraulic Conductivity

Table 4.3-4 Integrated Testing Program Summary

Component	Performance Parameter	Test
Backfill	• Diffusion Coefficients on radionuclides (RNs) in Air	Gaseous Diffusion
Backfill	• Diffusion Coefficients of RNs in Water	Aqueous Diffusion
Backfill	• Retardation Coefficients	TBD
Metal & Non-Metal Barriers	• Diffusion Coefficients of RNs in Corrosion Prod.	Solid Diffusion
Metal & Non-Metal Barriers	• Diffusion Coefficients of RNs in Water	Aqueous Diffusion
Metal & Non-Metal Barriers	• Crack Geometry (Effective Hydraulic Conductivity)	Hydraulic Conductivity

Table 4.3-5 Non-Metallic Barriers Testing Program Summary

Component	Performance Parameter	Test
Non-Metallic Container	• Dissolution Rates	Leach/Dissolution
	• Tensile Properties	Tension
	• Creep Properties	Creep (uniaxial)
	• Fracture Toughness	J-Integral Fracture
	• Crack Propagation Rates	Static/Cyclic Load
	• Threshold Stress Intensity Factors	Cyclic Load
	• Diffusion Coefficients of RNs in Water	Aqueous Diffusion
	• Diffusion Coefficient of C-14 Dioxide in Non-Metallic Materials	Solid Diffusion

The non-metallic materials being considered include oxides, such as alumina, titania, and alumina-silica combinations, as well as non-oxides, such as graphite, carbides, and nitrides. Early in the program, screening studies will be performed to narrow the candidate list, followed by sub-scale fabrication of components.

The important properties for this class of materials are the mechanical properties (particularly fracture toughness), permeability, and dissolution resistance. Fracture via delayed crack propagation under stress is believed to be a more limiting property of these ceramic materials than is permeability or dissolution resistance. There are two potential fracture sources to consider, pre-existing defects at the time of emplacement and defects formed after emplacement. These sources will be influenced by the fabrication and closure methods. The testing will emphasize fracture toughness determination. Fiber reinforcement can be utilized to improve the fracture toughness of these materials; however, the permeability of the resulting composite to gases and liquids is higher than for pure ceramics.

4.4 PERFORMANCE ASSESSMENT

4.4.1 FRAMEWORK

PA is both the tool for demonstrating regulatory compliance and the product, along with the WP/EBS design, submitted to NRC. The WP/EBS PA interfaces with, and is governed by, the repository PA Management Plan. The strategy of using a conservative design for the WP/EBS in order to demonstrate compliance with regulatory requirements also involves the use of a defensible and conservative PA.

Key performance parameters of the WP/EBS materials and/or components, which are invoked to demonstrate compliance through PA, must be modeled with adequate confidence. These parameters were listed in Table 4.1-1. These submodels should be deterministic and/or mechanistic to provide confidence of their validity over repository time periods. The submodels are the base of the PA model hierarchy.

The models to be developed will be placed in the context of an overall model hierarchy. This model hierarchy will provide the vehicle for the WP/EBS PA-determined resolution of SCP Issues 1.4 (Containment) and 1.5 (Release Control). At the base of the hierarchy, and providing the technical basis for the PA calculations, are the submodels which characterize quantitatively the performance parameters or responses of the WP/EBS materials/design in the repository environment. As the model hierarchy proceeds to higher level models (designed-component integrated responses) these performance parameter submodels may be simplified, but must remain defensible at the mechanistic submodel level. The testing activities described in this plan and/or the SIPS provide the basis for the use and defense of these submodels. The higher level PA analyses provide feedback for the prioritization of test activities and sensitivity analyses (required for design and performance allocation activities).

PAs will determine whether the candidate designs meet the requirements for "substantially complete containment" (SCC) and "controlled release" as defined in 10 CFR 60.113. The parameter values given in the SCP will be compared with those generated as a result of the test program. The test programs were described in Section 4.3.

