ATTACHMENT 5

Rockwell Hanford Operations

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Abstract

The Basalt Waste Isolation Project (BWIP) Performance Assessment Plan defines the approach to analysis and use of BWIP Performance Assessment activities for all phases of the project. The report describes both preclosure and postclosure activities. Preclosure activities address system safety during construction, operation, retrieval, and decommissioning. Postclosure activities address repository isolation capability to determine compliance with regulatory criteria. The plan and schedule of activities is consistent with the 1982 Nuclear Waste Policy Act. The plan is a living document and will be revised periodically in response to management and technical needs.

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BASALT WASTE ISOLATION PROJECT
PERFORMANCE ASSESSMENT PLAN

Staff

March 1983

Prepared for the United States
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FIGURES:

TABLES:

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1.0 EXECUTIVE SUMMARY

The Basalt Waste Isolation Project (BWIP) Performance Assessment Plan defines the approach to analysis and use of the BWIP Performance Assessment activities for all phases of the project. The Performance Assessment Plan describes activities related to analysis performed in support of:

- Delineation of system and subsystem performance requirements; i.e., establishing a performance assessment baseline, and allocating performance requirements for repository subsystems
- Preclosure system analysis during construction, operation, and decommissioning
- Postclosure performance analysis of repository isolation potential.

The technical plan is divided into three major sections, which address the activities in each of these subject areas. A section on the management of Performance Assessment activities is included in the plan.

The description of Performance Assessment baseline activities and performance requirements allocation includes: a discussion of the methodology that will be used to establish a baseline using the repository conceptual design (KE/PB, 1982), and the procedure that will be used to allocate system component performance requirements. System component performance specifications will be developed from the component performance requirements.

The preclosure Performance Assessment activity addresses system safety during construction, operation, retrieval, and decommissioning (closure). Over the near term, the primary effort of this task will focus on providing safety analysis support to repository design and contributing to the Preliminary Safety Analysis Report (PSAR).

The Postclosure Performance Assessment effort will evaluate repository performance to determine whether a repository sited at a given location will perform adequately and in compliance with regulatory criteria. The primary objective of Performance Assessment is to provide reasonable assurance of the long-term isolation of nuclear wastes.

The description of the Performance Assessment management and organization includes a discussion of the National Waste Terminal Storage (NWTS) Program interface and its relationship to the BWIP. A discussion of the peer review process, a presentation of the present Performance Assessment schedule and milestones, and the interrelationship of Performance Assessment activities to the balance of the BWIP technical effort is also included.

It is recognized that the Performance Assessment Plan is a living document and will be revised periodically in response to management and technical needs. When deemed appropriate, the document will be updated and reissued. The plan is consistent with the presently mandated schedule for the disposal of high-level radioactive waste, transuranic waste, and spent nuclear fuel.

2.0 INTRODUCTION

2.1 PURPOSE OF DOCUMENT

The Performance Assessment Plan has been prepared to establ' a framework for the purpose of conducting performance assessment a ses for the BWIP. The scope of the Performance Assessment Plan encom ses analyses pertaining to both preclosure and postclosure activitie d to system component performance requirements. Preclosure performan assessment analyses focus on standard radiological and industria . fety issues associated with operating a repository. Postclosure performance assessment analyses focus on the containment and isolation of nuclear wastes emplaced in a mined geologic repository in basalt. Performance requirements allocation analyses provide a basis for assigning performance requirements and the development of performance specifications.

2.2 OVERVIEW AND OBJECTIVES

In February 1976, the U.S. Energy Research and Development Administration, currently the U.S. Department of Energy (DOE), expanded its commercial radioactive waste-management programs and established the NWTS Program. The NWTS mission was defined to provide multiple repository facil''ies in various deep geologic formations within the United States for the terminal storage of nuclear waste. The scope of the program includes development of technology necessary for designing, licensing, constructing, operating, and decommissioning a repository, and identifying a number of geologic sites suitable for location of radioactive waste terminal storage repositories. The Columbia River basalts beneath the Hanford Site were among those geologies selected for initial study and characterization. The Nuclear Waste Policy Act of 1982 formalizes an overall schedule for the NWTS Program.

The BWIP mission is to identify a potential geologic repository site in the basalts beneath the Hanford Site and to develop the associated facilities and technology required for the permanent disposal of radioactive wastes in these formations. If feasibility is shown, DOE may proceed with the detailed design, construction, and operation of such a facility in these basalts.

The BWIP work is organized into major elements of work consistent with the NWTS Program work breakdown structure. Nine Tasks are included in the work breakdown structure for all NWTS projects. The BWIP has broken down these Tasks into end functions that comprise the major elements through which the BWIP is managed.

The BWIP activities within the work breakdown structure are directed toward developing the necessary information to:

- Ascertain the viability of using the basalts beneath the Hanford Site as a nuclear waste repository (Site End Function responsibility)

- Develop waste package designs that ensure waste packages emplaced in a repository in basalt meet proposed regulatory criteria (Waste Package End Function responsibility)
- Develop the technology and design for constructing, operating, and decommissioning a nuclear waste repository in basalt (NWRB) (Repository End Function responsibility).

The objectives of performance assessment activities for the BWIP are summarized as follows:

- Integrate all site characterization, materials testing, analytical results, and design requirements such that an assessment of system performance can be made
- Demonstrate compliance with proposed regulatory criteria and environmental standards
- Identify additional data and/or analyses needs for assessing compliance with proposed regulatory criteria and environmental standards
- Determine performance requirements for repository and waste package design
- Provide assurance of safety to operating personnel and public safety during repository operation
- Support the preparation of site documentation; i.e., Site Characterization Report (SCR) (Rockwell, 1982), semiannual Site Characterization Progress Reports, BWIP input to the Site Recommendation Report, and the PSAR
- Provide assurance of long-term waste isolation.

2.3 STATUS OF BWIP PERFORMANCE ASSESSMENT ACTIVITIES

The scope of the BWIP Performance Assessment activities serves to define isolation and system characteristics, including the near-term and far-term conditions in which the system or subsystem must function, of the repository and to assess this performance relative to regulatory criteria proposed by the U.S. Nuclear Regulatory Commission (NRC) and the U.S. Environmental Protection Agency (EPA). Current activities include acquisition of data for the system description, acquisition and/or development of computer models and related analytical methods, and establishment of performance requirements responsive to the regulatory criteria.

The primary purpose of the Performance Assessment activity is to measure the degree to which the regulatory criteria are met. The regulatory criteria are designated by the NRC in 10 CFR 60 (NRC, 1982) and by the EPA in 40 CFR 191 (EPA, 1982). The current versions of

proposed key criteria related to Performance Assessment are contained in Table 1. The regulatory criteria are presently in draft form. The integrated flux limits specified in 40 CFR 191 are the principal standard for analyses of component and system requirements.

An alternate option to the criteria presently proposed in 40 CFR 191 (EPA, 1982) is to include a dose-to-man criterion as the primary numerical constraint and to subordinate the current numerical limits to the role of design guidelines. As a result of the existence of this option, development of a capability for estimating radiation doses is included in the Performance Assessment activities described in this document.

Mathematical models developed thus far for predicting long-term performance support the design of engineered components of the system relative to the performance criteria developed by the federal regulatory agencies. Relevant and site-specific release scenarios have been formulated for use in these preliminary analyses. The BWIP modeling methodology is based on the conjunctive use of a suite of deterministic numerical models that describe the coupled processes of rock stress/strain, heat transfer, groundwater flow, and nuclide transport. Sensitivity and uncertainty analysis will be used to define probabilities to assist in the establishment of levels of confidence. A description of the various mathematical models that will be used in the BWIP performance assessment analyses is provided in Appendix A. As presented in Appendix A, a strategy for analysis using different combinations of computer codes will be used when addressing different criteria.

A summary of the definitions of terms used in this plan is listed in Appendix B. Performance assessment criteria are indexed in Appendix C. The U.S. Department of Energy proposed general guidelines (DOE, 1983) for the siting of nuclear waste repositories are indexed in Appendix D, and the transport pathway and parameter characteristics are described in Appendix E.

Table 1. Applicable Proposed Criteria.

Factor	Measure
Preemplacement groundwater travel time	The geologic repository shall be located so that preemplacement groundwater travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment shall be at least 1,000 yr (NRC, 1982).
Containment of high-level waste in a waste package	Containment will be substantially complete for a period of 1,000 yr after permanent closure of the geologic repository, or such other period as may be approved or specified by the commission (NRC, 1982).
Radionuclide release rate	The release rate of any radionuclide following the containment period shall not exceed one part in 100,000 per yr of the inventory of that radionuclide calculated to be present at 1,000 yr following permanent closure. This requirement does not apply to any nuclide that is released at a rate 0.1% of the calculated total annual release at 1,000 yr following permanent closure (NRC, 1982).
Total system performance	Integrated nuclide fluxes into the accessible environment during the 10,000-yr period following decommissioning must not exceed the values stated in Appendix B of 40 CFR 191 (EPA, 1982).
Modification of the subsystem performance requirements stated above	On a case-by-case basis, the NRC may approve or specify some other radionuclide release rate designed containment period or preemplacement groundwater travel time as needed for the commission to find that the overall system performance objective is satisfied (NRC, 1982).
Preclosure safety	The geologic respository operations area shall be designed so that until permanent closure has been completed, radiation exposures, radiation levels, and releases of radioactive materials to unrestricted areas, will at all times be maintained within the limits specified in 10 CFR 20 (NRC, 1979) and such generally applicable environmental standards as may have been established by the EPA (NRC, 1982).

3.0 TECHNICAL PLAN OVERVIEW

The basic approach to Performance Assessment is illustrated in Figure 1. This figure is a logic diagram that relates the basic activities that will be performed to accomplish the tasks discussed in the subsections that follow. The logic and organization of the plan is consistent with Performance Assessment as discussed in the BWIP SCR (Rockwell, 1982). Performance Assessment activities will be directed towards supporting design improvements by providing input to engineering studies, consequence and comparative risk assessment, and licensing activities. Although not shown in Figure 1, the approach is iterative and progressively refines the data and analytical techniques used to ensure an accurate portrayal of system behavior, and refines system design to ensure that the governing performance criteria are satisfied.

3.1 OVERVIEW

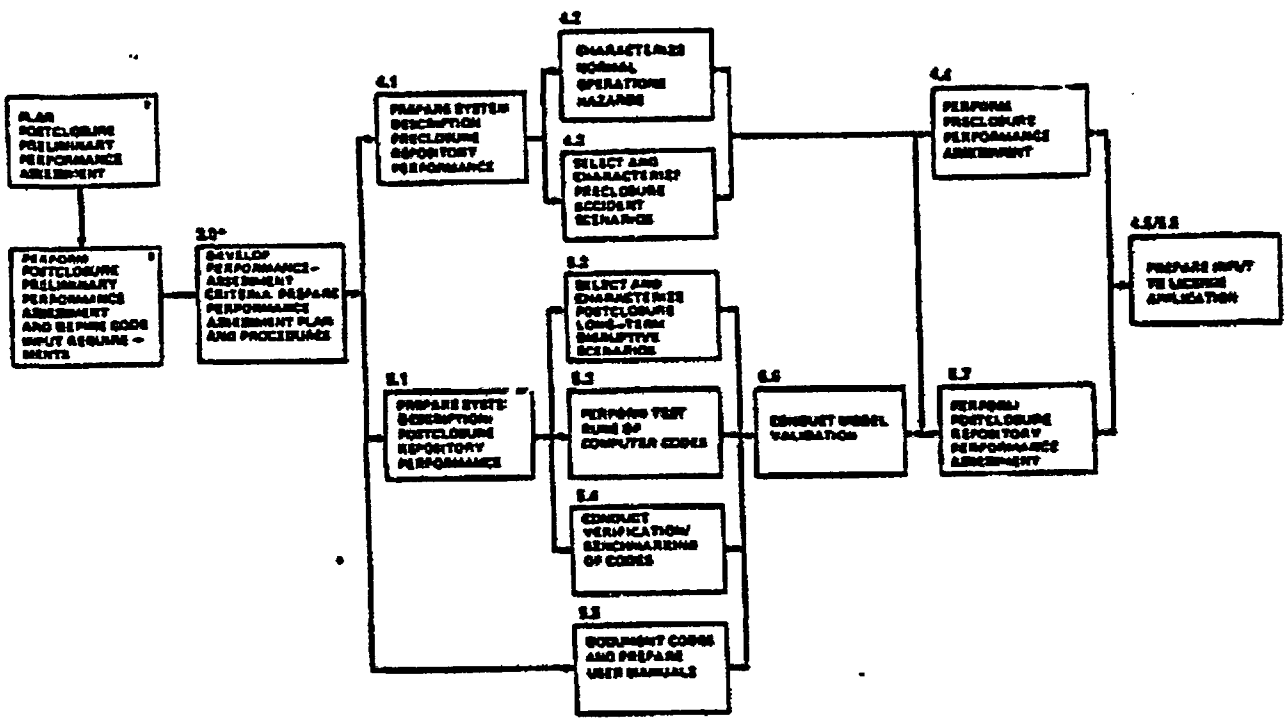
The activities identified in Figure 1 define an overall strategy that will be used to accomplish three primary tasks in support of the BWIP mission:

- Allocate system component performance requirements and establish subsystem performance specifications
- Perform preclosure safety analyses, design reviews, and special studies in support of system design
- Perform postclosure performance analysis to evaluate repository performance and compliance with regulatory criteria.

3.1.1 Baselining and System Component Performance Requirements Allocation

Computer codes that will be used by the BWIP in an initial baseline Performance Assessment have been developed. Use of these codes in conjunction with credible worst-case assumptions will provide the basis for an initial baseline Performance Assessment. The initial baseline Performance Assessment will serve two purposes. First, it will establish a preliminary subsystem level of performance for both the geologic and engineered subsystems. Secondly, the analysis will be used to identify appropriate sensitivity and uncertainty analysis that can be related to engineering safety margins, etc. A discussion of the preliminary baseline analyses is provided in the section entitled "Performance Assessment Initial Baseline" (5.3.2).

A procedure will be developed to allocate system performance requirements (i.e., waste package performance requirements and repository performance requirements) in conjunction with estimated site performance requirements. The approach will be to first identify the performance that can be achieved by the geologic setting (site) and then identify



*NUMBERS INDICATE SECTIONS OF THE PERFORMANCE ASSESSMENT PLAN WHICH DISCUSS ACTIVITY.

† ACTIVITIES CONDUCTED PRIOR TO PREPARATION OF THIS PLAN

FIGURE 1. The Basalt Waste Isolation Project Performance Assessment Logic Diagram.

the additional performance that must be achieved by each of the engineered subsystems(waste package and repository). For example, if it can be demonstrated that the geochemical characteristics of the site provide sufficient containment such that most nuclides cannot migrate in a basaltic environment, the complexity of the engineered subsystems can be reduced. Assuming that such simplification satisfies regulatory requirements, use of natural materials (clay and crushed basalt) might be substituted for more complex engineering. These types of analyses will be used to support engineering design studies and trade-off studies. A discussion of allocating system component performance requirements is provided in the section entitled "System Component Performance Requirements Allocation" (5.3.3).

3.1.2 Preclosure Performance Assessment

Preclosure Performance Assessment activities are directed towards evaluating repository operations to ensure compliance with applicable nuclear and non-nuclear safety performance criteria. The logic diagram for the BWIP Performance Assessment (Fig. 1) identifies the generic activities needed to perform a preclosure safety analysis. Based on identified normal operations hazards and accident scenarios, the preclosure Performance Assessment will include analyzing the consequences of hazardous operations and the recommendation of preventive and mitigating measures. These recommendations will be evaluated by the architect-engineer and appropriate changes in design criteria or design concepts will be made to eliminate safety-related deficiencies. The revised design will then be subjected to safety analysis. The process of repository design followed by safety analysis will be repeated for each design phase, eventually leading to the preparation of the PSAR and Environmental Report portions of the license applications for construction, operation, and decommissioning.

3.1.3 Postclosure Performance Assessment

The basic objective of postclosure Performance Assessment is to demonstrate that a repository in basalt will satisfy the requirements set forth by the regulatory agencies (NRC and EPA). Two iterative processes are included: (1) a process that progressively refines the analytical techniques used to assess performance to ensure an accurate representation of system behavior, and (2) a process that refines the system design and/or site layout to ensure that governing performance criteria are met. Both processes proceed in parallel, though it is obvious that the final assessment of isolation system acceptability cannot be completed until after final acceptance of the Performance Assessment methodology is found to be acceptable using appropriate testing procedures (i.e., verification, benchmarking, and validation).

The logic diagram (see Fig. 1) illustrates (excluding iterative processes) the orderly development and application of Performance Assessment methodology in support of the BWIP postclosure Performance Assessment licensing requirements.

3.2 PERFORMANCE ASSESSMENT CRITERIA

3.2.1 Preclosure Criteria

The principal regulatory criteria applicable to preclosure performance of the NWRB are listed in Table 2. In case of conflict between applicable standards, the most restrictive shall apply (see Table 2). A complete statement of the draft preclosure criteria contained in 10 CFR 60 (NRC, 1982) is included in Appendix C.

3.2.2 Postclosure Criteria

The draft proposed criteria that define the performance objectives for postclosure of an NWRB are summarized in Table 3. Complete statements of these criteria are found in Appendix C. The postclosure performance objectives in 10 CFR 60 (NRC, 1982) focus on the overlapping roles (multibarrier) of the waste package, repository, and site subsystems as required to control release of radionuclides from the engineered system. The EPA criteria focus on release from the site subsystem to the accessible environment. The NRC also considers the criteria on preemplacement groundwater travel time as an adjunct to defining a suitable site subsystem; however, due to the time phase covered, it is listed separately. Finally, the NRC has defined a requirement that the site subsystem accommodate any failure of the waste package system and mitigate any disruptive events or processes on the engineered system.

