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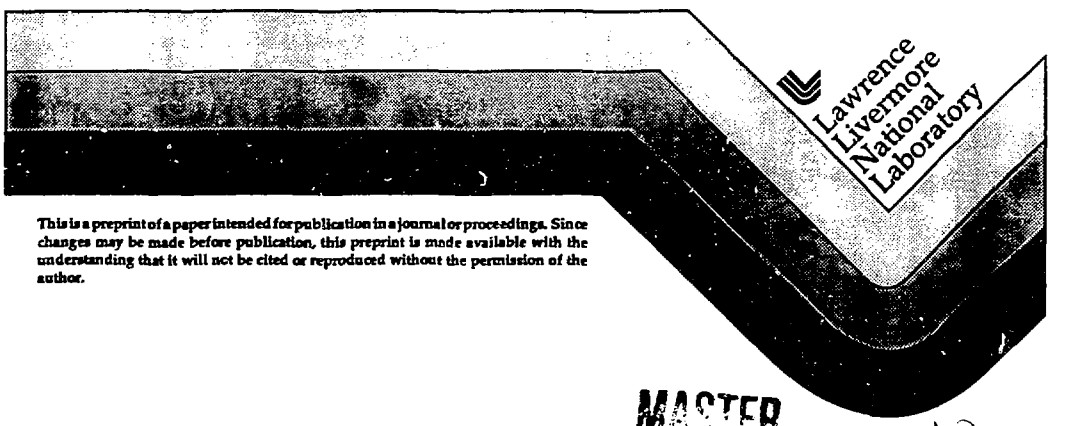

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ABSTRACT

The goal of the U. S. Department Of Energy's (DOE) Yucca Mountain Site Characterization Project (YMP) waste package program is to develop, confirm the effectiveness of, and document a design for a waste package and associated engineered barrier system (EBS) for spent nuclear fuel and solidified high-level nuclear waste (HLW) that meets the applicable regulatory requirements for a geologic repository. The Waste Package Plan describes the waste package program and establishes the technical approach against which overall progress can be measured. It provides guidance for execution and describes the essential elements of the program, including the objectives, technical plan, and management approach. The plan covers the time period up to the submission of a repository license application to the U.S. Nuclear Regulatory Commission (NRC).

INTRODUCTION

The Nuclear Waste Policy Act of 1982 (Public Law 97-425, the NWPA) established a national effort to develop a repository for the permanent disposal of spent fuel and HLW. The NWPA explicitly recognizes the need for development of a waste package program by requiring a discussion of the "possible form or packaging" for the HLW and spent fuel in both the Site Characterization Plan and the DOE Secretary's recommendation for site approval to the President. The NWPA does not mandate specific objectives or function to either the waste package or EBS, though it provides the definition of both terms.

The purpose of the YMP Waste Package Plan is to describe the waste package program and to establish the technical approach against which overall progress can be measured. It provides guidance for program execution and describes the essential elements of the program, including the objectives, the technical plan, and the management approach. The work described in this plan covers the time period up to the submission of a repository license application to the NRC. This plan will be revised as necessary to accommodate changes in the Yucca Mountain Site Characterization Project Office (Project Office) or the Office of Civilian Radioactive Waste Management (OCRWM), and their plans and procedures. The implementation of the Waste Package Plan has been delegated to the Lawrence Livermore National Laboratory (LLNL). LLNL has responsibility for detailed planning and implementation of all waste package program technical activities.

OBJECTIVES

The technical objective of the YMP waste package program is to develop a waste package and associated EBS that can meet these regulatory requirements in a way that compliance with the regulations can be demonstrated in a repository licensing proceeding before the NRC. The NRC rule 10-CFR-60.113 mandates two specific performance objectives for the waste package and EBS after the closure of the repository, and divides the post-closure period into two time periods, conventionally referred to as the "containment" and "controlled-release" periods. The containment requirement applies primarily to the waste packages, and the controlled-release requirement applies primarily to the EBS:

First, Containment [10-CFR-60.113(a)(1)(ii)(A)]:

> ". . . the engineered barrier system shall be designed, assuming anticipated processes and events, so that: Containment of HLW within the waste packages will be substantially complete for a period to be determined by the Commission taking into account the factors specified in 60.113(b) provided, that such period shall be not less than 300 years nor more than 1,000 years after the permanent closure of the repository."

Second, Controlled Release [10-CFR-60.113(a)(1)(ii)(B)]:

> ". . . the engineered barrier system shall be designed, assuming anticipated processes and events, so that: . . . The release rate of any radionuclide

from the engineered barrier system following the containment period shall not exceed one part in 100,000 per year of the inventory of that radionuclide calculated to be present at 1,000 years following permanent closure, or such other fraction of the inventory as may be approved or specified by the Commission; provided, that this requirement does not apply to any radionuclide which is released at a rate of 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."