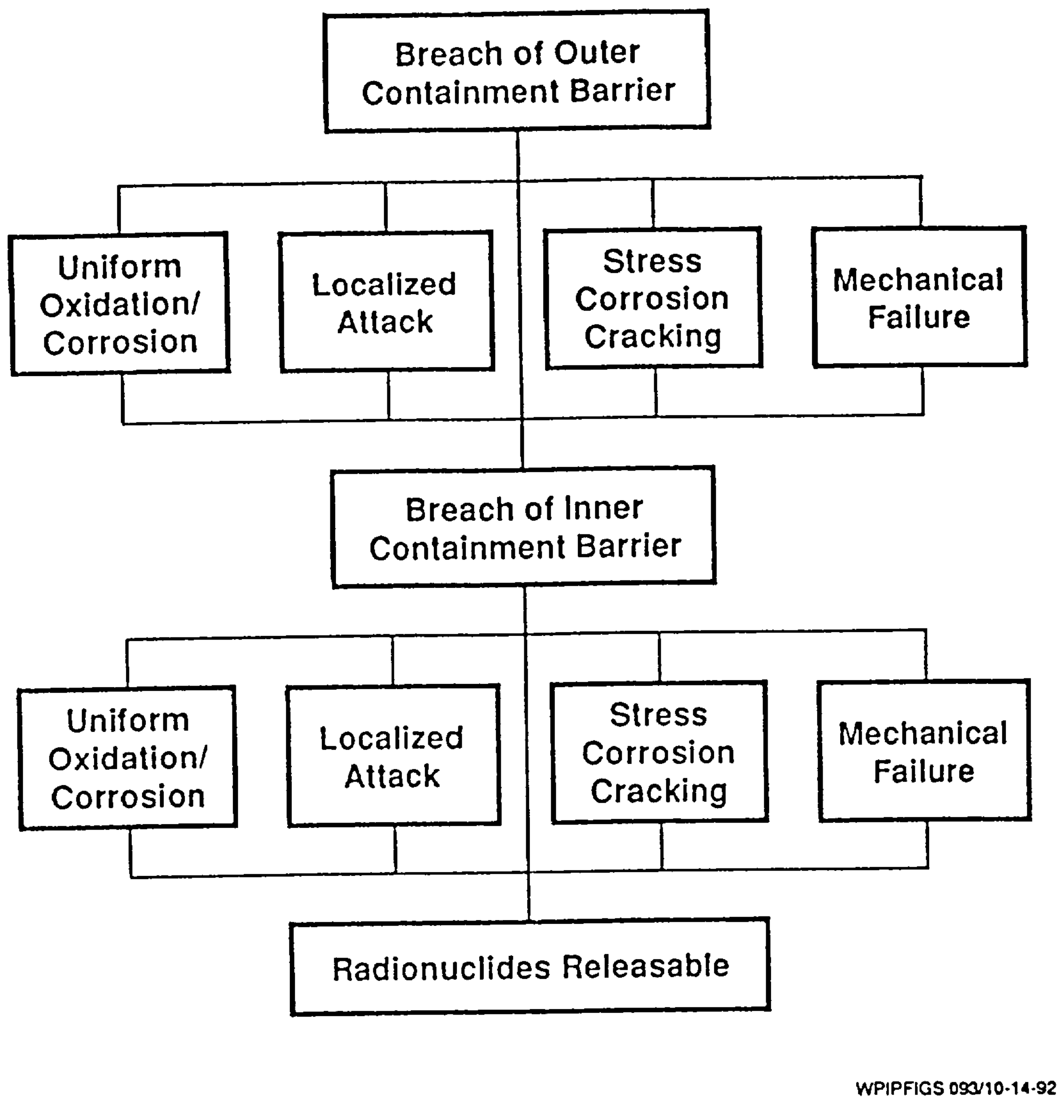

Figure 4.4-1 Waste Package Containment Breach Model Hierarchy

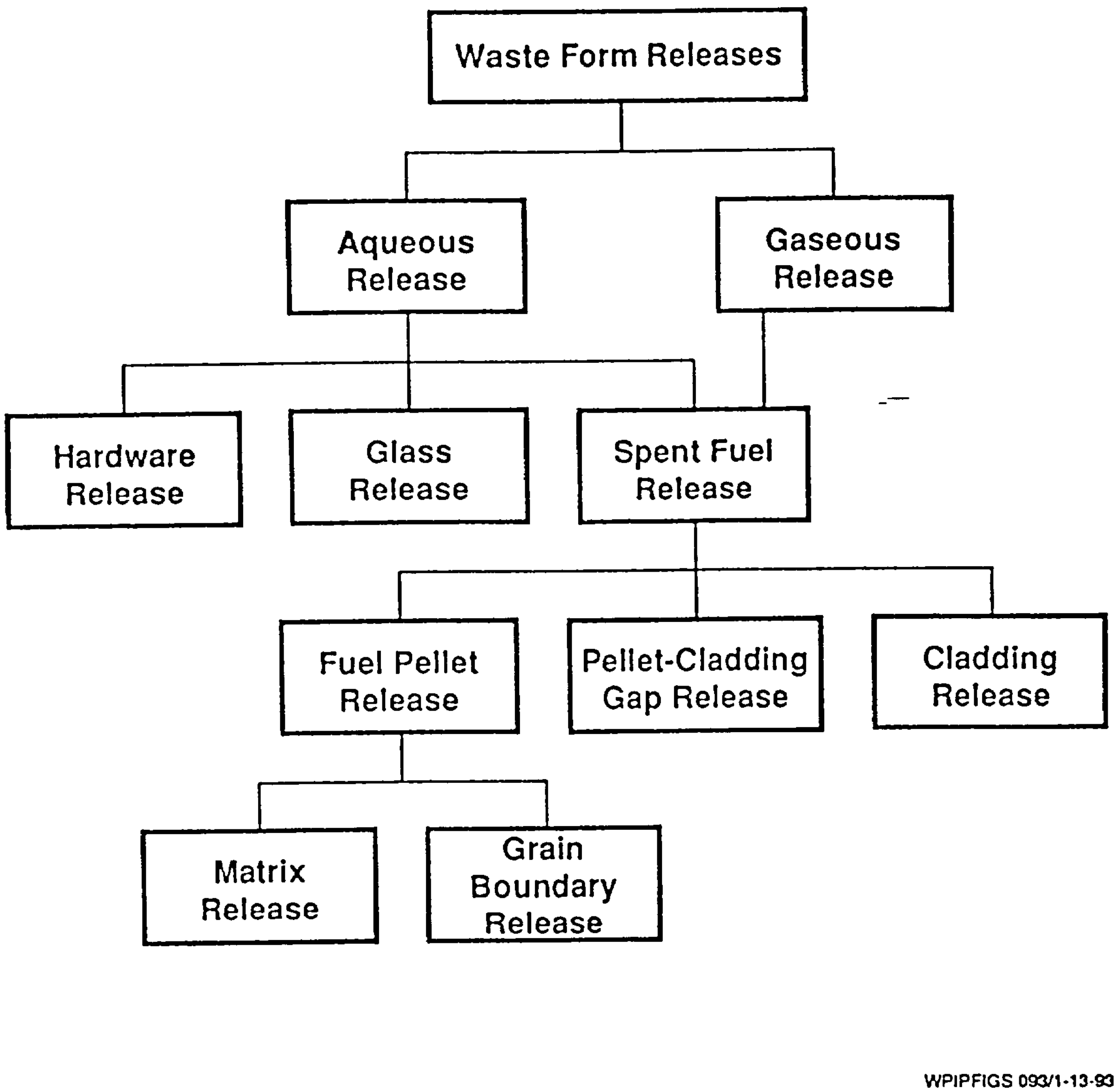

Figure 4 4-2 Waste Form Release Model Hierarchy model developed. It is worth noting that total validation in the classic sense is not achievable given the time frame of repository performance. However, partial validation may be possible with the aid of natural analogues, both for the corrosion-allowance WP materials and the waste forms. Long-term (several years to several decades) and in situ testing can also add confidence that the degradation modes are understood.

This model development approach is shown schematically in Figure 4.4-3. The approach shows the parallel nature of the model development and the testing efforts. Model and test plan development are closely coupled. Results from the early tests strongly impact the evaluation of the conceptual model, while results from confirmation tests and long-term tests impact the final model. Model validation involves both the long-term test results and information from appropriate natural analogues.