All regulatory criteria for mined geologic disposal are presently in draft form and revisions to the present draft criteria can be expected. The NWTS Program is using preliminary information from the NRC and the EPA, review comments from the nuclear industry, and analysis by the project staffs to prepare a "Mined Geologic Disposal System Requirements" document (ONI, 1982) for the waste isolation system (geologic disposal system). The purpose of the NWTS Mined Geological Disposal System Requirements (MGDSR) document is to provide the NWTS Program with generic requirements for the characterization, design, Performance Assessment, and field activities of the projects in the NWTS Program. The document defines the waste isolation system and its subsystems in terms of its bounds (definition), functional requirements, and performance requirements. The MGDSR, when complete, will serve as a requirements document for the activities of the BWIP. Some of the proposed criteria and definitions contained in this plan were taken from the MGDSR.

3.2.3 Department of Energy Siting Guidelines

The DOE has proposed general guidelines for selecting sites for Nuclear Waste Repositories (DOE, 1983). The proposed guidelines are presented in three parts: system guidelines, program guidelines, and

TABLE 2. Preclosure Performance Assessment Criteria for a Nuclear Waste Repository in Basalt.

eria and status	Criteria focus	NWRB subsystem	Reference	Criteria summary
FR 191 (Draft)	Radioactive releases	Total	10 CFR 60.111(a) (NRC, 1982)	Public exposure to radiation from normal repository operations shall be 25 mrem/yr to the whole body.
:FR 20 (Issued) :, 1979)	Radioactive releases	Repository	10 CFR 60.111(a) (NRC, 1982)	Radiation exposure of individuals in unrestricted areas shall be 0.5 rem/yr. Effluent concentrations shall comply with Appendix B, Table II.
:FR 60 (Draft)	Retrievability	Repository and Waste Package	10 CFR 60.111(b) (NRC, 1982)	Waste shall be retrievable until completion of a performance confirmation program.
:FR 20 (Issued) :, 1979)	Occupational radiation protection	Repository	10 CFR 60.131(a) (NRC, 1982)	Occupational exposure to radiation shall be limited to 5 rem/yr whole body dose and Appendix B, Table 1, Column I concentrations.
:FR 60 (Draft)	Criticality	Repository and Waste Package	10 CFR 60.131(b) (7) (NRC, 1982)	Criticality accident is not possible unless two unlikely, independent, and concurrent or sequential changes in safety systems occur and K_{eff} 0.95.
:FR 57, Chapter I, :hapters D, E, N (Issued) IA, 1981)	Mine safety	Repository	10 CFR 60.131(b) (9) (NRC, 1982)	Mine Safety and Health Administration Regulations.

CFR = Code of Federal Regulations.
OOE = Department of Energy.
ONI = Office of National Waste Terminal Storage Integration.

TABLE 3. Postclosure Performance Assessment Criteria for a Nuclear Waste Repository in Basalt*.

riteria and status	Criteria focus	NWRP subsystem	Reference	Criteria summary
0 CFR 191 (Draft)	Isolation	Total	10 CFR 60.111(a) (1) (NRC, 1982)	Integrated mass flux to the accessible environment at 10,000 yr after closure.
0 CFR 60 (Draft)	Isolation	Engineered System	10 CFR 60.113(a) (1)(ii)(B) (NRC, 1982)	Releases from the engineered system shall not exceed 10^{-5}/yr (does not apply to radionuclides that contribute 0.1% of the total annual curie release).
0 CFR 60 (Draft)	Containment	Waste Package	10 CFR 60.113(a) (1)(ii)(A) (NRC, 1982)	1,000-yr containment of waste after closure.
.0 CFR 60 (Draft)	Groundwater Travel Time	Site	10 CFR 60.113(a) (1)(ii)(B)(2) (NRC, 1982)	Preemplacement groundwater travel time from the disturbed zone to the accessible environment shall be >1,000 yr.

*Draft 10 CFR 60 and 40 CFR 191 regulations present numerical subsystem performance requirements. The current version of 10 CFR 60 provides that the subsystem requirements may be modified, subject to approval by the NRC. Therefore, alternate approaches to measuring system performance, such as a dose-to-man criterion, are being examined.

technical guidelines. The system guidelines address the primary objectives of protecting the health and safety of the public and the environment. They relate the performance of the geologic repository system to standards for allowable releases of radioactive material and provide the basis for developing the technical criteria. The program guidelines define the policy requirements to be followed in implementing the DOE's program for selecting a repository site.. The technical guidelines specify factors for the qualification and disqualification of sites and the conditions that would be considered favorable or potentially adverse. A summary of the proposed guidelines is contained in Appendix D.

The BWIP, in its Performance Assessment activities, will use the present waste isolation system criteria (EPA, 1982) as the primary basis for evaluating an NWRB until such criteria are formally replaced. The subsystem criteria in the present drafts of 10 CFR 60 (NRC, 1982) will be utilized as design criteria for the subsystems of an NWRB. Studies to assess the cost and safety impacts of these criteria will be conducted.

4.0 PRECLOSURE PERFORMANCE ASSESSMENT

The preclosure Performance Assessment activity addresses the safety of the NWRB during repository construction and operation until permanent closure of the facility, including optional retrieval of emplaced waste. Emphasis of the preclosure Performance Assessment activities is on ensuring safety of the engineered system (waste package and repository) through support of design and licensing of the NWRB. Preclosure safety analysis will include evaluations of:

- Normal and accident conditions
- Internal and external events that impact safety
- Radiological and nonradiological occurrences
- Onsite and offsite consequences.

Performance of the NWRB during the operational phase will be measured with respect to compliance with nuclear and non-nuclear criteria governing public health, occupational safety, and environmental standards. Studies of preclosure safety will be directed towards preparation of appropriate documentation of system safety to be incorporated in license applications for construction authorization, operation, and decommissioning (closure). Contents of the license application, specifically the Safety Analysis Report and Environmental Report are addressed in 10 CFR 60.21 (NRC, 1981a) and 10 CFR 51 (NRC, 1980), respectively.

Assessment of preclosure performance will involve an iterative process of safety analysis during each repository and waste package design phase. The level of detail and the techniques used in the safety analysis will be governed by the complexity and detail in the system design description. Formal documented safety analyses will be conducted following the completion of each major design phase: conceptual, upgraded conceptual (KE/PB, 1982), Title I, and Title II designs. Such safety analyses will provide input to design criteria and will include recommendations for ensuring that the design will comply with applicable safety critera. During each design phase, the preclosure Performance Assessment team will provide assistance to the architect/engineer responsible for design in identifying and resolving safety issues.

Federal, state, and local standards will be screened for their applicability to environmental releases and occupational safety for the NWRB. Nuclear safety, industrial safety, and mine safety criteria will be considered. Criteria may take the form of existing or proposed regulations directly applicable to a nuclear waste repository (10 CFR 60 (NRC, 1982), 10 CFR 20 (NRC, 1979), 40 CFR 191 (EPA, 1982), 29 CFR 1910 (CFR, 1979a), 29 CFR 1926 (CFR, 1979b) etc.) or existing guidelines for similar nuclear or non-nuclear operations. Regulatory criteria will then be translated into more specific design safety criteria. Regulatory agency and pertinent project-specific design criteria are reviewed at each design phase to determine their continuing applicability and adequacy.

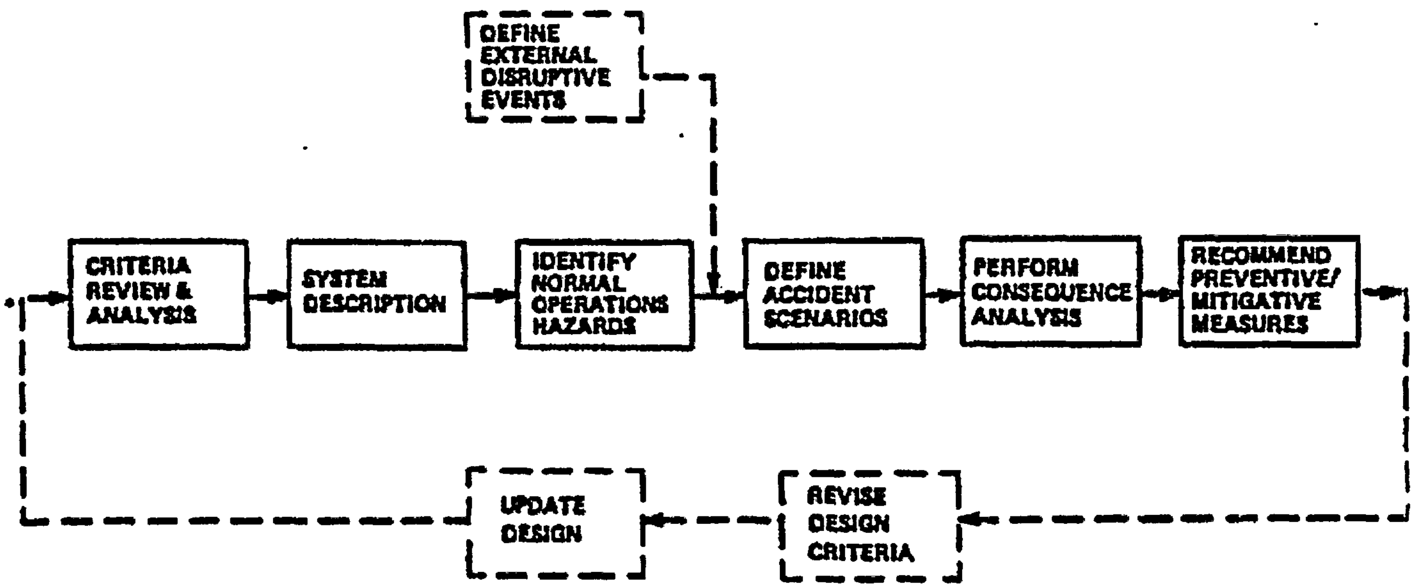
Changes in regulations, design analysis methods, or information from test results will be evaluated for their impact on repository preclosure safety. While the focus of this task is on the development of safety criteria, it is recognized that safety considerations may influence related reliability, structural, maintenance, quality assurance, and operating criteria.

The depth of each formal safety analysis will be governed by the complexity and detail of the design on which it is based. Therefore, the techniques used in the analysis will become progressively more quantitative and precise with each design iteration. Early preclosure safety studies based on the Conceptual System Design Description will rely on qualitative description of hazards, while a safety analysis based on Title I Design will employ quantitative risk assessment and fault-tree techniques. However, each phase of safety analysis will follow a similar logic sequence. A generic methodology for safety analysis is shown in Figure 2 and is described below. This figure describes an iterative process that is directed towards design safety support.

4.1 SYSTEM DESCRIPTION

To conduct a safety analysis requires an accurate description of the process or system under evaluation. The system description will be based on available design and test data that can be used to characterize repository construction, operation, decommissioning, and retrieval operations under normal operational conditions. The system description will be developed in sufficient detail to serve as the basis for subsequent safety analysis and will be updated following the completion of each major design phase. Flow diagrams may be utilized to describe repository operations and will typically identify associated personnel requirements and duration of each process. These flow diagrams will allow an evaluation of occupational exposure to radiological and nonradiological hazards. In addition, subcomponent and equipment descriptions will define the physical characteristics and operating conditions of hardware utilized and identify the chemical species present. The boundary conditions for each subcomponent will be defined and interfaced with other subcomponents identified. When detailed design information becomes available, the system description activity will be directed towards the preparation of a unit operations list. Each unit operation will be defined by a unique set of conditions containing a:

- Distinct set of radiological, chemical, and environmental conditions
- Specific population or number of workers involved
- Defined duration
- Defined physical boundary or work space.



* NOTE: DASHED LINES INDICATE RELATIONSHIPS OF ACTIVITIES TO OTHER PROJECT ELEMENTS THAT ARE NOT WITHIN THE PRECLOSURE PERFORMANCE ASSESSMENT TASK.

FIGURE 2. Preclosure Performance Assessment Safety Analysis Methodology.

4.2 CHARACTERIZATION OF NORMAL OPERATIONS HAZARDS

This task focuses on the identification and evaluation of subsystem operations that involve potential hazards. Hazardous material inventories and dispersal mechanisms that can impact system safety under normal operating conditions are identified. Each hazard is then classified into appropriate categories, such as radiological, chemical, occupational, environmental, etc. A review of the repository design will be performed to ensure compliance with established safety criteria. Hazards that warrant further quantitative analysis of associated consequences will be identified. Prior to formal consequence analysis, preventive and/or mitigative measures that can be incorporated as alternative design concepts or improved operating procedures will be presented.

4.3 SELECT AND CHARACTERIZE ACCIDENT SCENARIOS

For preclosure safety analysis, accident scenarios that may impact system safety will be identified and described. Scenarios considered will be those that can result in occupational or offsite hazards to the general public. Accident conditions that may be created by events induced both within and external to the facility will be examined. As shown (see Fig. 2), external disruptive events, including both natural phenomena and man-induced events, are defined as part of a separate task outside the scope of the preclosure Performance Assessment activity. Failure Modes and Effects Analysis and fault-tree analysis will be used to evaluate accident conditions resulting from equipment failure and operator error within the facility. Probabilities will be assigned to accident-initiating events and succeeding events to allow an assessment of the cumulative probability of a given scenario. All postulated abnormal occurrences will be appropriately categorized according to the expected type of consequences (e.g., radiological, chemical), and a ranking of various accidents by probability of occurrence will be established. The complete list of accident scenarios should represent a full range of possible occurrences, from low to high probability, to ensure that bounding conditions for accident analysis have been defined. Criteria for selection of credible accident scenarios will be developed and applied to the categorized list of scenarios. Accident scenarios deemed credible will be subjected to a formal analysis of possible consequences.

4.4 PRECLOSURE PERFORMANCE ASSESSMENT: CONSEQUENCES AND MITIGATIVE MEASURES

4.4.1 Consequence Analysis

The consequences of selected hazardous repository operations under normal and accident conditions will be evaluated and compared to applicable criteria. Consideration will be given to radiological, industrial, and mine safety hazards to the public and to repository personnel. This task will lead to the documentation of quantitative estimates of consequences

and a measurement of risk (probability times consequence) for various normal operations hazards and accidents. Safety hazards will then be classified and ranked in terms of relative risk.

Mine accidents will be analyzed for their impact on occupational safety and relationships to radiological hazards will be identified. For radiological incidents, the consequence analysis will be carried to the point where occupational or public exposures can be calculated. To this end, the consequence analysis will include evaluation of:

- Contaminant source terms
- Transport pathways
- Radiological dose consequences.

Source terms will be quantified through detailed analysis of previously described accident scenarios. Release characteristics will depend on the type of initiating event (e.g., fire, explosion) and the fraction of waste inventory involved. Within the facility, transport pathways will be determined by ventilation system performance, radioactive waste system capabilities, and the anticipated response of monitoring systems and personnel to accident conditions. Environmental pathways through air and water will be evaluated with appropriate models, such as those currently used in safety analysis of nuclear power reactors. Radiological dose to the public and to repository personnel will be calculated considering the population exposed and doses accumulated through the processes of direct exposure, inhalation, ingestion, or immersion.

4.4.2 Recommendation of Preventive and Mitigative Measures

The consequence-based analysis culminates in the recommendation of specific means of improving the repository design with respect to system safety. Preventive measures are utilized to preclude the possibility of an accident occurring, whereas mitigation measures are designed to minimize the consequences of an accident and permit recovery from accident conditions. Recommendations are tailored to revising pertinent safety design criteria, identification of alternate design concepts that meet functional requirements with greater safety, or modifying operating procedures. Because this task represents an integration of safety analysis studies with the repository design, the final list of recommendations must be the result of a cooperative effort between performance assessment activities and the repository architect/engineer.

Based on the quantified risk of various hazards identified in the previous task, a risk (safety) management approach will be outlined that sets specific goals for dealing with preclosure safety hazards. Threshold criteria for safety risks will be established above which preventive or mitigative measures must be employed. Those events that fall below this threshold will be considered unlikely to compromise safety. However, those subsystem operations considered safe will be examined for risk reduction through cost-effective means. Such an approach to balancing

risk versus cost with respect to radiological exposure will be used in the development of an ALARA (as low as reasonably achievable) methodology applicable to the operational phase of the NWRB. Recommendations for safety improvements will be referred to the architect/engineer for redesign of affected repository systems. Because of the interaction of often conflicting objectives relative to safety, reliability, maintenance, constructibility, and cost-effectiveness, the architect/engineer will be responsible for selection of preventive or mitigative measures. The revised design will then be subjected to a final safety analysis to ensure that safety criteria and risk management objectives have been achieved.

4.5 PRECLOSURE PERFORMANCE ASSESSMENT SCHEDULE AND INTERFACES

The previous section has identified a generic methodology for preclosure Performance Assessment that will be iteratively applied at the completion of each repository design phase. The preclosure Performance Assessment activity will serve as the focal point for preparing safety analysis input to licensing documents. The major safety analysis activities leading to the preparation of a license application for repository construction authorization are shown in Figure 3.

4.5.1 Preliminary Hazards Analysis

The Preliminary Hazards Analysis will involve an initial safety analysis of conceptual waste package and repository design. This analysis will be documented in a report to be completed by the end of the fiscal year 1984 in support of the initiation of the repository Conceptual Design Upgrade. The level of detail in the current repository conceptual design dictates that the Preliminary Hazards Analysis will be qualitative in many areas. Emphasis will be on identifying significant safety hazards that warrant further consideration in the development of design criteria and in the Conceptual Design Upgrade. Fiscal year-1983 activities will concentrate on establishing safety criteria, methodology development, and definition of accident scenarios. An interim report will be prepared documenting the results of fiscal year-1983 studies, primarily as an input to the update of design criteria. Fiscal year-1984 preclosure safety studies will quantitatively define the consequences of potential hazards and document recommendations for hazard prevention and mitigation.

4.5.2 Design Support - Upgraded Conceptual Design

During the preparation of the Upgraded Conceptual Design, the preclosure Performance Assessment activity will function in a level of effort commensurate with the need of the architect/engineer. Assistance will be provided in concept selection and safety design review, as needed.

4.5.3 Safety Assessment

Based on the Upgraded Conceptual Design, a detailed safety assessment will be conducted as input to the Repository Preliminary Design and the license application for construction authorization. The analyses will be summarized in a Safety Assessment Report to be completed by the end of the second quarter of fiscal year 1986. Analyses in the Safety Assessment Report will form the technical basis for the preparation of oreclosure safety input to the Site Recommendation Report and the license application for construction authorization.