Third, the requirements relating to post-closure performance of the total repository system [10-CFR-60.112] place additional requirements on the design and performance of the waste package and EBS as follows.

> "The geologic setting and the engineered barrier system and the shafts, boreholes and their seals shall be designed to assure that releases of radioactive materials to the accessible environment following permanent closure conform to such generally applicable standards for radioactivity as may have been established by the Environmental Protection Agency with respect to both anticipated processes and events and unanticipated processes and events."

A fourth requirement is to perform a "comparative evaluation of alternatives to the major design features that are important to waste isolation, with particular attention to the alternatives that would provide longer radionuclide containment and isolation" [10-CFR-60.21(c)(1)(ii)(D)].

There are a number of other requirements that apply to the waste package and EBS prior to the permanent closure of the repository. These include radiological protection [10-CFR-60.111 (a)], retrievability [10-CFR-60-111(b)], and geologic repository operations area design criteria [10-CFR-60.131].

Finally, 10-CFR-60.135 sets forth specific design criteria for the waste package and its components that must be met. These criteria include constraints on the general performance of the package, its chemical reactivity, and provisions for its handling and labeling, as well as design criteria for the waste forms.

The quality objectives of the waste package program are as specified in Subpart G of the Code of Federal Regulations, Chapter 10, Part 60 (10-CFR-60) requiring that all information relating to the design, design analysis, testing, and performance assessment of the waste package and EBS that will form a basis of the license application must be acquired or developed under an NQA-1 quality assurance program based on the criteria of Appendix B of 10-CFR-50 defined as the Office of Civilian Radioactive Waste Management (OCRWM) Quality Assurance Plan (QAP). To this end, all participants in the YMP have developed or adopted Quality Assurance Program Plans (QAPPs) that reflect all requirements of the OCRWM QAP. In the case of the waste package and EBS work, the requirements of the LLNL QAPP are being implemented through a system of Quality Procedures (QPs). The QAPP and QPs are supplemented by a Software Quality Assurance Plan (SQAP) that specifically addresses the implementation of the requirements of the QAPP to computer software. The QAPP, QPs, and SQAP governing the waste package and EBS program are those developed and used by LLNL.

The schedule objectives include the major milestones from the OCRWM and Project Office Repository Program elements for the period of 1990 through the repository license application submission.. The design of the waste package and associated EBS will be developed in three phases, to be consistent with the OCRWM milestones. These phases are: (1) pre-Advanced Conceptual Design; (2) Advanced Conceptual Design (ACD); and (3) License Application Design (LAD). During each phase, designs will be developed based on the requirements and the documented technical data (waste form characteristics, near-field environment, and container and EBS materials properties). Because the final design analyses of the waste package and associated EBS depend on information that will be obtained from both surface-based testing and the underground Exploratory Shaft Facility (ESF), the milestones associated with these aspects of the YMP are linked to the design of the waste package and EBS. A final documentation package will be prepared as input for the license application.

TECHNICAL APPROACH

The technical plan used to develop an acceptable waste package and engineered barrier system (EBS) design will use a classical systems engineering approach. This approach will consist of the following sequence of steps:

a. Define waste package and EBS design requirements.

b. Develop design options to meet requirements.

c. Evaluate design options.

d. Select preferred design option.

e. Develop and engineer the selected preferred design option.

f. Verify that design requirements have been satisfied.

The steps of the systems engineering approach will be pursued in the manner illustrated by the flow diagram in Figure 1 which shows that the waste package program consists of three phases: pre-advanced conceptual design (pre-ACD), currently in

license application design (LAD). Activities included in each of these phases are identified and graphically illustrated in Figure 1. These activities can be subdivided into four categories: design, and environmental, waste form, and materials characteristics. Each of these categories have activities that run through each of the three phases. Also shown in Figure 1 is the interface with performance assessment whose activities are covered in a separate plan.

The first step of the waste package design and development process is to define and document higher-level non-concept-specific requirements that the waste package must meet (box 1, Figure 1). These requirements will be derived directly from the various NRC regulations. Next, the OCRWM adds additional legislative, programmatic, and engineering requirements and defines a top-level allocation of the generic and site-specific requirements among the major subsystems that comprise the Mined Geologic Disposal System (MGDS). After the development of the higher-level requirements and the development of design concepts (box 4, Figure 1), concept-specific Waste Package Design Requirements (WPDR) documents will be prepared and baselined to establish a common basis for the wide variety of activities within the waste package program and for interface activities external to the waste package program that have a need for such information. The allocation of requirements to the waste package components will also be defined and documented in the WPDR. These initial allocations will be based on the preliminary near-field environment characteristics and the preliminary waste-form characteristics which will be documented in the Near-Field Environment Report (NEFR) and Waste Form Characteristics Report (WFCR), respectively.