The degree of detail provided in each of the submodels will vary depending on the contribution that each is expected to make to the degradation process. For example, the degradation of the corrosion allowance materials due to a localized corrosion process is expected to be small. Thus, the submodel that describes this process can be bounding, rather than totally mechanistic. This assumption, of course, will be confirmed as an outcome of testing or degradation mode surveys. A similar approach will also be taken for waste form release, for example, for the release of radionuclides from hardware.

The submodels developed for each degradation mode must be adapted for system application, as shown in Figure 4.4-3. This implies that the system model must be less complex and be bounding of the results predicted by the more detailed submodels. However, the parametric dependencies provided in the submodels must be retained in the system models, and the overall predictions must also be retained.

4.4.4 COMPLIANCE DETERMINATION

The total number of WP breaches during the containment period, as well as the potential for early breaches, will be calculated for a range of environmental scenarios. Both qualitative and quantitative sensitivity and uncertainty analyses will be performed and compared to the performance objective for SCC to show that it has been met with sufficient margin.
PAs will be performed to determine whether the candidate designs meet the requirements for release of radionuclides as defined in 10 CFR 60.113 and 40 CFR 191.13. The focus of the WP/EBS effort will be on the near-field release and not the total system performance. The assessments will include a range of environmental scenarios. Release will be calculated based on WP, waste form and near-field models. The potential release of radionuclides as a result of the total calculated breaches will be evaluated using source terms developed for each scenario based on the waste form performance (source term) data. Compliance focusses on the release from the EBS and not on the individual WPs. The computational models will include the releases from the packages and the EBS based on the most likely water migration processes. These releases will be integrated, by the Total System PA activity, over all of the processes as a function of time to determine the release to the accessible environment.