4.5.4 Preclosure License Application Input

The license application for construction authorization will require input from the preclosure Performance Assessment activity, specifically to the Preliminary Safety Analysis Report (cited in 10 CFR 60.21) (NRC, 1982) and the Environmental Report (cited in 10 CFR 51) (NRC, 1981b). Appropriate sections of the license application documents will be prepared during fiscal year 1986 based on the Upgraded Conceptual Design and the Safety Assessment Report results. The preclosure input to the license application will be completed by the end of fiscal year 1986 to allow for nine months review and approval by the DOE.

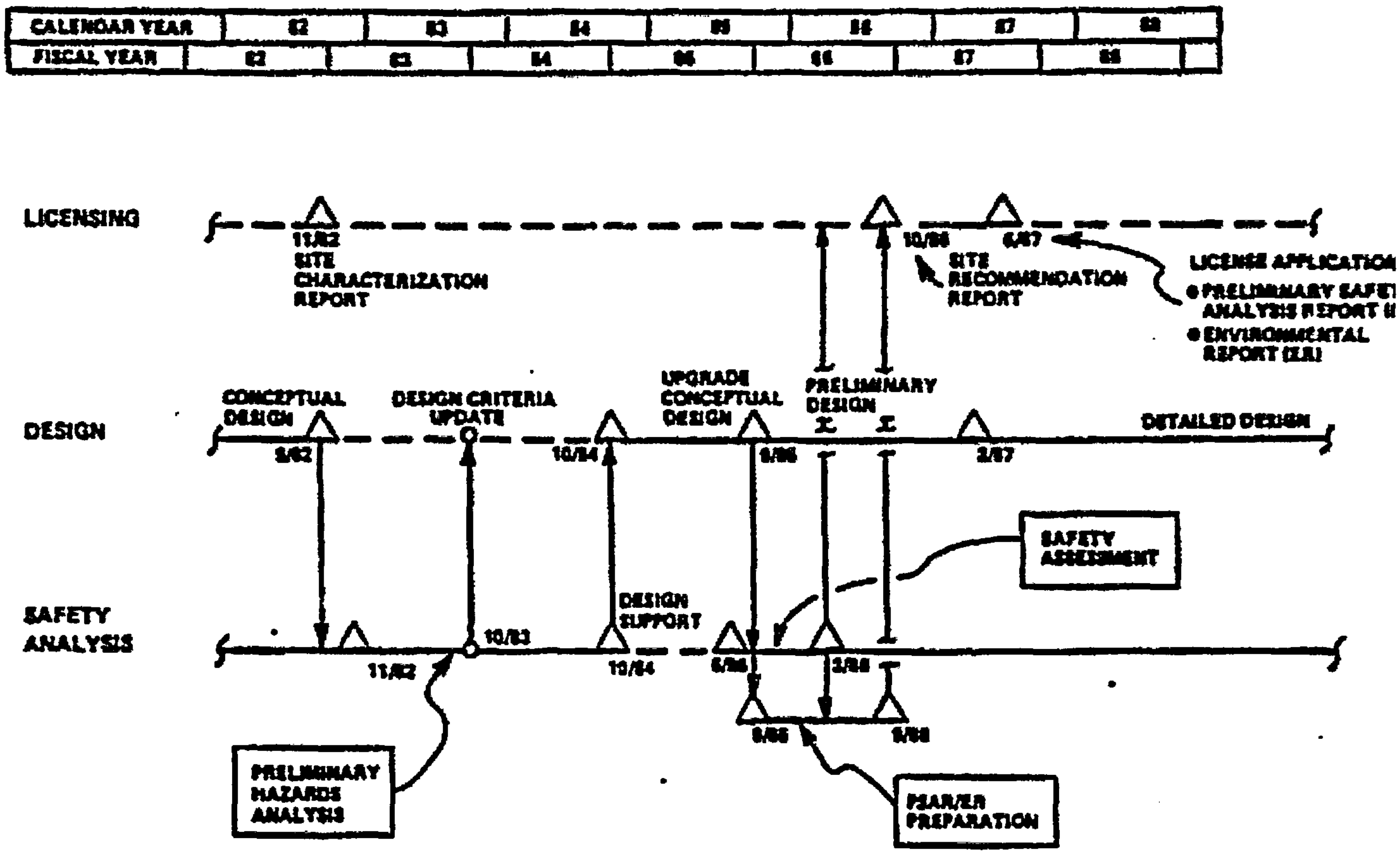


FIGURE 3. Preclosure Performance Assessment Schedule and Interfaces.

5.0 POSTCLOSURE PERFORMANCE ASSESSMENT

The present philosophy guiding the BWIP postclosure Performance Assessment activities is defined in this section. This philosophy is subject to change pending finalization of regulatory requirements. Principal application of postclosure performance analysis is twofold: to predict the long-term behavior of the repository system under anticipated and postulated geologic conditions, and to assist in the design of the engineered facility so that compliance with technical criteria is ensured.

5.1 PREPARATION OF SYSTEM DESCRIPTION: POSTCLOSURE REPOSITORY PERFORMANCE

5.1.1 System Description

The long-term performance analysis of a nuclear waste repository is a systematic evaluation process that quantifies how well the system achieves its basic design objective; that is, the isolation of the nuclear waste from the accessible environment. Principal goals of such long-term performance analysis are twofold: to assist in the design of an engineered facility that complies with technical criteria and to predict the long-term behavior of the repository system under anticipated and postulated conditions. To achieve these goals, it is necessary to:

- Identify the conditions and phenomena that will significantly affect the rate, quantity, and direction of radionuclide movement
- Develop an acceptable understanding of such conditions and phenomena
- Develop a methodology that properly relates the significant processes and conditions to the isolation criteria
- Assemble adequate evaluation tools (predictive model and data analysis codes)
- Identify data needs in terms of the model requirements and collect needed data
- Develop quantitative descriptions of plausible disruptive events that can be used by the models for Performance Assessment
- Apply Performance Assessment methodology to determine waste isolation system or subsystem performance under expected and disruptive conditions, taking uncertainty into account.

A discussion of transport pathway considerations and parameter characterization is provided in Appendix E.

5.1.2 Analysis Methodology

Predicting repository system performance over large-space scales and very long time frames (i.e., tens of kilometers and 10,000 yr) strongly indicates the need for the use of mathematical models based on the underlying physical and chemical principles to extrapolate measured system behavior. Such models provide an efficient and versatile way to predict the interrelationships and long-term changes in the waste isolation system. Construction of conceptual models is a necessary precursor to the development of more detailed models. Conceptual models are used to place bounds on the key system parameters.

5.1.3 Scale

Because the critical processes can in many cases function at different spatial scales, the overall long-term performance analysis problem is best broken down into three subregions. These are the very near-field (canister-to-room scale), the near-field (repository-to-emplacement horizon scale), and the far-field scale. This subdivision was developed from a recognition that some processes were more important at one scale than at another scale. Using this approach, mathematical models for each subregion can be developed that realistically portray the dominant physical processes, without neglecting less important effects. Thus, the objective of adequate predictive analysis is achieved while functional practicality is also preserved.

A suite of computer codes have been developed and will be used in the BWIP studies. The computer codes span the spatial scales discussed. A description of the computer codes grouped by spatial scale is provided in Appendix A.

5.1.4 Type of Models

Once the important chemical and physical processes and parameters are identified, the model types can be identified. Not all model types require implementation in the form of sophisticated, numerical computer codes. It follows from the description of the transport pathway system that the model types needed are:

- Groundwater flow in a continuum (porous media)
- Groundwater flow in a fractured system (very near field)
- Heat transport (very near field, near field)
- Waste package degradation (very near field)
- Waste form dissolution (very near field)

- Radionuclide release rate (very near field, near field)
- Radionuclide mass transport (far field)
- Groundwater velocity and path orientation (near field, far field).

The relationships among the various processes, characteristics, and related models are discussed in Appendix E. A description of the various computer codes and the linking of computer codes (input/output) relationships is provided in Appendix A.

5.2 SELECTION AND CHARACTERIZATION OF POSTCLOSURE LONG-TERM DISRUPTIVE SCENARIOS

Selection and characterization of postclosure disruptive scenarios define the credible events, processes, and resultant radionuclide releases and pathways that must be considered as the basis for repository site-suitability selection and engineered system design. The basic objective of this activity is to identify and characterize in detail scenarios having a reasonable probability of occurrence and sufficient consequences to represent a meaningful design concern. At the present time, the various scenarios that have been identified are being reviewed in terms of recommendations set forth in drafts of 10 CFR 60 (NRC, 1982) and 40 CFR 191 (EPA, 1982). Scenarios will be selected for detailed parametric analysis using a Delphi method of opinion solicitation from nationally recognized experts. Scenario description documents (culminating in a final report documenting scenarios for use in analysis supporting the repository construction license application) will be prepared periodically during conduct of this work.

Several credible non-site-specific disruptive event scenarios have been proposed in the technical literature. These generic scenarios have been screened and evaluated based on BWIP site-specific geologic and hydrologic knowledge, event likelihood, and release potential from a repository in Columbia River basalt (Arnett and others, 1980). Scenarios initially considered applicable consisted of the following natural, man-induced, and repository-induced events for the first 10,000 yr following repository decommissioning:

- Fault zone directly or indirectly connecting repository with biosphere
- Shaft seal degradation or failure
- Intrusion by borehole
- Loss of integrity due to microearthquake swarm
- Intrusion by basaltic dike.

Currently, no attempt has been made by the BWIP to estimate the probabilities of occurrence of such events. Instead, consequence analyses have been undertaken to determine their potential for disruption of a

repository in basalt. In many instances, the consequences of a particular event are sufficiently small to cause the issue of probability of occurrence to be of limited interest; i.e., even if the probability of occurrence of an event is 1.0, the radionuclides released would be contained in the deep basalt away from the accessible environment. If it is determined that an event or process has the potential for significant consequence, the overall risk will be calculated from the consequence and probability of occurrence.

The current list of plausible scenarios will be modified, if necessary, to incorporate the results of the Delphi Method of Solicitation. The list of plausible scenarios will be categorized in terms of:

- Natural system dynamics
- Man-induced phenomena
- Site characterization uncertainty

5.3 TEST RUNS OF COMPUTER CODES

Computer test applications or runs with the major Performance Assessment models will be performed for the purpose of: (1) developing a detailed understanding of flow and transport processes in the basalt, and (2) ensuring that the computer codes are capable of describing the unique characteristics of the basalt. Some computer test runs will consist of parametric and sensitivity studies to provide information on key parameters. Furthermore, because of the inherent uncertainty in predicting system performance, the Performance Assessment methodology must incorporate the use of both deterministic and probabilistic models.

5.3.1 Summary of Conclusions from Preliminary Long-Term Repository Performance Analysis

Very Near-Field Modeling Studies. The modeling studies completed to date have emphasized the estimation of waste-package performance requirements.

Simulation studies of the very near field clearly reflect the favorable geochemical environment of the basalt. In particular, the reducing (anoxic) environment of the deep basalt increases the stability of the canisters and significantly decreases the solubility of many key radionuclides.

The primary preliminary conclusions developed from the available modeling studies are as follows:

- Solubility of radionuclides limits many release rates to levels well below the NRC criteria
- High sorptive properties of basalt will retard the movement of many radionuclides.

Near-Field Modeling Studies. Modeling studies for the reference repository location (RRL) have been performed that predict groundwater and radionuclide pathways and travel times. Performance-analysis models that describe the coupled processes of heat transfer, fluid flow, and radionuclide transport have been applied using representative hydrologic data obtained from field testing. These near-field simulations generally indicate that the groundwater flow paths are controlled by the occurrence and hydraulic characteristics of the basalt flow contacts above the emplacement horizon. This trend is expected because groundwater will follow the path of least resistance; that is, primarily along the more pervious flow contacts.

With regard to waste-isolation effectiveness of the RRL, the preliminary results of the near-field performance analysis support the preliminary conclusion that the radionuclide release across the boundary to the accessible environment (at 10 km) appears to remain well below the EPA regulations, for both no-disruption and postulated fault-zone conditions.

Far-Field Modeling Studies. Far-field hydrologic modeling studies of the groundwater system in the basalts have been performed over the past several years by a number of independent organizations, using the hydrologic data sets available at the time each study was performed. These studies simulated the three-dimensional groundwater head patterns and estimated flow paths and travel times from a hypothetical repository location to the biosphere. The preemplacement travel times calculated to date significantly exceed the 1,000-yr travel time from the repository to the accessible environment in the proposed NRC regulations. However, the effect of model and data uncertainty are not totally understood at the present time.

5.3.2 Performance Assessment Initial Baseline

Analyses will be performed to assess the isolation capability of the basalt repository system, based on current estimates of site and engineered subsystem characteristics. The primary purpose of the analysis is to identify any major deficiencies in subsystem performance. Sensitivity analysis will be performed to identify characteristics that have the greatest impact on systems performance. The analysis will be conducted using existing data and a suite of computer codes.

The baseline analyses will use "as-is" computer codes. The PORFLO (see Appendix A) computer code will be used to calculate groundwater flow, heat transfer, and radionuclide transport in the near field (see Appendix B). The PORFLO computer code will be used in the near field where thermal loading significantly influences the vertical hydraulic gradients. The MAGNUM-3D and PATH-3D (see Appendix A) computer codes will be used to analyze groundwater transport in the far field (see Appendix B). A different combination of computer codes is used for analysis in the far field since the groundwater flow regime is unaffected by thermal loading.

To ensure traceability, the data base used in the analysis will be obtained from the most current applicable BWIP data packages. The data base and analyses used to establish the initial baseline will be archived.

The postclosure Performance Assessment baseline will be updated periodically in support of major project documents (i.e., the final Site Characterization Progress Report (Rockwell, 1982) and the input to the Site Recommendation Report). Simulations will be performed using the site assessment codes to determine the impact of disruptive events and the variation in site characteristics (hydrologic and geochemical parameters) on the performance of the site. Both sensitivity and uncertainty analysis will be used to establish confidence limits or bounds. The objective of the analysis will be to establish confidence limits for the measures of performance, (i.e., groundwater travel times, radionuclide fluxes, dose-to-man, etc.) to determine if the regulatory performance criteria are satisfied by the NWRB.

5.3.3 System Component Performance Requirement Allocation

A geologic repository is a system consisting of several subsystems, both natural and engineered. The natural subsystem is defined as the geologic setting, and the engineered subsystems are defined as waste package and repository seal subsystems. It is assumed, a priori, that the total system will satisfy appropriate regulatory criteria and, furthermore, that a methodology can be identified to allocate subsystem performance requirements. For each engineered subsystem, the performance requirements can be used to establish project-specific design criteria from which design alternatives can be analyzed and trade-off studies can be performed. Such analyses will provide a basis for preparing waste package and seal system performance specifications. The analyses performed by the BWIP will be consistent with the requirements set forth in the NWTS-MGDSR document.

The BWIP approach to Performance Assessment consists of several steps, outlined in Figure 4. The first step is to define the performance objectives for the repository system (i.e., release limits, dose-to-man limits, etc.) The next major process is to identify the radionuclides critical to the performance of the repository and to list the assumptions associated with the radionuclide screening process. Details of the key radionuclide identification process are illustrated in Figure 5.

The relationships between the required performance of the repository subsystems are evaluated in terms of the key radionuclides. The approach to allocation assumes that certain criteria can be satisfied by an individual subsystem or collectively by several subsystems . Quantitative relationships are established between the various subsystems and the required performance for each subsystem is defined. The subsystem performance requirements will be used as input to the design and engineering trade-off studies. The analyses or subsystem performance requirements will be used as input to the design and engineering trade-off

studies. An iterative process employing the use of Performance Assessment, engineering trade-off studies, and design review will be used to determine waste package and seal system design specifications and to establish priorities for research and development and testing programs.

5.3.4 Sensitivity Analysis

Due to the complexity and interrelationships of the various conditions and processes affecting the waste isolation capability of the site, and because of the variation in the BWIP's ability to characterize such conditions or processes, it is important to identify and quantify the variables for which the results of the performance analysis are most sensitive. This should first be done from an integrated, total Performance Assessment viewpoint to identify the parameters that have the greatest influence, and then at the subsystem level of analysis to trace their influence in more detail. Sensitivity analysis is performed to determine which parameters have the greatest influence on the results or solution.

Sensitivity analysis can take a variety of forms. One method is to vary model input parameters using a decision-tree approach. Sensitivity analysis may also take place at a more elementary level, where each parameter or group of parameters is simply varied and its effect on the solution is evaluated. Where the NWTS methods are available, they will be applied to the NWRB. In either case, sensitivity analysis should identify the parameters of important processes, and facilitate the identification of highlight design features that have the greatest influence on performance. Sensitivity analyses have been conducted from the earliest period of the BWIP. In the context of future Performance Assessment, sensitivity analysis will be both systematic and well documented.