Based on the best available data for the underground conditions at Yucca Mountain, the near-field environment will be defined and documented (box 2, Figure 1). This document will be baselined and used with the requirements to develop design options during the pre-ACD phase. The environmental conditions of primary concern that will be addressed in this report are: (a) hydrological (water flow and quantity), (b) geochemical (water quality), (c) thermal, (d) radiation, and (e) mechanical loading conditions associated with the near-field environmental perturbations caused from excavation and construction activities, waste emplacement, and closure operations. Initial characterization of the environment will be conducted through field and laboratory tests, model development, and analyses. The environmental characterization analyses will be based on currently available laboratory tests and documented data available from all YMP participants and other available sources in addition to waste package program studies completed prior to the end of FY 90. Repository horizon samples will not be available from either surface-based testing or from the ESF. Therefore, the document will focus on general tuff environments to provide data to bound the environmental conditions. As new data are developed, they will be incorporated in the document using approved change control procedures. Details of specific activities that will be performed will be described in Study Plans and Scientific Investigation Plans.

The waste package plan assumes that anticipated environmental conditions, as used in 10 CFR-60, will be defined during the ACD phase. Prior to that time, the near-field environment activities will establish evaluations of bounding conditions of the expected environmental underground conditions present.

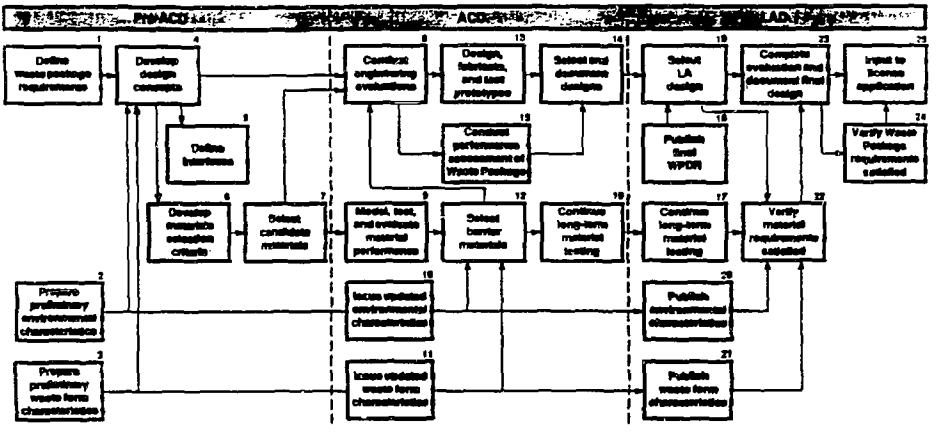

Figure 1. Flow diagram of Waste Package Program.

The values of the parameters in the preliminary document will be selected to include the bounding values that quantify the near-field environment. It is assumed that bounding values include the anticipated conditions to be developed in ACD, and they will be used in all design and WP performance evaluations.

It is well understood that there is a spatial variation of the environmental parameters when considering the overall repository site. It is expected that the acquisition of additional near-field site characterization data under more realistic conditions in subsequent program phases after pre-ACD will establish, for some parameters, narrower distributions and possibly shifts in the mean distribution values. When this occurs, the bounding values may be reduced. Such a shift could enable the designer to modify the design for less severe conditions, or to document and take additional credit for greater design margins.

During pre-ACD, resources will be directed to the documentation of the waste form characteristics that impact the design, development and evaluation of the waste package and the engineered barrier system (box 3, Figure 1). This preliminary Waste Form Characteristics Report will be based on the best information currently available. The WFCR will ensure consistency within all of the various subsystem elements. Special emphasis will be placed on the identification of characteristic parameters that will be required by the designers and evaluators of the components of the waste package and the EBS. Such characteristics include the quantities of various waste forms and the ranges of waste form ages, decay heat contents per unit mass or volume, the specific radionuclide inventories per unit mass or volume, the initial uranium-235 enrichments in spent fuel, and different types of PWR and BWR spent fuel assemblies and associated physical properties. Additional characteristics are required for performance evaluations and performance assessments.

There are two primary types of waste forms, i.e., spent nuclear fuel and vitrified high level nuclear waste (HLW). It is recognized that there may be "other" radioactive wastes that may be emplaced in the repository; however, unless these materials are better defined, no waste package program effort will be expended toward projecting their characteristics until the ACD phase. Details of specific activities that will be performed on all waste forms will be described in Scientific Investigation Plans.

The characteristics used by the designers and performance evaluators must be representative of the total inventory of spent fuel and HLW to be emplaced in the repository. The distributions of the preliminary characteristics will be estimated in pre-ACD in a quantitative form using the best information available. So that the representativeness can be established, bounding values will be established for developing designs; subsequent in-depth investigations and analyses in later design phases will further refine the data to better develop the distributions of the data and to establish more definitive bounding values. These initial distribution estimates will require significant refinements throughout all phases of design. Efforts will be focused on the characteristics of the spent fuel and HLW essential to the design and evaluation of the waste package and engineered barrier systems. Special attention will be given to quantifying parameters where there are near-term applications.