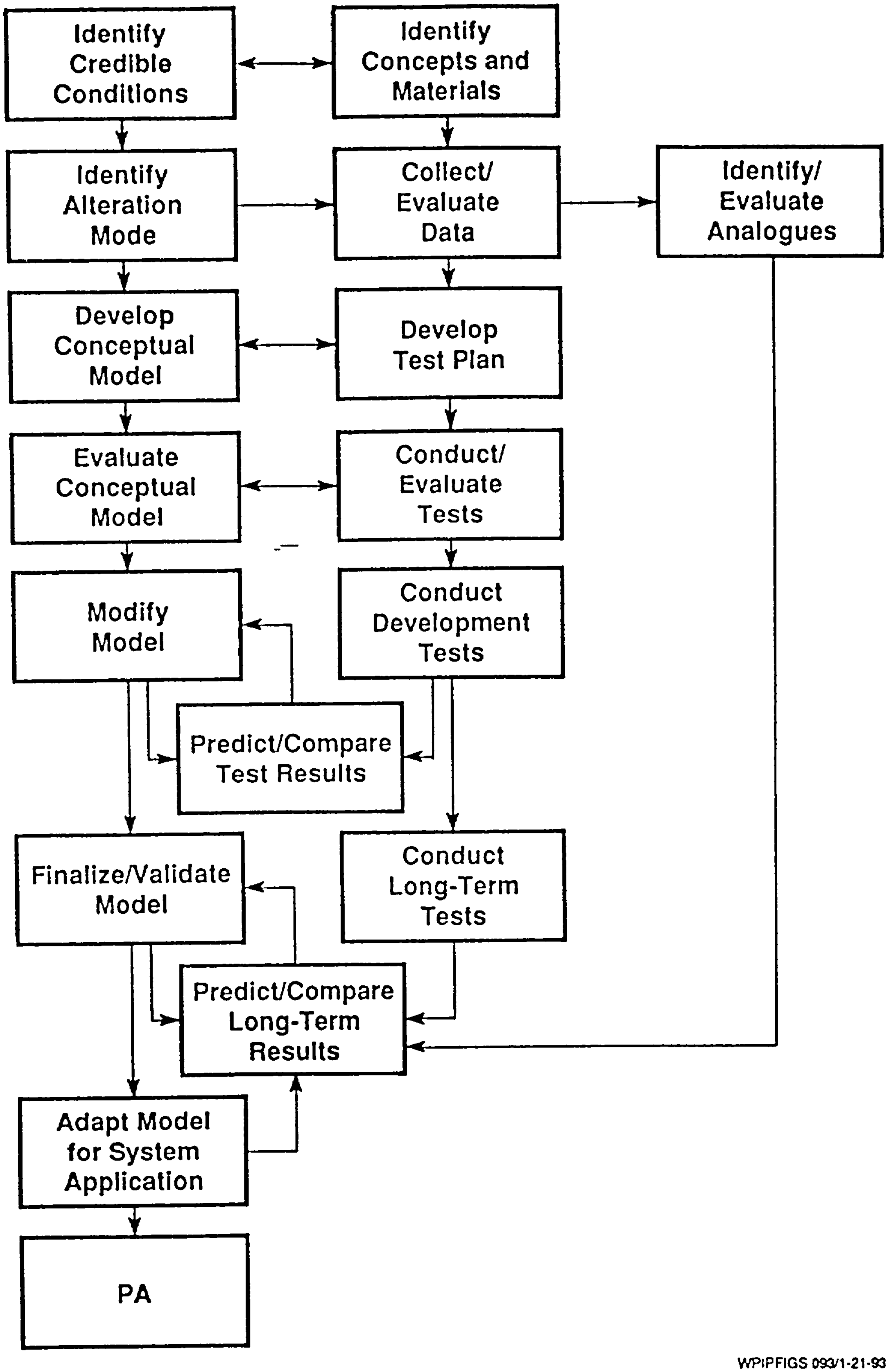

Figure 4.4-3 Model Development Process Chart

Experimentally-derived performance measures will be compared with those predicted by the subsystem level and total system level computational models. These performance measures are based on the allocation of performance to each of the barriers and the performance parameter goals previously established. PA provides suggested changes to these values, following the process steps shown in Figure 1-1, and therefore interfaces with both the design and testing activities. Both qualitative and quantitative sensitivity and uncertainty analyses will be performed to show that compliance has been achieved with sufficient margin. PA will become more detailed and complete as performance measures become available.

5.0 WASTE PACKAGE DEVELOPMENT INTEGRATION

The program summary schedule leading to License Application was provided in the WPP. The activities chart (Figure 5-1) shows the relationships between the major activities in the near term, FY 93 and FY 94. This chart has been taken from the detailed PACS output and shows the high-level activities. The four fields below each activity refer to activity number, duration in days, and start and completion dates. The PACS schedule will be updated to reflect major program modifications.

5.1 WASTE PACKAGE/ENGINEERED BARRIER SYSTEM DESIGN ACTIVITIES

The ACD design calculation will be focused in three interrelated areas: mechanical, thermal, and neutronic characteristics. Included in these activities will be the material selection and the performance analyses. These evaluations are described in Sections 5.2 and 5.3. Using the comprehensive analyses described in Section 4.2, each WP/EBS will be analyzed. A general outline of required calculations include:

1. Mechanical analysis of the WP/EBS
    - 1.1. Emplaced Loads
        - 1.1.1. Internal loads
            - SNF/HLW loads
            - Differential thermal stresses
            - Residual fabrication stresses
            - Internal structural loads
        - 1.1.2. External loads
            - Imposed loads such as rock fall and backfill loads
            - Repository operational loads
    - 1.2. Transportation loads
        - 1.2.1. Internal loads
            - SNF/HLW loads
            - Differential thermal stresses
            - Internal structural loads
        - 1.2.2. External loads
            - Handling accidents
            - Repository operational loads, i.e., transporter induced loads.
    - 1.3. Hot-Cell loads
        - Handling
        - WP loading

2. Thermal Evaluation (time dependent)
    - 2.1. Internal
        - 2.1.1. SNF and HLW
        - 2.1.2. WP basket
        - 2.1.3. WP internal barrier(s)
        - 2.1.4. WP body
        - 2.1.5. Closure
    - 2.2. External, EBS and near field
    - 2.3. Receipt rate thermal variability