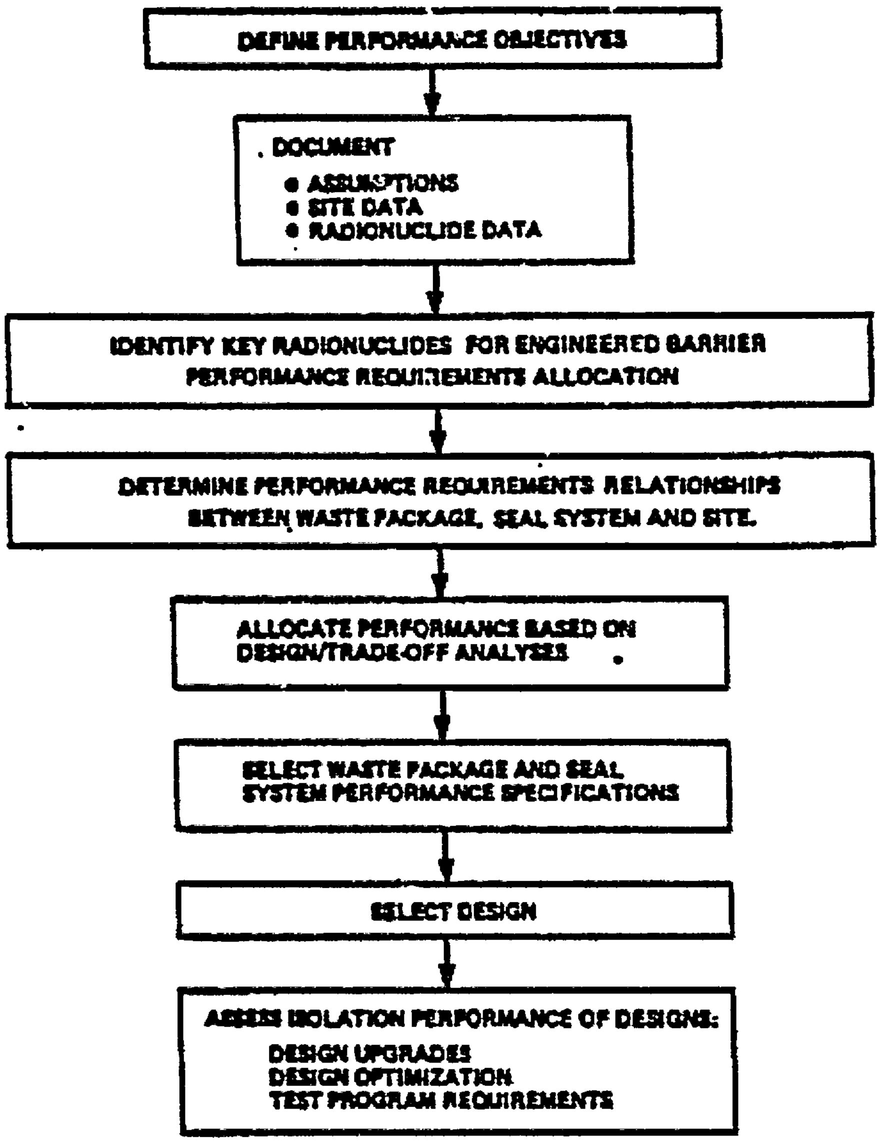


FIGURE 4. Use of Performance Assessment Analysis to Assist Design.

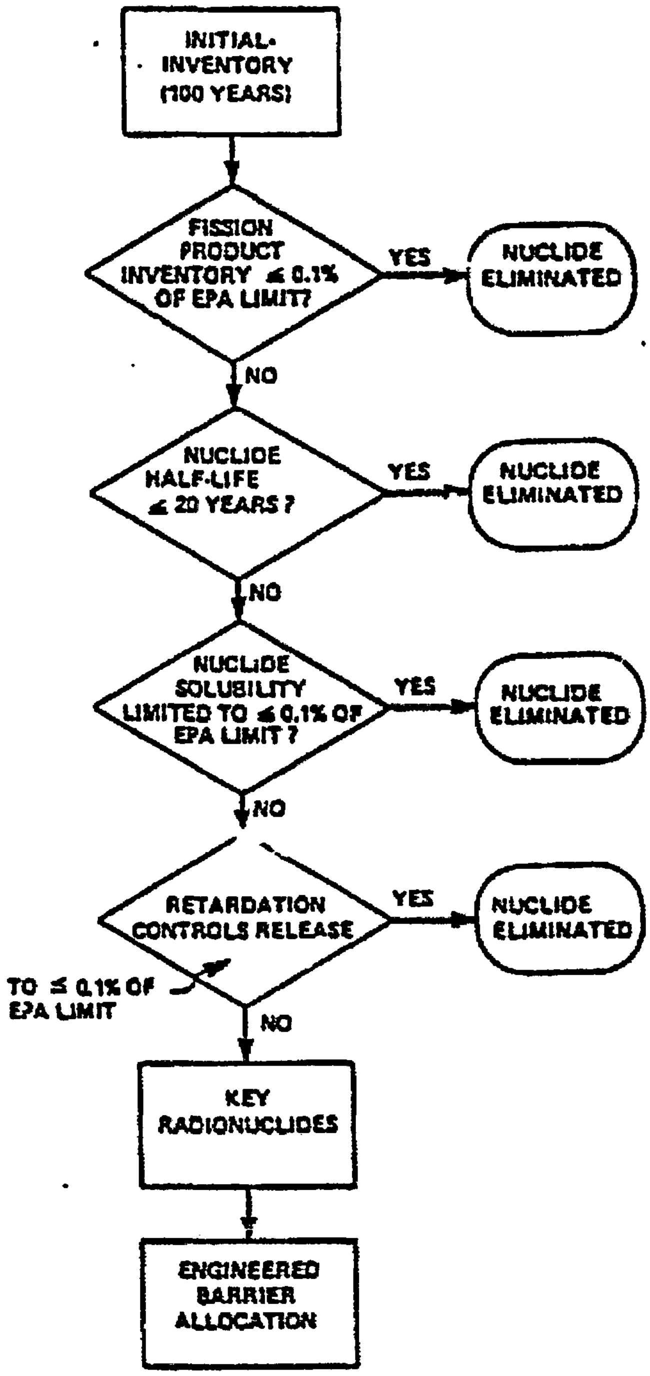


FIGURE 5. Key Radionuclide Identification Process.

Presently, the BWIP is performing a sensitivity analysis to evaluate the impact of data and model uncertainty on postclosure repository isolation performance. A modeling task force with representation from the BWIP, U.S. Geological Survey, Pacific Northwest Laboratory (PNL), and Lawrence Berkeley Laboratory has been assembled to: (1) review and synthesize a data base and (2) using the revised data base, interpret and revise the regional and Pasco Basin hydrologic models to establish a consensus among task force participants. Using the revised data and model base, the PNL will then conduct a sensitivity analysis to identify important parameters. Parameters likely to be considered are: vertical hydraulic conductivity, hydraulic potential, boundary conditions, and geologic structural considerations.

In terms of methodology, the BWIP is presently reviewing various advanced techniques of sensitivity analysis as it pertains to both the existing BWIP suite of computer codes, and codes that will be developed by the BWIP. A retrofit of sensitivity analyses techniques to existing codes could be extremely complex and time consuming. It is assumed that with proper coding procedures and software management controls, the cost of formulating and implementing these methodologies to developing codes can be minimized.

5.3.5 Uncertainty Analysis

Recognizing that decisions regarding the repository site will rely heavily on model predictions, it is essential to address the uncertainty associated with both the simulation models and the data used in the analysis. For the most part, uncertainty in model predictions can be attributed to five major sources:

- Random and systematic errors in field and laboratory measurements of geotechnical properties
- Errors arising from subjective interpretations of the spatial or temporal variations of parameters based on discrete data
- Incomplete characterization
- Limited understanding of important physical, chemical, and mechanical processes
- Limitations in the mathematical models, including the computer codes that describe the processes.

A number of techniques that can be used to determine the uncertainty of model input parameter estimates have been developed by the PNL for the Assessment of Effectiveness of Geologic Isolation Systems (AEGIS) program funded through the Office of Nuclear Waste Isolation (ONWI). The techniques are presently under review by the BWIP to determine their usefulness for evaluating the uncertainties of key hydrogeologic parameters used in repository performance analysis and conceptual hydrologic modeling.

These techniques are being reviewed to determine their usefulness for evaluating the need for additional hydrogeologic data and as a means of identifying the locations where these data should be collected.

Uncertainty analysis will include the establishment of probability distributions for hydrogeologic model input parameters and the application of these uncertainties in conjunction with deterministic models. Parameter uncertainty and associated propagation of uncertainty through the models will be quantified. Statistical sampling techniques such as the Monte Carlo technique are available and will be applied where appropriate. Statistical sampling techniques under review by the BWIP include finite order analysis, and stochastic Lagrangian techniques.

5.4 VERIFICATION AND BENCHMARKING OF CODES

A major Performance Assessment activity is the acquisition and/or development of computer codes. Code verification consists of reviewing the code to ensure that the software is developed in accordance with the requirements set forth and that the software product is free of errors. Benchmarking is the process of comparing the numerical results from different codes. Verification testing is best addressed as an activity that occurs during the software development process. Benchmarking is a process that is used to develop additional confidence in the software. Both the verification and benchmarking activities will be subject to external peer review.

Standardization of verification and benchmarking activities will be accomplished by creating a set of procedures. In support of this effort, a review of existing industrial and regulatory software standards is underway. Several DOE Hanford contractors; the PNL, the Westinghouse Hanford Company, and Boeing Computer Services, Richland are assisting the BWIP in this effort. Procedures for verification and benchmarking will be written during fiscal year 1983.

The computer codes are in various stages of development. The BWIP Performance Assessment codes are divided into two categories: site and engineered barriers. As a general rule, development of the site codes tends to be further advanced than the development of the engineered barrier codes. The site hydro geochemical radionuclide transport codes will be documented, verified, and benchmarked during calendar years 1983 and 1984. The engineered barrier codes and waste package performance codes will be documented, verified, and benchmarked during calendar years 1984 and 1985.

At the present time, six site codes have been identified that will be verified and benchmarked. The codes include: PORFLO, MAGNUM-2D and MAGNUM-3D, FECTRA-2D and FECTRA-3D, and CHAINT. PORFLO and MAGNUM-3D will be the first two codes verified and benchmarked.

The PORFLO computer code will be used as a test case for the verification and benchmarking activities. Documentation of the code is nearing completion. The PORFLO computer code has been verified and is presently being benchmarked.

The MAGNUM-3D computer code is presently being documented by the BWIP with assistance from Boeing Computer Services, Richland. The PNL will assist the BWIP in the benchmarking effort by performing a set of analyses using the FE3DGW computer code. A set of verification and benchmark problems will be defined and each will be solved using FE3DGW, and MAGNUM-3D and the results compared. Analysis of the benchmarking problems using other three-dimensional codes (i.e., SWENT and TRESCOTT) will be considered.

The engineered barrier codes include waste package and repository computer codes. The primary effort during Fiscal Year 1983 will be to define the total requirement for engineered barrier software and secure the necessary software. Emphasis will be placed on the application of existing, as opposed to the development of new software. Computer codes that are presently under review for waste package performance assessment include BARIER, WAPPA, ADINA, ADINAT, DAMSWEL, HEATING5, ANSYS, and others. Computer codes that are presently under review for repository seal performance assessment include BETA, DAMSWEL, ANSYS, and others.

5.5 CODE DOCUMENTATION AND PREPARATION OF USER MANUALS

Documentation of the major Performance Assessment codes will consist of the following:

- Technical report
- User manual
- Documentation of computer code listing.

The technical report will contain information on the model theory, numerical techniques, and results from the code verification and benchmarking. The user manual will contain instructions for use of the code, sample input and output for selected test cases, and a copy of the code listing. The document will be prepared in accordance with the BWIP procedures written to meet ANS 10.4 (ANS, 1981), NUREG-0856 (NRC, 1981a), NQA-1 (ANSI/ASME, 1979), and other applicable guidelines. A system for continuing documentation, which updates the computer code listing will be implemented.

A number of computer codes that will be used in the BWIP Performance Assessment either have been developed or are under development. For those codes, it is assumed that it would be difficult to retrofit a computer code software development procedure. Retrofit of a style guide (NUREG-0856, NRC, 1981a) might be imposed if necessary for external review.

A procedure will be written to guide the development of new software. The procedure will include instructions for the preparation of code documentation.

5.6 MODEL VALIDATION

Validation consists of demonstrating that the simulation model used adequately represents physical reality. Model validation is approached using a set of property values taken from laboratory, field data, and modeling assumptions as input to the simulation model, and comparing the model output to another set of field data. Engineering judgment on the reasonable magnitude and direction of probable divergence resulting from input assumptions is a critical step towards completing model validation. Model validation activities will be subject to peer review.

The approach to validation will depend upon the particular model addressed. A detailed plan will be prepared for each model to be validated. The plan will describe all work associated with demonstrating the adequacy of the model. To the extent possible, validation of Performance Assessment models will be performed prior to submitting the license application. Model validation will continue through the licensing, construction, and operational phases of repository development to confirm repository performance.

Validation of the BWIP Performance Assessment site models is scheduled to begin in calendar year 1984. Validation of the engineered barrier models will be initiated in 1985. Validation of the repository systems code will be performed in situ in conjunction with exploratory shaft operations.

5.7 POSTCLOSURE REPOSITORY PERFORMANCE ASSESSMENT

As discussed in the early portion of this document, the guidelines and requirements are chosen at the subsystem level to support overall criteria through a range of subsystem performances. Various combinations of subsystem performance models will be used to assess compliance with a specific criterion. A summary of the various model subgroups that will be used is provided in Appendix A. Once an analysis is completed, the results are compared to the performance requirements and guidelines. If requirements and guidelines are met, it indicates the waste isolation system is adequate under the conditions of the analysis. It is expected that a variety of analyses will be conducted. Studies on repository postclosure isolation capability will be directed towards the preparation of appropriate documentation in support of the license application. Contents of the License Application are specifically addressed in 10 CFR 60.21 (NRC, 1982) and 10 CFR 51 (NRC, 1980).

The iterative Performance Assessment process will continue throughout the design upgrade phase of the project. The analyses will support design upgrade using the BWIP current-at-that-time computer codes and models.

As with the baseline analysis, the analyses will provide strong feedback upgrading the relationships of the various subsystems and will flag any isolation problems. If the results of the analyses do not meet criteria or guidelines, then may indicate that additional characterization is required to refine the analysis, or a repository or waste package design change is needed, or possibly the site is unsuitable even with engineered barriers.

5.8 POSTCLOSURE PERFORMANCE ASSESSMENT SCHEDULE AND INTERFACES

The previous sections identified the methodology which will be used to examine the isolation capability of the repository. The analyses will support activities associated with the preparation of design upgrades and a license application for repository construction authorization. The activities in support of design upgrades and a license application are shown in Figure 6.

5.8.1 Design Support - Upgraded Conceptual Design

The methodology outlined in Section 5.3.3, "Systems Component Performance Requirements Allocation", will be used in support of preparing the upgrade design criteria.. The methodology will be used to define requirements for each of the designed subsystems. Sensitivity analysis will be used to identify the parameters which have the greatest influence on design. Design requirements will be prepared in response to the needs identified in the sensitivity analysis.

5.8.2 Postclosure Support for Site Recommendation Report

The postclosure isolation performance analysis will be upgraded for the Site Recommendation Report. The computer codes used in support of these analyses will be verified and benchmarked. The analyses will be completed by the end of the second quarter of fiscal year 1986.

5.8.3 Postclosure License Application Input

The license application for construction authorization will require input from the postclosure Performance Assessment activities. The postclosure Performance Assessment analyses in support of the preliminary Safety Analysis Report will use computer codes which have been partially validated. The postclosure input to the license application will be completed by the end of fiscal year 1986 allowing nine months for review and approval by the DOE.

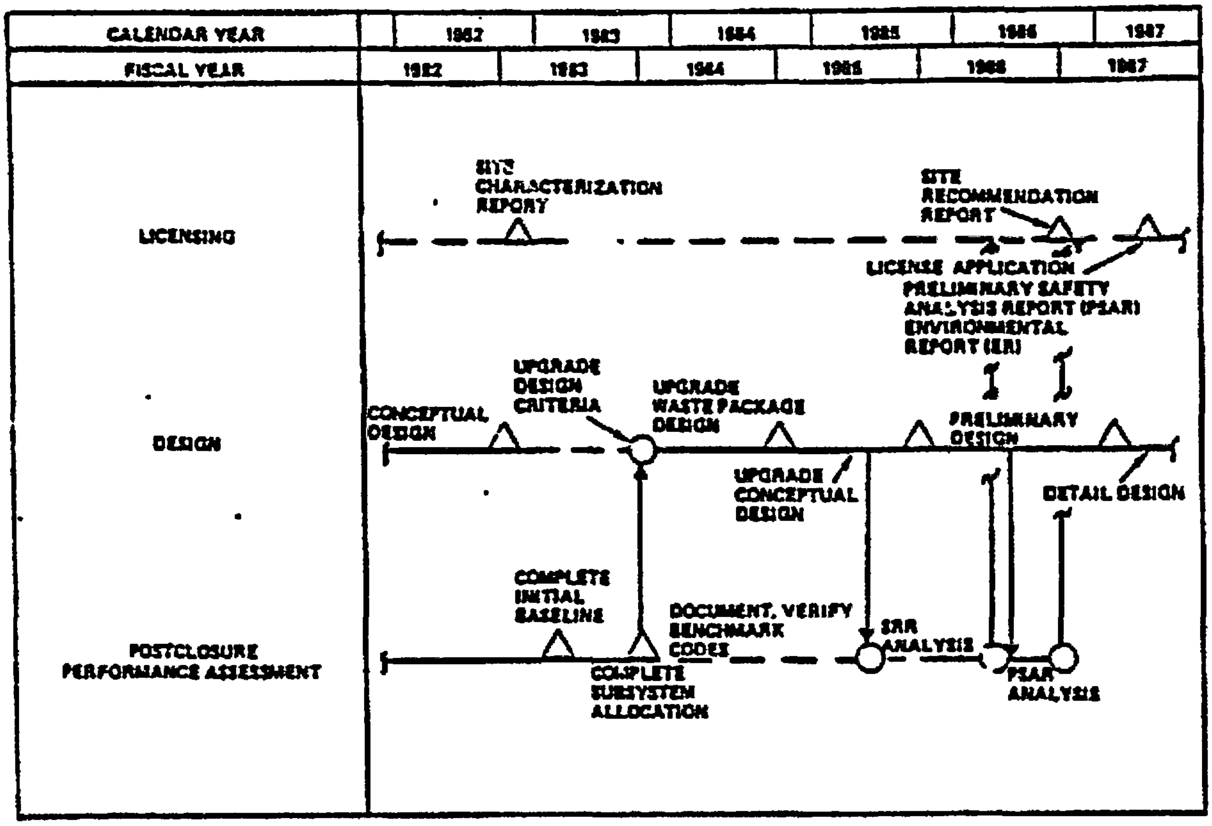


FIGURE 5. stclosure Performance Assessment Schedule & interfaces

6.0 MANAGEMENT OF PERFORMANCE ASSESSMENT ACTIVITIES

6.1 WORK BREAKDOWN STRUCTURE

The BWIP is organized in accordance with the approved NWTS work breakdown structure. This work breakdown structure shows two distinct types of performance-related activity. The first type of performance evaluation is conducted by the Waste Package, Site, and Repository End Functions. This activity includes technical evaluation of how effectively each end function is completing its assigned work with respect to milestone completion and/or satisfaction of the issues and work elements as defined in the technical plans.