Based on the higher-level requirements, the WFCR, and the NFER, a series of waste package design concepts will be developed and documented. The development of the design concepts will include initial assessments of the feasibility of appropriate container manufacturing and closure processes, with particular attention to aspects that may require development beyond existing industrial practices. These design concepts will be used as the basis for concept-specific waste package design requirements (WPDR's) needed for detailed engineering evaluations during the ACD phase.

Criteria for selection of the container and EBS materials to be used in the ACD will be developed and documented (box 6 in Figure 1). These criteria will follow from the requirements in the WPDR's. The selection criteria translate the functional requirements allocated to the various waste package barrier components in the WPDR into material properties and performance attributes that can be both assessed and quantified to compare candidate materials.

The selection of candidate container and associated barrier materials (box 7 in Figure 1) will be accomplished by the application of the selection criteria. Prior to the material selection, supporting information will be gathered, including existing data on material performance and on barrier fabrication and container closure procedures.

Laboratory testing of the proposed container and associated EBS materials (box 9 in Figure 1) will continue to provide data to demonstrate that the material performance is adequate and also to support the development of predictive failure models. Materials tests to be performed include aqueous corrosion, oxidation, localized corrosion (crevice or pitting), biologically-enhanced corrosion, environmentally assisted cracking (stress corrosion cracking and hydrogen effects), full-scale electrochemical corrosion and stress effects, and long-term phase transformation These tests will lead to the development of models used to predict the required design lifetime.

Engineering evaluations will be conducted at the start of ACD of selected container and associated EBS design concepts to establish their ability to satisfy design requirements and material performance requirements, based on the reference sets of near-field environment and waste form characteristics. A variety of

processes will be evaluated and the preferred design concepts will be selected and documented for further design development.

During the early ACD phase, the initial selection process is expected to result in the recommendation of two or more alternative designs for further development until the final designs can be selected. Prototype waste packages will be designed, fabricated and laboratory tested for each alternative during the second phase of ACD. Based on the engineering evaluations of the design concepts, prototype fabrication and testing, and input from the in-situ tests in the ESF, a final selection will be made during LAD among the waste package design configurations for further development. The selection will be based on (1) the final published WPDR, (2) the existing near-field environment characterizations obtained from both large repository-horizon block tests and from limited underground ESF/EBS field-test data of waste package configurations, (3) existing waste form characterization data, and (4) existing long-term container and associated barrier materials testing data. An initial step of the LAD phase is to review the design requirements and reconfirm that they are satisfied by the design concepts developed during the ACD phase.

Following the selection of a single waste package design, that design will be fully developed, evaluated, and documented. The detailed design will focus on those aspects that will allow the final repository design to be completed and the waste package and repository performance evaluations to proceed. Once these features have been developed, a design configuration freeze will be placed on those elements.

During the LAD phase, the selected design will be documented and verified for conformance with all of the waste package design requirements as specified in the WPDR. This verification process consists of three separate, but inter-related, activities that address: (1) design verification, (2) performance assessment, and (3) confirmation testing.

Verification of the design analysis by qualified individuals who did not perform the analyses will be supplemented by other methods as appropriate. These other verification methods will include formal design reviews, independent peer reviews, or verification tests.

Performance assessments will be conducted to verify those aspects of the design requirements that are mandated by the regulations for time periods beyond the scope of conventional engineering analyses, including "substantially complete" containment for 300 to 1000 years and subsequent control of release of radionuclides from the EBS for 10,000 years following closure of the repository. Compliance will be verified for the design-basis anticipated processes and events. In addition, assessments of the consequences of unanticipated processes and events will be provided as required for the total-system assessments.

The third component of the verification process is the execution of a performance confirmation testing program. The confirmation testing program is comprehensive and extends over the operational life of the repository until closure. Confirmation tests prior to the license application will include manufacture of prototype components to verify the specified processes for fabrication, assembly, and inspection of the engineered waste package assemblies and some in-situ field tests constructed in the ESF as soon as that facility is available. Data from these tests will be utilized in the license application. After repository operations are initiated, in situ monitoring of the performance of representative emplaced waste packages in designated test areas of the facility will continue the performance confirmation testing program.

CONCLUSION

The minimum performance requirements given in the regulations and DOE's EBS mission objectives requires a complex integrated program of activities which will continue for several years. The four categories of activities shown in Figure 1 must provide feed-back between each category and among other elements of the MGDS program during all three phases leading to license application. The Waste Package Plan provides the basis upon which more detail plans can be prepared by each implementing organization involved during each of these phases.

ACKNOWLEDGMENT

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