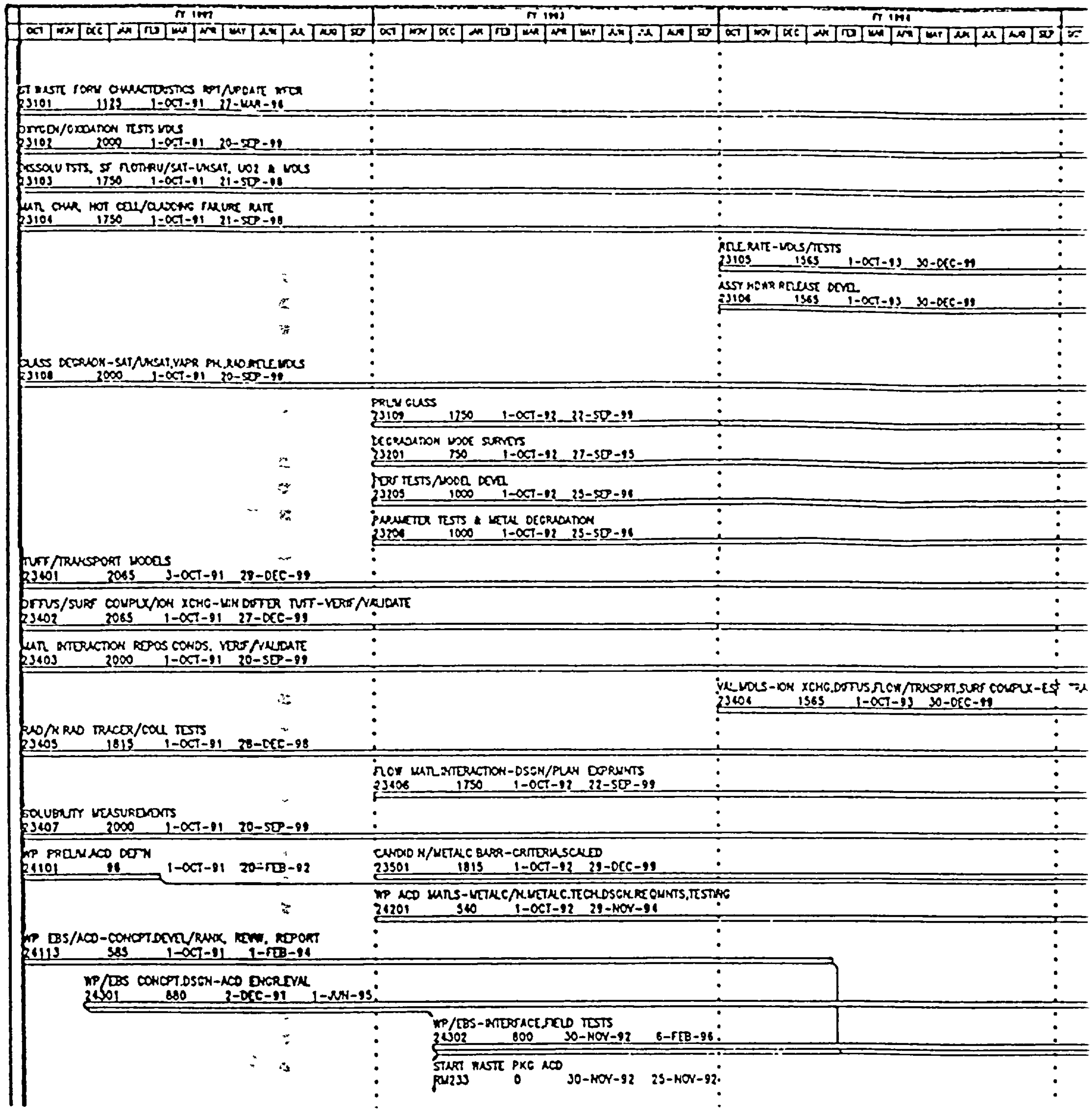

Figure 5-1 Waste Package/Engineered Barrier System Activities Chart

3. Criticality Evaluation (BWR, PWR and Mixed WPs)
   3.1. Time dependency
   3.2. Variable loading, number of assemblies
   3.3. Age, burn-up, burn-up credit and enrichment variability
   3.5. Subsurface
   3.6. Emplacement
   3.7. Stability of components

4. Shielding
   4.1. Time dependent
   4.2. Variable loading, number of assemblies
   4.3. Age, burn-up, and enrichment variability
   4.4. Burn-up credit
   4.5. Subsurface
   4.6. Emplacement

Activity plans will be written to cover the activities planned. The upper-level activity for all of the design calculations is shown in Figure 5-1 as WP/EBS Conceptual Design. Also shown is the effort dealing with the initial screening of concepts under WP/EBS Concept Development.