The second type of performance-related activity and the subject of this Performance Assessment Plan lies within the Systems Integration and Performance Assessment End Function and consists of the assessment of preclosure and postclosure waste isolation and safety performance with respect to the total system (engineered and geologic).

6.2 BWIP PERFORMANCE ASSESSMENT ORGANIZATION

The BWIP Performance Assessment activity is organized such that the performance efforts of all BWIP End Functions are integrated through the Performance Assessment and Analysis Group.

The Performance Assessment and Analysis Group is responsible for the following activities:

- Criteria analysis
- Engineered subsystems performance requirements allocation
- Preparation of an initial Performance Assessment baseline and subsequent Performance Assessments
- Selection and characterization of preclosure failure scenarios and postclosure long-term disruptive scenarios
- Assurance that the suite of computer codes used in the Performance Assessment analyses are properly documented, verified, benchmarked, and validated
- Definition of a Performance Assessment data baseline and control of codes
- Development of a Performance Assessment strategy in support of licensing.

6.3 NATIONAL WASTE TERMINAL STORAGE PROGRAM INTERFACE

The Office of NWTS Integration is responsible for integrating project Performance Assessment activities. In order to affect this integration, a plan for Performance Assessment at each of the repository sites has been requested (DOE/NWTS-2, 1982). The BWIP Performance Assessment Plan has been prepared in response to that direction.

In addition to preparation of the site-specific Performance Assessment plans, the Office of NWTS Integration has been given specific guidance to develop an analytical performance model that can be used to mathematically describe a disposal system. The model, if applicable, will be used in support of benchmarking activities. In addition, the Office of NWTS Integration is responsible for providing U.S. Department of Energy-Headquarters with an overview of Performance Assessment codes/model selection made by the projects. This will involve an evaluation of the total system at each project to ascertain that appropriate codes were selected and to determine what integrating activities, if any, are appropriate.

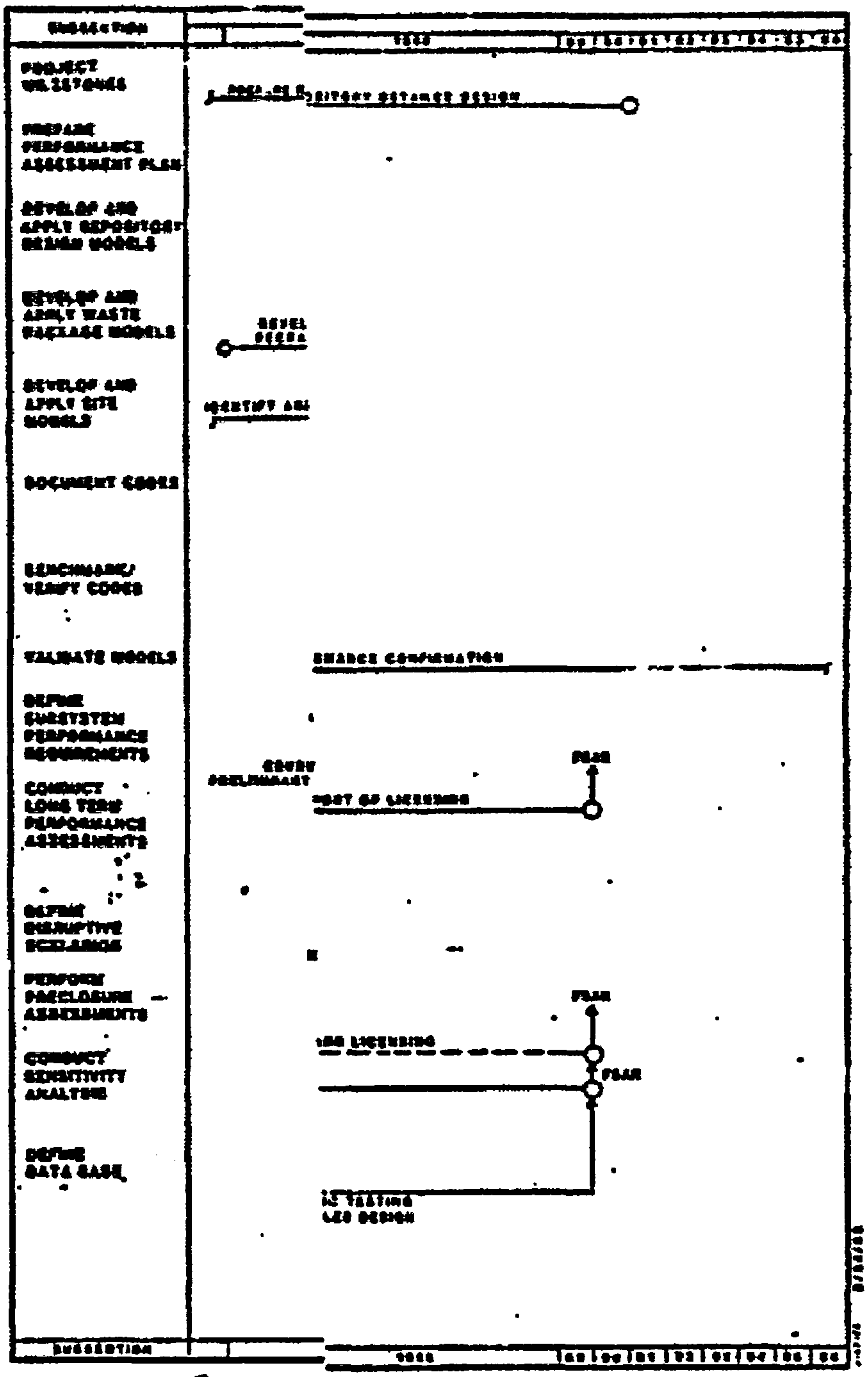
6.4 PEER REVIEW

This Performance Assessment plan and progress will be reviewed by the BWIP Overview Committee. This committee is chartered to advise the DOE-Richland Operations Office independently of the BWIP operating contractor regarding progress towards resolution of issues and completion of work elements identified in the SCR (Rockwell, 1982), and to review procedures, data, and analyses generated by the project. The Overview Committee also functions to identify program deficiencies and areas requiring further studies. The BWIP Overview Committee functions as a third party reviewer of BWIP activities and is organized along the lines of the SCR (Rockwell, 1982) to include members covering the following areas:

- Site/licensing
- Waste package/geochemistry
- Rock mechanics/engineering
- Performance assessment.

6.5 SCHEDULE AND MILESTONES

The schedule for Performance Assessment activities and their interrelationship with the balance of the BWIP technical efforts is shown in Figure 7. The schedule indicates that the major effort of the Performance Assessment task will be to support an improved repository and waste package design, to support the BWIP input to the Site Recommendation Report, and to provide input to the PSAR. A listing of the significant milestones associated with the Performance Assessment task and a description of the deliverables is shown in Table 4.



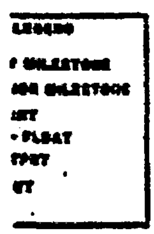


FIGURE 7
PERFORMANCE ASSESSMENT ACTIVITIES

TABLE 4. Performance Assessment Milestones.

Item Date	Title	Description	
1	Define proposed V/B/V procedures	The BWIP approach to verification, benchmarking, and validation will be outlined. A list of potential Rockwell and BWIP operating procedures will be delineated.	11/31/82
2	Submit Performance Assessment Plan to BWIP Director	The Performance Assessment Plan will be submitted to the BWIP Director for review.	12/15/82
3	Complete initial long-term baseline assessment	Prepare assessment of total system isolation performance versus the NRC and EPA criteria. Submit draft report to DOE-RL. Results will be used as input to design optimization studies.	12/30/82
4	Issue BWIP Performance Assessment Plan	Issue plan to the DOE-HQ for NWTS review and integration.	3/31/83
5	Finalize disruptive scenarios	Complete selection of disruptive scenarios.	8/31/83
6	Define uncertainty and sensitivity techniques	Complete review of uncertainty and sensitivity analysis techniques. Recommend technique to be used in conjunction with the BWIP hydrologic model parameters.	8/31/83
7	Complete verification and benchmarking of codes	Establish final suite of codes to be used for the PSAR.	09/30/85

V/B/V = Verification/benchmarking/validation
BWIP = Basalt Waste Isolation Project
NRC = U.S. Nuclear Regulatory Commission
EPA = U.S. Environmental Protection Agency
DOE-RL = U.S. Department of Energy-Richland Operations Office
DOE-HQ = U.S. Department of Energy-Headquarters
NWTS = National Waste Terminal Storage Program
PSAR = Preliminary Safety Analysis Report

REFERENCES

ANS, 1981, "Guidelines for the Verification and Validation of Scientific and Engineering Computer Programs," Draft 5, 10.4, American Nuclear Society, November 1981.

ANSI/ASME, 1979, Quality Assurance Program Requirements for Nuclear Power Plants, NQA-1-1979, American National Standards Institute/American Society of Mechanical Engineers, New York, New York, August 31, 1979.

Arnett, R. C., Baca, R. G., Caggiano, J. A., Price, S. M., Gephart, R. E., and Logan, S. E., 1980, Preliminary Hydrologic Release Scenarios for a Candidate Repository Site in the Columbia River Basalts, RHO-BWI-ST-12, Rockwell Hanford Operations, Richland, Washington, November 1980.

CFR, 1979a, Occupational Safety and Health Standards, Title 29, Code of Federal Regulations, Part 1910, Department of Labor, Washington, D.C.

CFR, 1979b, Safety and Health Requirements for Construction, Title 29, Code of Federal Regulations, Part 1926, Department of Labor, Washington, D.C.

DOE, 1981, "Environmental Protection, Safety and Health Protection Program for Department of Energy (DOE) Operations," DOE Order 5480.1A, Chapters 3 and 11, U.S. Department of Energy, Washington, D.C., August 13, 1981.

DOE, 1983, "Department of Energy, 10 CFR 960, Nuclear Waste Policy Act of 1982: Proposed General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories," Federal Register, Vol. 48, No. 26, pp. 5670-5682, February 7, 1983.

DOE/NWTS-2, 1982, National Waste Terminal Storage Program, NWTS Performance Assessment Plan, Draft 3, U.S. Department of Energy, Washington, D.C., June 1982.

EPA, 1982, "Environmental Protection Agency, 40 CFR 191, Environmental Standards and Federal Radiation Protection Guidance for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes," Federal Register, Vol. 47, No. 250, December 29, 1982, Proposed Rule.

KE/PB, 1982, Engineering Study, Nuclear Waste Repository in Basalt, Project B-301, RHO-BWI-C-116, Vol. I and II, A Joint Venture of Kaiser Engineers, Inc. and Parsons Brinckerhoff Quade and Douglas, Inc., for Rockwell Hanford Operations, Richland, Washington, March 1982.

MSHA, 1981, Regulations and Standards Application to Metal and Nonmetal Mining and Milling Operations, Title 30, Code of Federal Regulations, Part 57, Mine Safety and Health Administration, U.S. Department of Labor, Washington, D.C.

NRC, 1979, Standards for Protection Against Radiation, Title 10, Code of Federal Regulations-Energy, Part 20, U.S. Nuclear Regulatory Commission, Washington, D.C., June 15, 1979.

NRC, 1980, Domestic Licensing of Production and Utilization Facilities, Title 10, Code of Federal Regulations-Energy, Part 50, Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants," U.S. Nuclear Regulatory Commission, Washington, D.C., August 1, 1980.

NRC, 1981a, Draft Technical Position on Documentation of Models, NUREG-0856, U.S. Nuclear Regulatory Commission, Washington, D.C., December, 1981.

NRC, 1981b, Licensing and Regulatory Policy and Procedures for Environmental Protection, Title 10, Code of Federal Regulations-Energy, Part 51, U.S. Nuclear Regulatory Commission, Washington, D.C., August 1981.

NRC, 1982, Disposal of High-Level Radioactive Wastes in Geologic Repoositories, Title 10, Code of Federal Regulations-Energy, Part 60, Subpart E, U.S. Nuclear Regulatory Commission, Washington, D.C., November 18, 1982, Final Draft.

Nuclear Waste Policy Act of 1982, Public Law 97-425.

ONI, 1982, "Mined Geologic Disposal System Requirements," Revised Draft, Office of NWTS Integration, U.S. Department of Energy, Washington, D.C., November 1982.

Rockwell, 1982, Site Characterization Report for the Basalt Waste Isolation Project, (DOE/RL 82-3,) 3 Vol., Rockwell Hanford Operations for the U.S. Department of Energy, Richland, Washington, November 1982.

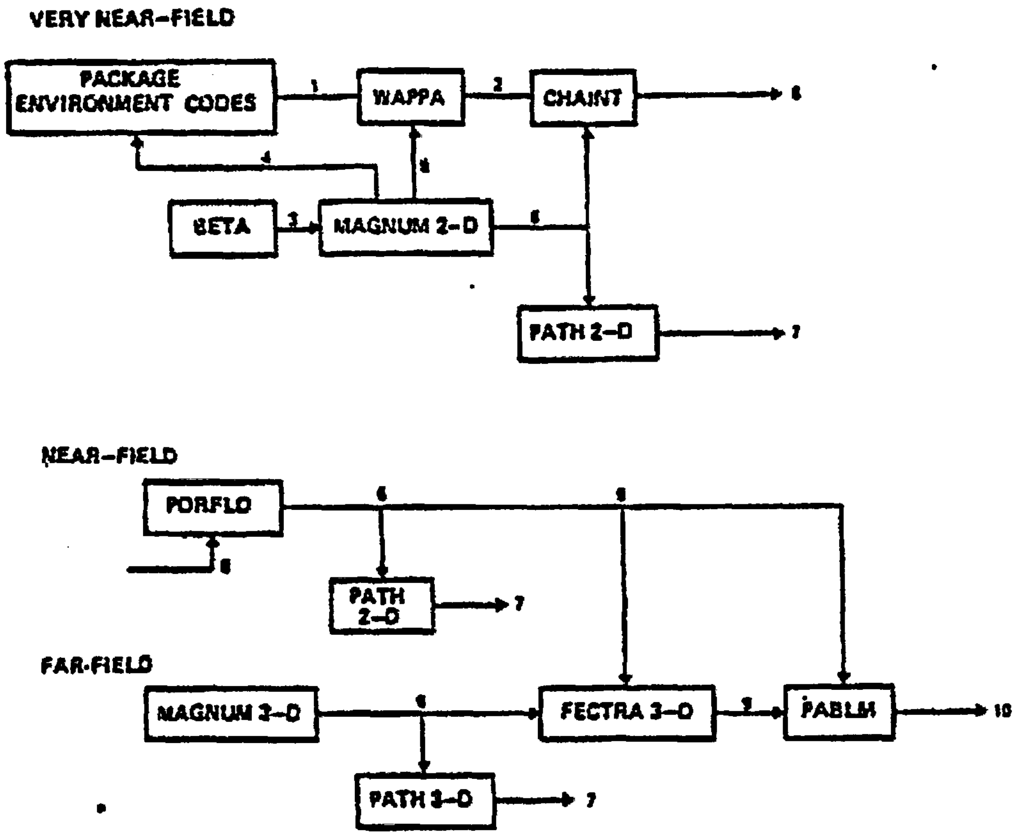
APPENDIX A

PERFORMANCE ASSESSMENT CODES

PERFORMANCE ASSESSMENT CODE DESCRIPTIONS

The relationships between codes presently viewed as the principal components of the BWIP performance assessment system model are shown in Figure A-1. Various combinations of the indicated codes will be utilized, depending on the specific performance criterion being assessed. In Figures A-2 to A-6, subgroups from Figure A-1 are highlighted to identify the portion of the overall system that is applied to particular NRC or EPA criteria.

The codes shown in Figure A-1, in addition to codes that may be incorporated to replace or augment the indicated system, are listed in Table A-1. Brief descriptions of these codes are presented in the remainder of this section.



1. TEMPERATURE, Eh, Ph, OTHERS
2. CONTAINMENT TIME AND SOURCE TERM
3. FRACTURE PERMEABILITY
4. RESATURATION TIME
5. WATER FLOW RATES
6. GROUNDWATER FLOW FIELDS
7. FLOWPATHS AND WATER TRAVEL TIMES
8. REPOSITORY SOURCE TERMS
9. RADIONUCLIDE CONCENTRATIONS AND FLUXES
10. DOSE-TO-MAN

FIGURE A-1. Typical System Model.

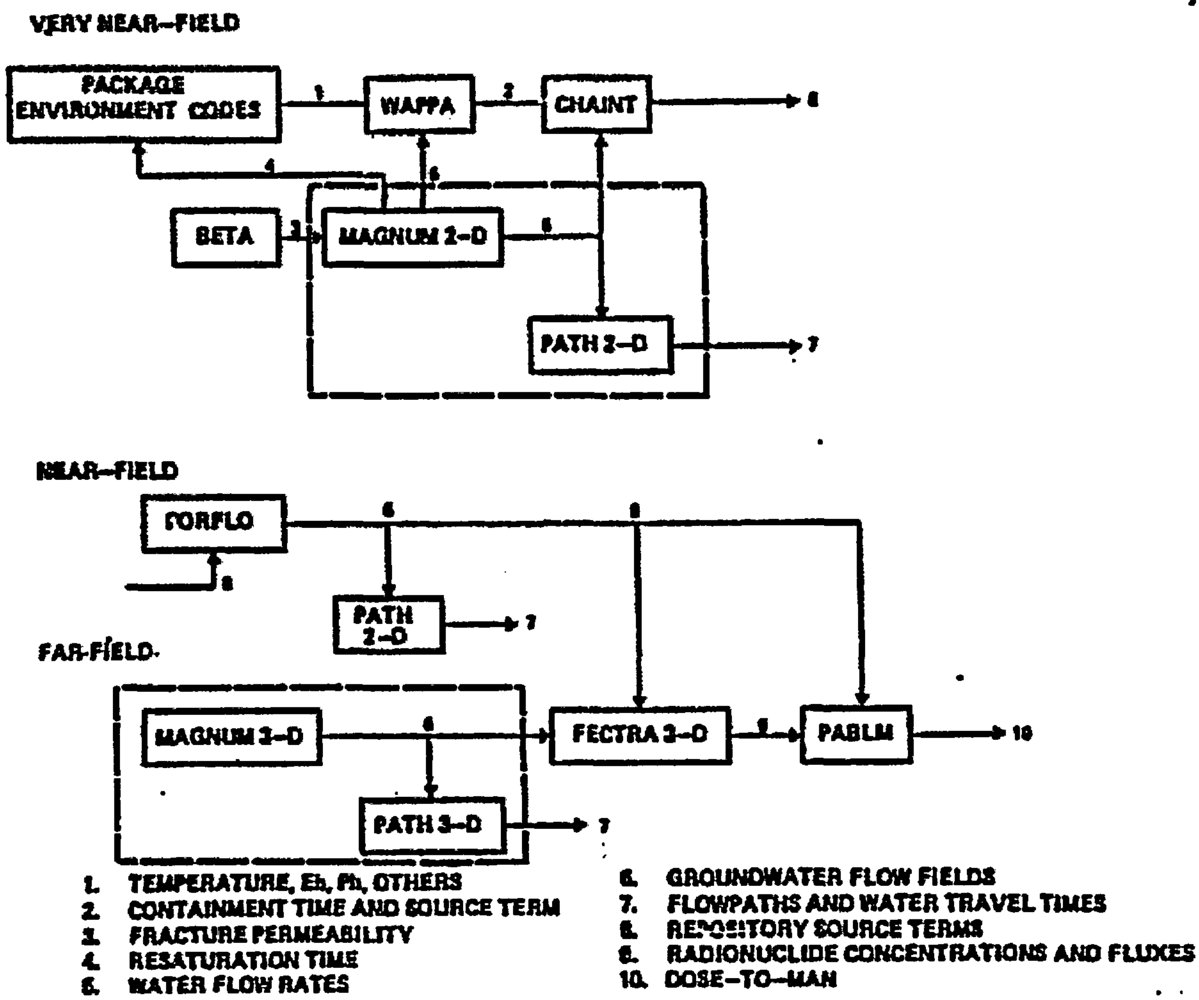


FIGURE A-2. Relationship of Regulatory Criteria to Performance Assessment System Model; 1,000-Yr Groundwater Travel Time (10 CFR 60) (NRC, 1981).

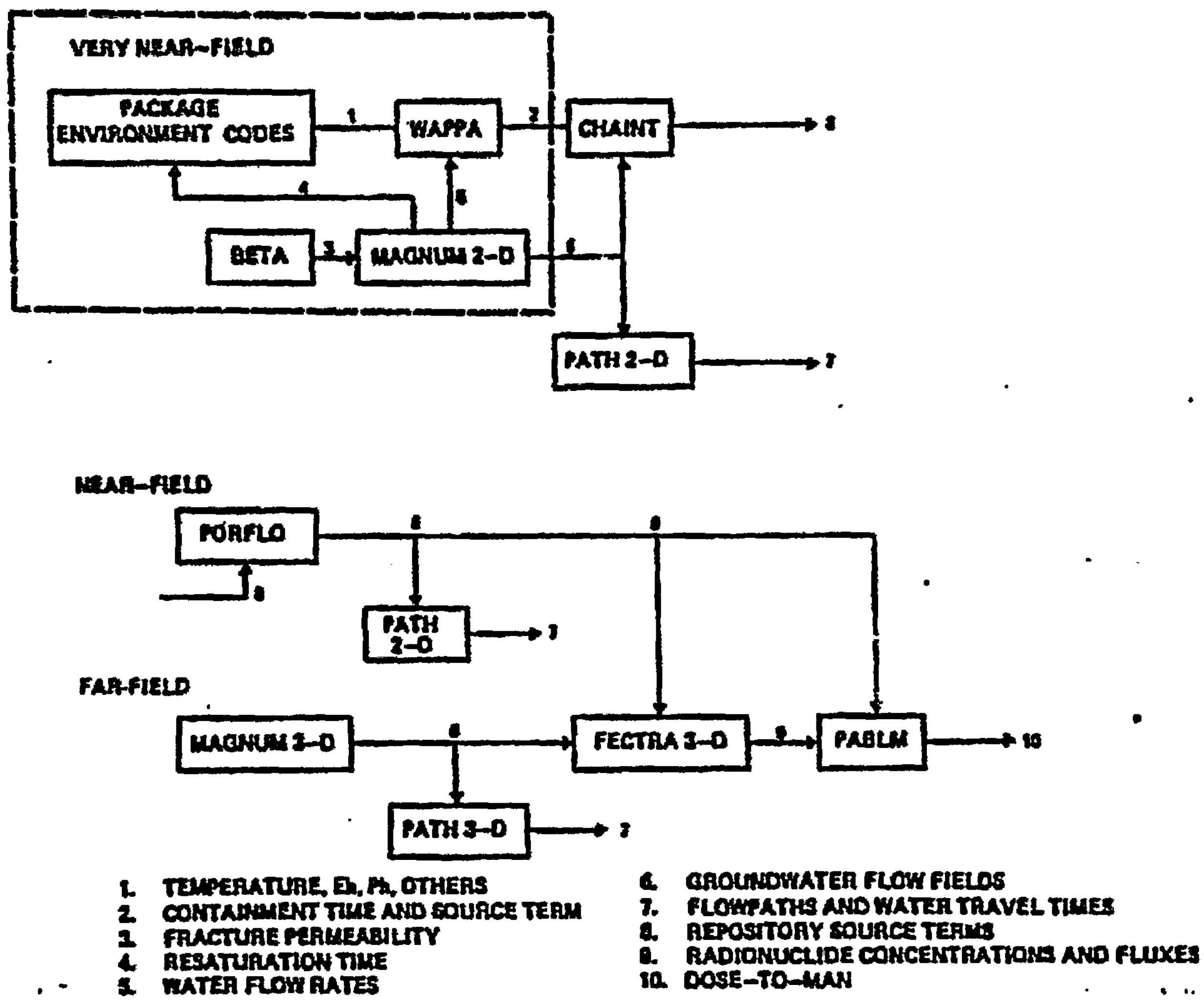


FIGURE A-3. Relationship of Regulatory Criteria to Performance Assessment System Model; 1,000-Yr Containment in Waste Package (10 CFR 60) (NRC, 1981).

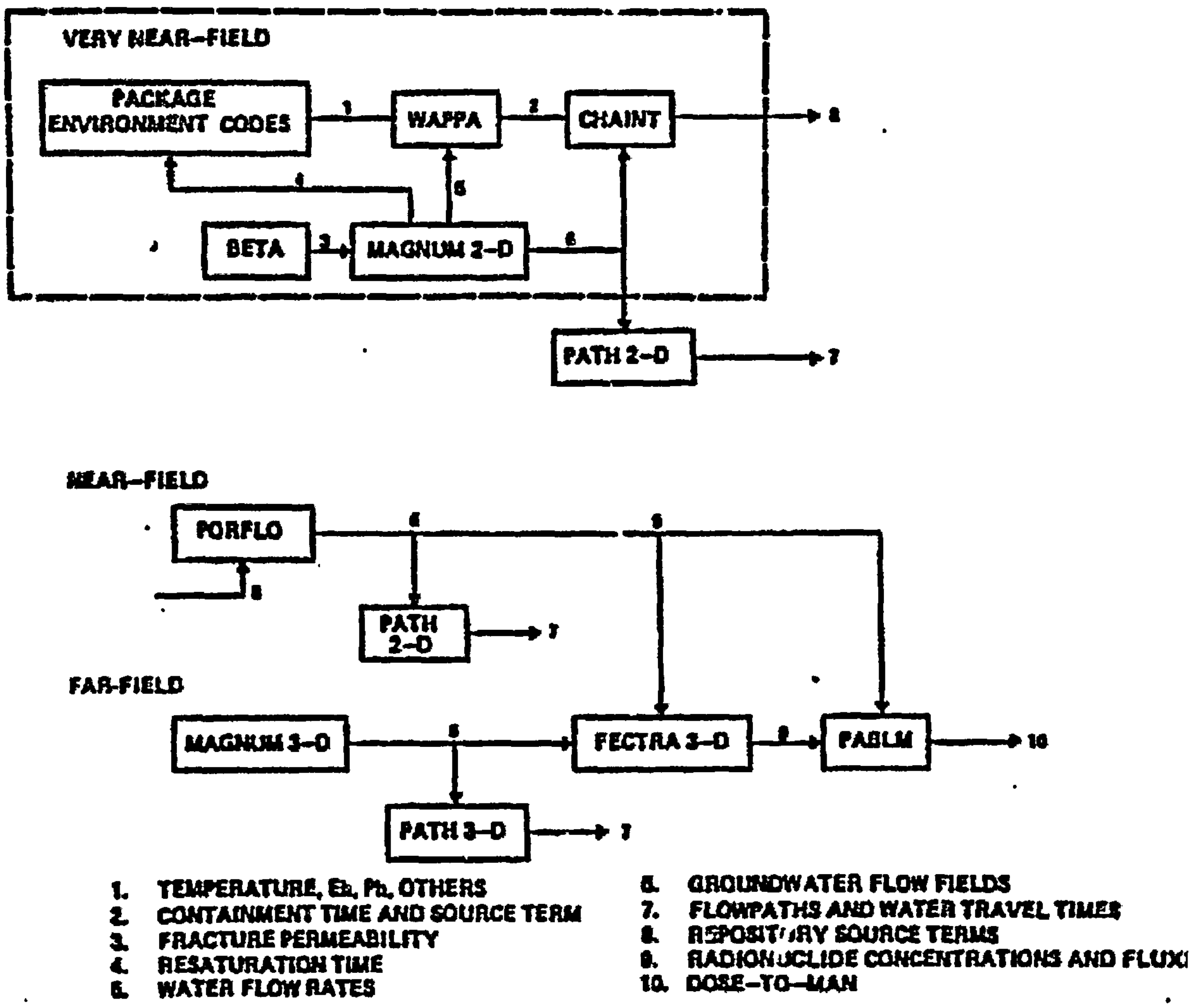


FIGURE A-4. Relationship of Regulatory Criteria to Performance Assessment System Model; 10-5 Annual Release from Engineered System (10 CFR 60) (NRC, 1981).

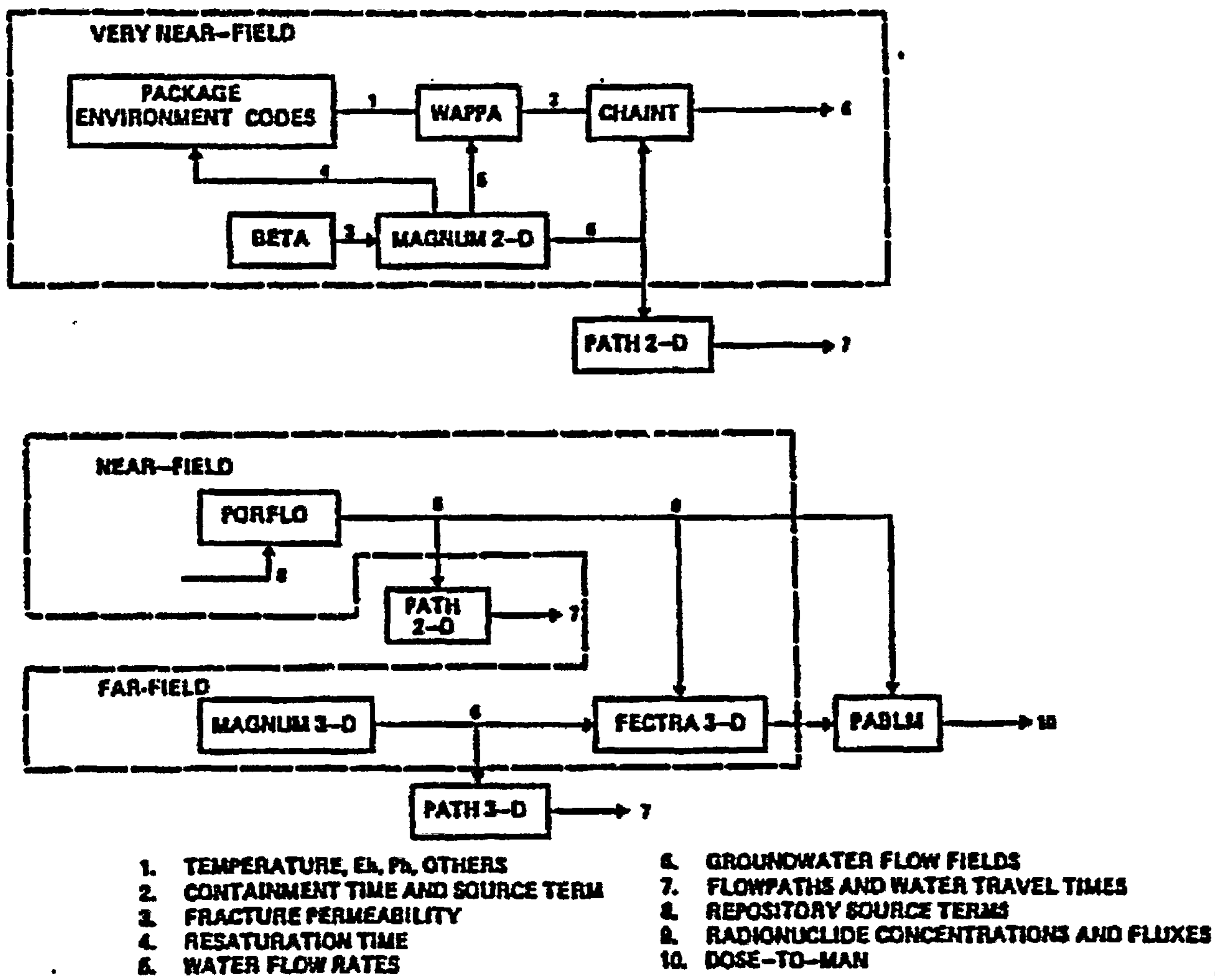
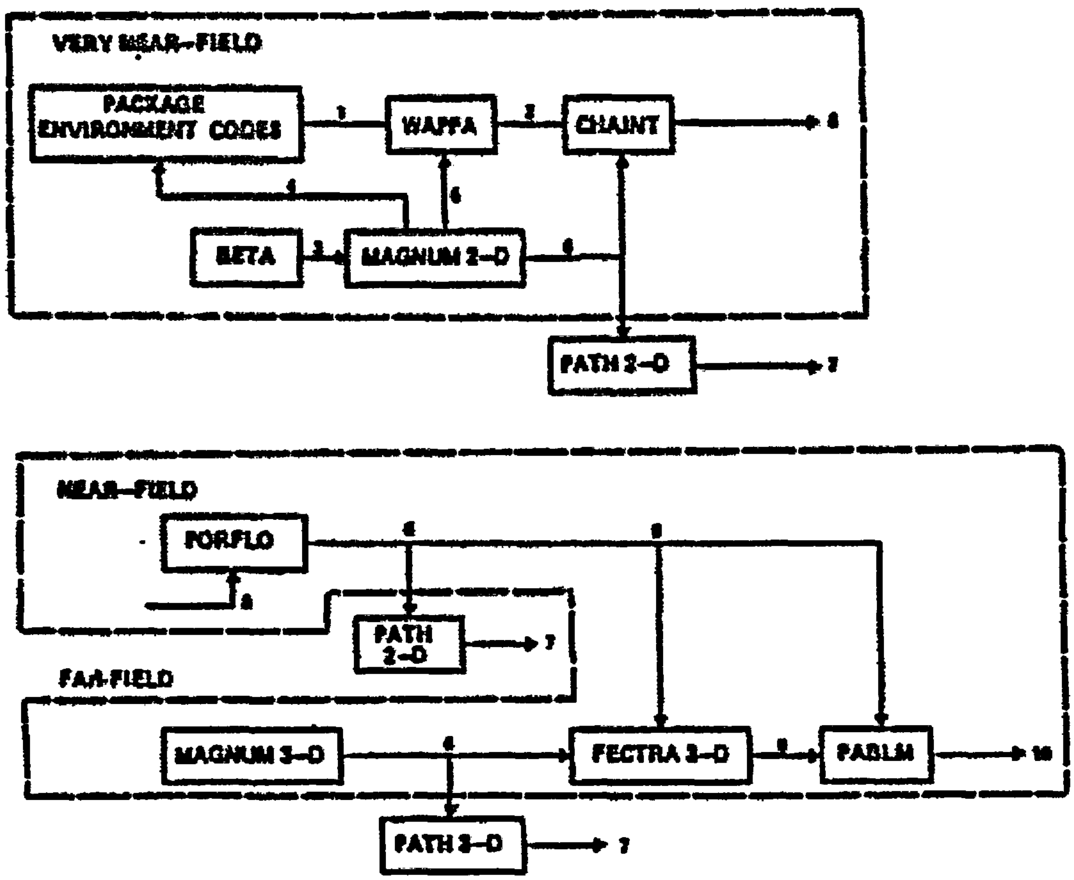


FIGURE A-5. Relationship of Regulatory Criteria to Performance Assessment System Model; Total Radionuclide Release to Accessible Environment in 10,000-Yr (40 CFR 191) (EPA, 1981).



1. TEMPERATURE, Eh, Ph, OTHERS
2. CONTAINMENT TIME AND SOURCE TERM
3. FRACTURE PERMEABILITY
4. RESATURATION TIME
5. WATER FLOW RATES
6. GROUNDWATER FLOW FIELDS
7. FLOWPATHS AND WATER TRAVEL TIMES
8. REPOSITORY SOURCE TERMS
9. RADIONUCLIDE CONCENTRATIONS AND FLUXES
10. DOSE-TO-MAN

FIGURE A-6. Relationship of Regulatory Criteria to Performance Assessment System Model; Dose-to-Man Limit (Proposed by DOE).