5.2 MATERIALS TESTING ACTIVITIES

Metal barrier testing that will be performed by LLNL is described in the LLNL SIP for Metal Barrier Selection and Testing. Glass and spent fuel waste form testing that will be performed by LLNL is described in the LLNL SIPs on Glass Waste Form Testing and Spent Fuel Waste Form Testing. Integrated testing that will be performed by LLNL is described in the SIP on Integrated Testing.

Integration of the results of these activities will be performed by the CRWMS M&O. The prioritization of the activities to be performed in any fiscal year will be recommended by the CRWMS M&O in cooperation with the national laboratories as part of the annual development of the budget.

5.3 PERFORMANCE ASSESSMENT ACTIVITIES

The activities performed under model development by the national laboratories and the CRWMS M&O generally are separated into engineering and research activities, respectively. Currently, the work that requires the development of a mechanistic understanding of container materials and waste forms is within the scope of the national laboratory effort. These models are the base of the performance assessment hierarchy pyramid. The intermediate and upper levels of the pyramid are the subsystem and system models, including the development of a WP performance model that interfaces between the mechanistic models and the system models.

Metal barrier performance modeling that will be performed by LLNL is described in the LLNL SIP for Metal Barrier Selection and Testing. Integration of the results of these activities will be performed by the CRWMS M&O. However, parametric and validation testing that supports the model development will be performed by LLNL, as described in Section 5.2.

Glass and spent fuel waste form behavior modeling that will be performed by LLNL is described in the LLNL SIPs on Glass Waste Form Testing and Spent Fuel Waste Form Testing. Integration of the results of these activities will be performed by the CRWMS M&O. However, parametric and validation testing that supports the model development will be performed by LLNL, as described in Section 5.2.

The prioritization of the activities to be performed in any fiscal year will be recommended by the CRWMS M&O in cooperation with the national laboratories as part of the annual development of the budget. The DOE/YMPO will review and approve these recommendations.

6.0 QUALITY ASSURANCE

The Quality Assurance requirements are defined in the DOE Quality Assurance Requirements and Description (DOE, 1992) (QARD) and implemented through the use of approved procedures. The QARD describes the activities for which QA shall be applied. Other activities, such as preliminary or scoping activities, will be performed using standard engineering practices, unless more stringent practices are required by management.

APPENDIX A

REFERENCES

APPENDIX A

REFERENCES

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APPENDIX B

ACRONYM LIST

APPENDIX B

ACRONYM LIST

ACD	Advanced Conceptual Design
ANSI	American National Standards Institute, Inc.
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
BWR	Boiling Water Reactor
CFR	Code of Federal Regulations
CRWMS	Civilian Radioactive Waste Management System
DOE	U.S. Department of Energy
DWPF	Defense Waste Processing Facility
EBDRD	Engineered Barrier Design Requirements Document
EBS	Engineered Barrier System
EPA	Environmental Protection Agency
HLW	High Level Waste
ISI	In-service Inspection
LLNL	Lawrence Livermore National Laboratory
LAD	License Application Design
MGDS	Mined Geologic Disposal System
MIC	Microbiologically Influenced Corrosion
M&O	Management and Operating
NDE	Nondestructive Examination
NRC	Nuclear Regulatory Commission
PA	Performance Assessment
PWR	Pressurized-Water Reactor
RN	Radionuclide
SCC	Substantially Complete Containment
SCP	Site Characterization Plan
SIP	Scientific Investigation Plan
SNF	Spent Nuclear Fuel

TBD	To Be Determined
TP	Task Plan
TRD	Technical Requirements Document
WBS	Work Breakdown Structure
WP	Waste Package
WPP	Waste Package Plan
WVDP	West Valley Demonstration Plant
YMP	Yucca Mountain Site Characterization Project
YMPO	Yucca Mountain Site Characterization Project Office