TABLE A-1. Summary of Codes for Performance Assessment.

Computer code	Approach		Stress/ strain		Ground-water flow		Heat		Radionuclide transport			Computational method			
	CO	DC	LI	NL	IS	NI	AD	DS	S	MC	DE	FE	FD	AL	DI
Very Near Field															
ADINA	X		X	X								X			3
ADINAT	X				X	X		X				X			3
BETA	X		X		X	X		X				X			2
DAMSWEL	X		X	X	X	X		X				X			2
ANSYS	X	X	X	X	X	X		X				X			3
HEATINGS	X					X		X					X		3
MAGNUM	X	X			X	X	X	X				X			2
CHAINT	X	X							X	X	X	X			2
WAPPA	X					X			X				X		1
Near Field															
PORFLO	X				X	X	X	X	X				X		2
PATH	X	X			X	X						X			2
Far Field															
MAGNUM-3D	X				X							X			3
PATH-3D	X				X							X			3
FECTRA	X								X			X			3
PABLM	X									X	X			X	1

LEGEND:

AD=advection
AL=analytical
CO=continuum
DC=discontinuum
DE=decay chains

DI=dimensionality
DS=diffusion
FD=finite difference
FE=finite element
IS=isothermal

LI=linear properties
MC=multicomponent
NI=nonisothermal
NL=nonlinear properties
S=single component

CODE DESCRIPTIONS

Very Near Field

ADINA. The ADINA code (Bathe, 1978a) is a finite-element code for static and dynamic displacement and stress analysis of solids and structures. The code can perform analyses with linear and nonlinear material properties that may be temperature dependent. A companion code, ADINAT, is available for analysis of linear and nonlinear steady-state and transient heat-transfer problems. File structures are compatible between the two programs to allow coupled thermomechanical analysis. Code capabilities of interest are:

- Temperature-dependent isotropic and orthotropic elastic material response
- A curve description model where the instantaneous bulk and shear moduli are defined as individual functions of the current volumetric strain; nonsymmetrical stress-strain curves can be simulated with a tension cutoff or tensile failure option
- Accommodation of a variety of yield criteria to model plasticity and may be used in combination with a creep law.

Additional advantages accrue from other code capabilities. Many discrete elements are available for modeling complex physical boundaries. Superelements can be used to reduce run costs and at the same time provide accurate problem representation.

ADINAT. This code (Bathe, 1978b) was developed as a companion program to ADINA for the purpose of coupling thermal and mechanical analyses. ADINAT provides capabilities for analysis of linear and nonlinear steady-state and transient heat-transfer problems. File structures are compatible between the two programs to allow coupled solutions. Analogies between the governing equations allow solution of other field problems such as groundwater diffusion. Heat transfer within an element is by conduction with convection and radiation boundary conditions. Useful general code capabilities include:

- Capabilities for one-, two- and three-dimensional analyses with coupling to a mechanical code
- Accommodation of temperature-dependent material properties
- Compatibility with available preprocessors and postprocessors for presentation of analysis results.

This code is widely used because of the capabilities for formulation of complex models that can be easily modified and upgraded.

BETA. The finite-element code, BETA, is a modified version of a computer code developed by the University of Minnesota. The BETA code is designed to simulate the thermomechanical response of a continuous rock mass in two dimensions (i.e., cartesian or cylindrical coordinate systems). Stresses and strains in the rock mass surrounding the repository are computed as functions of stress boundary conditions, gravity loads, and transient thermal conditions. Heat transport through the rock mass is assumed to occur by conduction only; advection of the groundwater and convective boundary conditions are not considered.

The specific governing equations, which may be found in most stress analyses (Timoshenko and Goodier, 1970) and finite-element texts (Cook, 1981), are based on elastic behavior. Some of the basic features of the BETA code are:

- A continuous rock mass is represented by quadrilateral isoparametric elements
- Accommodation of plane stress and plane strain analysis
- Provides option for isothermal stress calculations and coupled stress and temperature calculations
- Transient heat transfer calculations to accommodate arbitrary heat source loading
- Easy and inexpensive to use.

DAMSWEL. The computer code, DAMSWEL, was developed by Dames and Moore for thermomechanical analysis (Boonlualohr and others, 1980). Similar in application to the BETA code, DAMSWEL is a two-dimensional finite-element code. DAMSWEL, however, has the following major differences and advantages:

- Accommodation of linear and nonlinear rock properties
- Requires rock temperatures to be input (rather than solving the heat equation)
- More advanced computational algorithms compared to those in the BETA code.

ANSYS. The ANSYS computer code is a generalized stress-analysis code widely used in the nuclear industry. This proprietary computer code, developed by Swanson Analysis Systems, has a broad capability to analyze the thermomechanical response of the basalt rock. Some of the unique capabilities of this computer code are:

- Accommodation of a continuous and jointed rock mass
- Capacity to analyze stresses and strains in two or three dimensions

- Generalized to simulate coupled heat and stress transients
- Can consider linear and nonlinear rock properties.

HEATING5. This code is designed to solve steady-state and/or transient heat conduction in one, two, or three dimensions. The principal application of HEATING5 in performance analysis studies is to model the thermal environment surrounding the waste package. The governing equations, finite-difference technique, and boundary conditions may be found in Turner and others, (1977). Some of the general features and capabilities of this code are:

- Generalized to accommodate cartesian, cylindrical, or spherical coordinate systems
- Accommodation of temperature-dependent thermal properties
- Handles a wide variety of boundary conditions.

MAGNUM. MAGNUM is a two-dimensional finite-element code designed to simulate transient groundwater flow and heat transport in fractured-porous rock systems. The theoretical framework of the code is based on concepts for a porous continuum and for discrete conduits. In particular, a dual-porosity approach is used to represent the continuous rock mass, where flow through planar conduits is described by Poiseuille's equation. The governing equations and finite-element solution techniques are presented by Baca and others (1981b). The principal features of the MAGNUM code are as follows:

- Continuous rock mass represented with isoparametric finite elements; line elements embedded along the sides of two-dimensional elements to represent discrete fractures
- Accommodates complex stratigraphic features with variable media properties
- Provides options for coupled or uncoupled solutions of heat and flow equations
- Flow-field calculations provided for input to pathline and transport models.

CHAINT. The CHAINT code simulates multicomponent radionuclide transport in a fractured-porous medium. The processes modeled include advection, dispersion/diffusion, sorption, chain-decay coupling, and mass release. The computational method is based on a finite-element solution of the system of equations. Continuum portions of the medium are modeled as a single-porosity system, using two-dimensional isoparametric elements. Discrete features are modeled using isoparametric line elements that are embedded along the sides of the two-dimensional elements. Principal inputs

to this code are the groundwater-flow calculations obtained with the MAGNUM code (or a comparable nonisothermal flow model). The CHAINT code has the following major features:

- Generalized to handle any combination of nuclides (actinides, fission, or activation products) with different half-lives
- Accommodates subzone calculations in which the region of active nodes, within the finite-element mesh, is varied with time as the problem progresses
- Second-order accurate and fully implicit.

The CHAINT code has been verified with boundary-value problems and benchmarked with the PORFLO code. Additional work is proceeding to reduce computational times and to validate the transport model using experimental data.

WAPPA. The WAPPA code is a generalized waste-package performance code. The WAPPA code is an extended version of an earlier code, BARIER (Lester and others, 1979), with greater capabilities to describe corrosion, radiation effects, thermomechanical response to the canister, and leaching of the waste form. Assumptions include:

- Constant repository temperature
- Completely resaturated repository
- Zero initial radionuclide concentration in water outside of package. (This implies large volume of water and/or high near-field water-turnover rate)
- Corrosion rates dependent on temperature ranges and radiation level (i.e., linear corrosion)
- Uniform stress field around the package
- Intact backfill at all times.

Although the WAPPA code will provide a very general predictive capability, some modification of the code is anticipated to model basalt conditions. For example, modifications may include: (1) capability to handle temperature history at the waste package/basalt interface, (2) consideration of desaturation/resaturation phenomena, (3) laboratory bulk-corrosion data, and (4) solubility limitation of waste-form dissolution.

Near Field

PORFLO. PORFLO is a finite-difference code with options for modeling the coupled processes of groundwater flow, heat transfer, and radionuclide transport. The code is applicable to porous media or highly jointed rock systems that may be represented as an equivalent porous continuum. The

finite-difference method is based on a nodal-point integration technique used in conjunction with an alternating-direction implicit method. Additional description of this code is contained in Baca and others (1981a). Major features of the PORFLO computer code are:

- Simple and inexpensive to use
- Ensures energy and mass conservation at the grid-block level
- Computes total activity crossing specified boundaries for the simulation period.

PATH. Using the numerical results from a two-dimensional groundwater model, PATH computes the pathlines or streamlines for an arbitrary set of starting points in the study region. In addition to computing the particle trajectories, the code computes the cumulative time of travel along each trajectory (i.e., travel times). The program solves the pathline equations on a finite-element grid network, thereby tracing the particle trajectory from element to element. Major features of the PATH code are:

- Solves pathline equations using a predictor-corrector algorithm and finite-element shape functions
- Accommodates two-dimensional isoparametric elements with one-dimensional line elements
- Graphic output with options provided for superimposing the finite-element mesh, rock-type boundaries, as well as plots for subzone grids.

The PATH computer code is designed for interactive use on a standard graphics terminal. Versions of this program are currently interfaced with the MAGNUM and PORFLO computer codes.

Far Field

MAGNUM-3D. The MAGNUM-3D code was developed to solve the three-dimensional (3D) form of the groundwater flow equation, using the same fundamental numerical procedures as the MAGNUM code. MAGNUM-3D is limited to isothermal conditions; future versions may consider three-dimensional nonisothermal effects as needed. The code is based on the continuum theory of porous media and is designed for analysis of flow patterns in large-scale groundwater basins. Some of the important features of MAGNUM-3D are:

- Accommodates complex three-dimensional geometry through the use of various three-dimensional isoparametric finite elements (e.g., tetrahedrons and parallelepipeds)
- Considers different types of boundary conditions (e.g., specified heads and/or fluxes)

- Provides a three-dimensional flow field for input to pathline and transport codes.

PATH-3D. The PATH-3D code is similar to PATH except that it calculates three-dimensional pathlines or streamlines. It is interfaced with the MAGNUM-3D code.

FECTRA. The FECTRA code analyzes radionuclide transport in porous media. This code is based on the dual approach that considers the interaction of the mobile and immobile radionuclide components. The theoretical framework includes advection, dispersion/diffusion, sorption, decay, and mass release of a single species. The code was originally developed for application to the partially saturated flow regime. Basic features of FECTRA are:

- Two versions available (two-dimensional and three-dimensional), using various isoparametric finite elements
- Second-order accurate and fully implicit numerical techniques
- Verified and benchmarked to a limited extent
- Accommodates complex stratigraphic features with variable media properties
- Provides options for coupled or uncoupled solutions of heat and flow equations
- Flow-field calculations provided for input to pathline and transport models.

The FECTRA code is designed to be interfaced with a three-dimensional fluid-flow code such as MAGNUM-3D, as well as for far-field radionuclide transport.

PABLM. The PABLM code computes radiation doses to man from ingestion or contact with radionuclides (Napier and others, 1980). The code is intended for linkup with the output of a far-field transport code; PABLM then analyzes distribution in the biosphere and uptake by humans. Principal features of PABLM include:

- Accommodates deposition from groundwater or atmospheric release
- Considers radioactive decay
- Computes maximum man or population exposures
- Considers wide range of ingestion and contact pathways.

The codes described above represent an integrated set of codes specifically applicable to modeling a repository system in basaltic rock. The complete set of codes provides a predictive capability for use in evaluating compliance with regulatory requirements. A high degree of flexibility exists such that new submodels can be easily included in the modeling methodology.

REFERENCES

Baca, R. G., Langford, D. W., and England, R. L., 1981a, Analysis of Host Rock Performance for a Nuclear Waste Repository Using Coupled Flow and Transport Models, RHO-BWI-SA-140, Rockwell Hanford Operations, Richland, Washington.
Baca, R. G., Arnett, R. C., and King, I. P., 1981b, Numerical Modeling of Flow and Transport Processes in a Fractured-Porous Rock System, RHO-BWI-SA-113, Rockwell Hanford Operations, Richland, Washington; also in Proceedings of the 22nd U.S. Symposium on Rock Mechanics, Massachusetts Institute of Technolcgy, Cambridge, Massachusetts.

Bathe, K. J. (1978a), ADINA, A Finite Element Program for Automated Dynamic Incremental Nonlinear Analysis, Acoustics and Vibration Laboratory, Mechanical Engineering Dept. Report 82448-1, Massachusetts Institute of Technology, Cambridge, Mass.

Bathe, K. J. (1978b), ADINAT, A Finite Element Program for Automated Dynamic Incremental Nonlinear Analysis of Temperatures, Acoustics and Vibration Laboratory, Mechanical Engineering Dept. Report 82448-1, Massachusetts Institute of Technology, Cambridge, Mass.

Boonlualohr, P., Mustoe, G. and Williams, J. R., 1980, Program DAMSWEL Programming Manual, Code Verification, Program Listing, RHO-BWI-C-74, Rockwell Hanford Operations, Richland, Washington.

Cook, R. D. 1981, Concepts and Applications of Finite Element Analysis, 2nd ed., John Wiley & Sons, New York, New York.

EPA, 1982, "Environmental Protection Agency, 40 CFR 191, Environmental Standards and Federal Radiation Protection Guidance for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes," Federal Register, Vol. 47, No. 250, December 29, 1982, Proposed Rule.

Lester, D. H., Stula, R. T., and Kirstein, B.E., 1979, System Study in Engineered Barriers - Task 3-Barrier Performance Analysis, ONWI/Sub/79/E515-02000-1, Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, Ohio.

Napier, B. A., Kennedy, W. E., Jr., Soldat, J. K., 1980, PABLM- A Computer Program to Calculate Accumulated Radiation Doses from Radionuclides in the Environment, PNL-3209, Pacific Northwest Laboratory, Richland, Washington.

NRC, 1982, Disposal of High-Level Radioactive Wastes in Geologic Repositories, Title 10, Code of Federal Regulations-Energy, Part 60, Subpart E, U.S. Nuclear Regulatory Commission, Washington, D.C., November 18, 1982, Final Draft.

Timoshenko, S. and Goodier, J., 1970, Theory of Elasticity, 3rd ed., McGraw-Hill Book Company, New York.

Turner, W. D., Elrod, D. C., and Siman-Tov, I. I., 1977, HEATING5-An IBM 360 Heat Conduction Program, ORNL/CSD/TM-15, Oak Ridge, Tennessee.

APPENDIX B

GLOSSARY

The preclosure and postclosure boundary conditions for some of the terms defined herein, and an illustration of their usage are shown in Figures B-1, B-2, and B-3. The relationship of a projected dose criteria with other doses mandated for fuel cycle operations, and general exposure limits for individuals in the country is illustrated in Figure B-4. As the regulatory requirements change, there will be a need to modify some of the definitions.

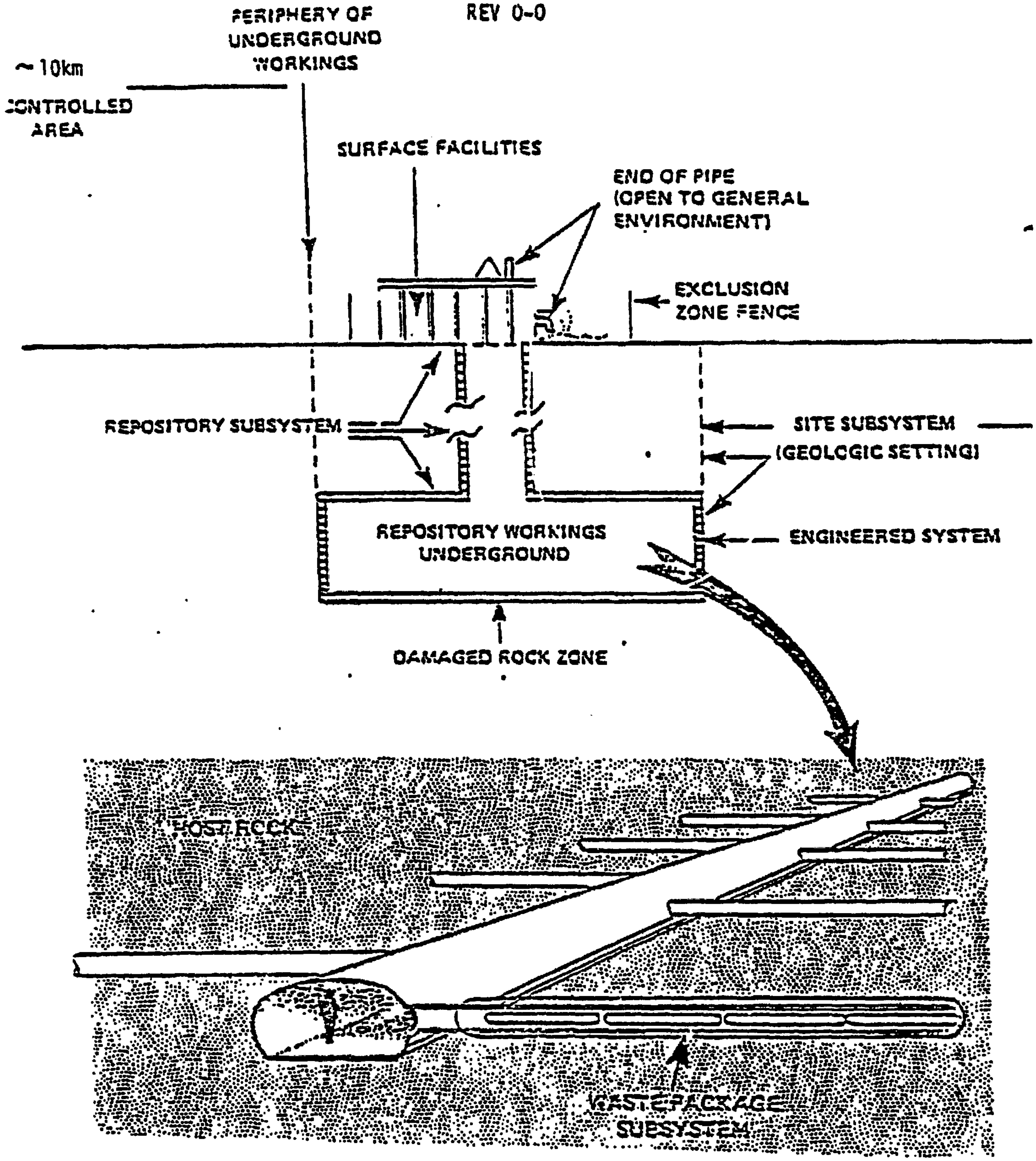


FIGURE 8-1. Preclosure Boundary Conditions for the Waste Isolation System.

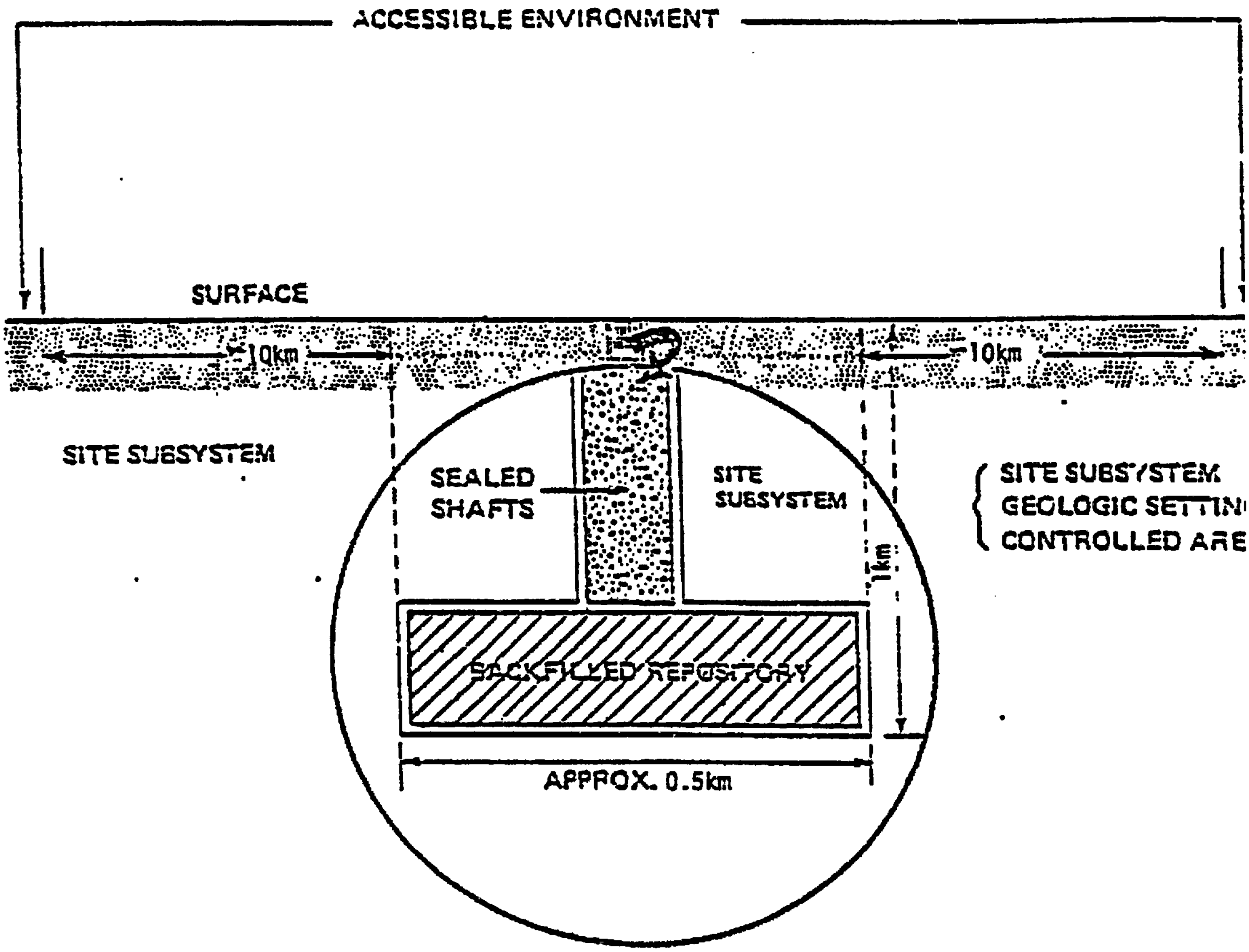


FIGURE 8-2. Postclosure Boundary Conditions for the Waste Isolation System.

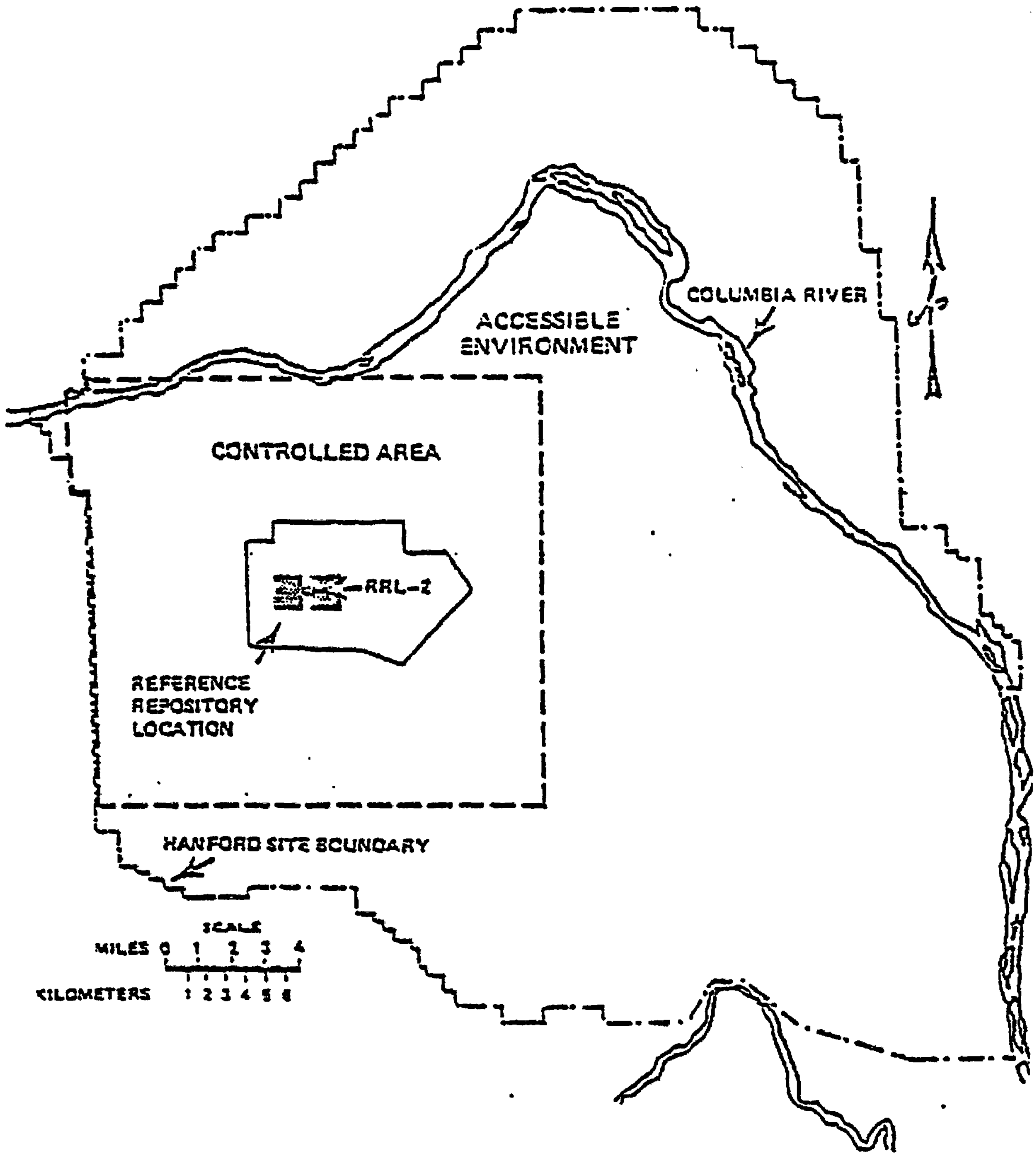


FIGURE 8-3. Definition of Controlled Area and Accessible Environment.

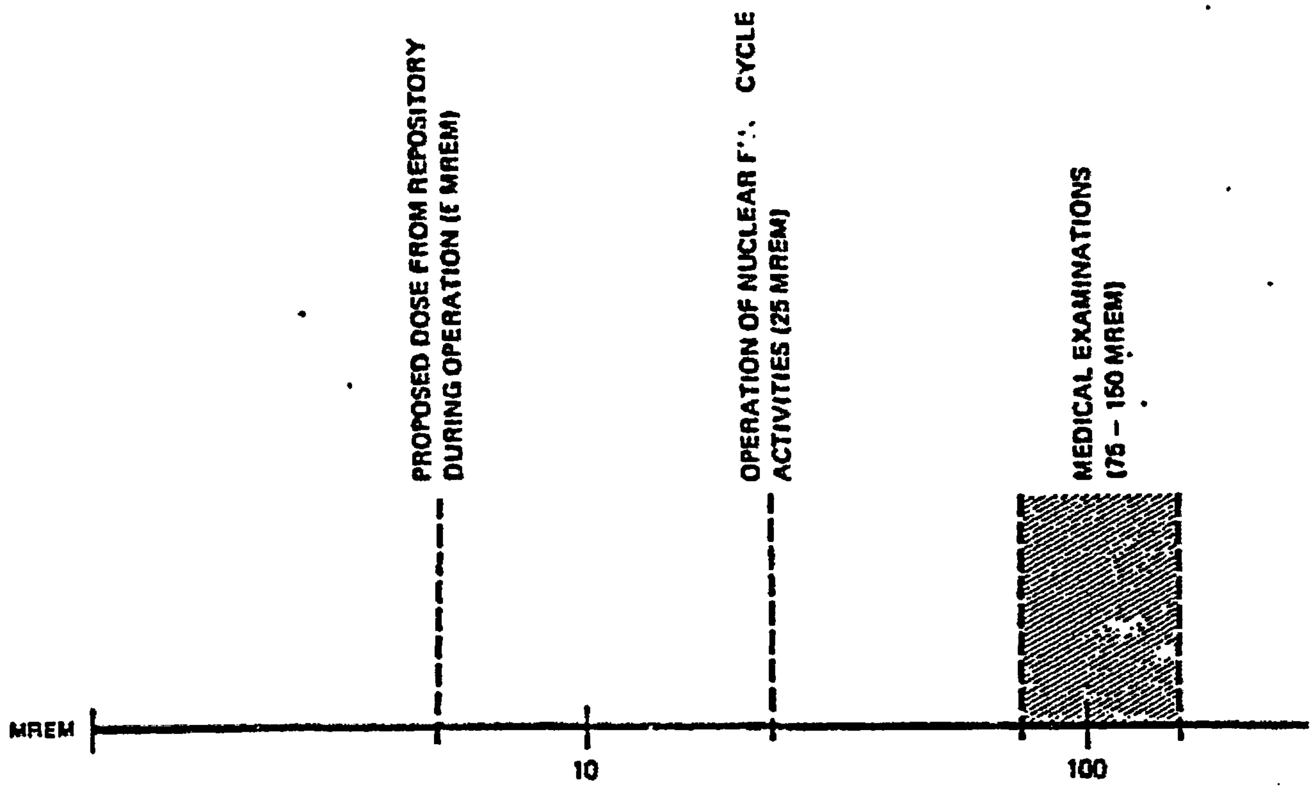


FIGURE B-4. Annual Dose from Various Events/Conditions.

accessible environment — means the atmosphere, the land surface, surface waters, oceans, and the parts of the lithosphere that are more than 10 kilometers in any direction from the original location of any of the radioactive waste in a disposal system. (DOE, 1983)

adjoint — a sensitivity analysis technique.

anoxic — a general term meaning in the absence of oxygen, usually implying reducing conditions.

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

as low as reasonably achievable (ALARA) — refers to limiting release and exposure and is used by the NRC (1980a, 1980b, 1981) in the context of "... as low as reasonably achievable taking into account the state of technology, and the economics of improvements in relation to benefits to the public health and safety and other societal and socioeconomic considerations..."

baseline — that body of information which, in the aggregate, defines a project as it exists at a specific time. Typically, this concept is utilized as a management device to control project content (technical, cost/schedule, contractual).

benchmarking of computer codes — code-to-code comparisons in which simulations obtained with BWIP codes are compared to those obtained with other available codes. The test cases used for benchmarking will use data representative of the actual repository setting. Benchmarking is complete when a reasonable consensus between independent code predictions is achieved.

BWIP — Basalt Waste Isolation Project.

BWR — boiling water reactor.

candidate repository horizon — a rock layer; e.g., a basalt flow with sufficient favorable properties to be designated as a potential host rock for a nuclear waste repository.

canister -- (as related to radioactive materials) the primary metal or ceramic container for remote-handled solid transuranic waste, high-level waste, or spent fuel. The canister affords physical containment for the waste, but is not primarily designed to provide shielding.

CHLW -- commercial high level waste.

colonnade -- in columrar jointing, the lower portion of a basalt flow that structurally has thicker and better formed columns than the upper portion (or entablature). The colonnade may also occur in the upper third of a flow (directly below the flow top).

containment -- means confinement of the radioactive wastes within prescribed boundaries (e.g., within a waste package). (DOE, 1983)

controlled area (as used by NRC) -- a surface location extending horizontally no more than 10 km (6.7 miles) in any direction from the edge of the disturbed rock zone and the underlying subsurface, which area has been committed to use as a geologic repository and from which incompatible activities would be restricted following permanent closure (NRC, 1981b). The outer edge of the controlled area marks the inner edge of the accessible environment.

criterion -- a standard rule or test by which something can be judged.

curie -- a unit of radioactivity defined as the amount of a radioactive material that has an activity of 3.7×10^{10} disintegrations per second; millicurie = 10^{-3} curie; microcurie = 10^{-6} curie, nanocurie = 10^{-9} curie; picocurie = 10^{-12} curie.

DHLW -- defense high level waste.

distribution coefficient -- the ratio of the concentration of a solute sorbed by ion exchange substances such as Earth materials, particularly clays, to the concentration of the solute remaining in solution. A large distribution coefficient implies that the substance is readily sorbed and is redissolved slowly. The concentration of a material in the solid phase (i.e., rock or sediment) (moles per gram) divided by the concentration of material in the aqueous phase (moles per liter).

disturbed rock zone -- means that portion of the controlled area whose physical or chemical properties have changed as a result of underground facility construction or heat generated by the emplaced radioactive waste such that the resultant change in properties may have a significant effect on the performance of the geologic repository. (DOE, 1983)

DOE — U.S. Department of Energy.

earthquake swarm — a series of minor earthquakes, none of which may be identified as the main shock, occurring in a limited area and time.

Eh — a measure of the oxidation reduction potential (volts); the difference in potential measured in a cell having both oxidized and reduced form of an element (measured) and the standard hydrogen electrode potential.

engineered barrier — means manmade components of a disposal system designed to prevent the release of radionuclides into the geologic medium involved; such term includes the high-level radioactive waste form, high-level radioactive waste canisters, and other materials placed over and around such canisters. (DOE, 1983)

engineered subsystem — (1) the underground facility, waste package, shaft and tunnel seals, tunnel backfill, and disturbed rock zone caused by excavation or from the high heat pulse generated by the emplaced radioactive waste. (2) The waste package plus the underground facilities, including the envelope of rock to the maximum extent of the 100°C isotherm.

Environmental Report — a detailed document that is submitted to the NRC as part of the license application. The document provides a detailed description of the expected environmental impacts associated with a proposed construction project, in this case a nuclear waste repository in basalt.

EPA — U.S. Environmental Protection Agency.

exclusion area — that area surrounding an individual nuclear facility in which the licensee has the authority to determine all activities including exclusion or removal of personnel and property from the area. The BWIP has defined this as the outer fence of the surface workings.

flow top — the uppermost portion of a basalt flow, which consists of vesicular and rubbly-to-brecciated basalt.

foldbelt — a linear region that has been subjected to folding and deformation.

groundwater -- subsurface water existing in the saturated zone, including underground streams.

groundwater travel time -- the time required for groundwater to flow along a path length.

horizon -- (1) in geology, a given definite position or interval in the stratigraphic column. (2) In this document, a specific underground level, altitude, or elevation.

host rock -- means rock within which radioactive waste is emplaced for disposal. (DOE, 1983)

hydraulic potential (or hydraulic head) -- a measure of the mechanical energy per unit mass of fluid present at a given point within a porous medium. For groundwater flow systems the parameter is generally determined in the field by measuring the elevation of water within tightly cased wells or by measuring the pressure within a hydraulically isolated portion of a borehole or well. Generally expressed in units of length.

hydrogeologic unit -- any soil or rock unit or subsurface zone that has a distinct influence on the storage or movement of groundwater by virtue of its porosity or permeability.

hydrological regime -- the distribution, characteristics, and inter-relationships of the aqueous components of the geologic environment.

Hydrologic modeling -- the process of using a mathematical representation of a hydrologic system (as embodied in a computer code) to predict the flow of groundwater and the movement of dissolved substances.

hydrologic transport -- transport of solutes through a geologic formation due to movement of groundwater.

important to safety -- (NRC, 1981a) with reference to structures, system, and components means those engineered structures, systems, and components essential to the prevention or mitigation of an accident that could result in a radiation dose to the whole body, or any organ, of 0.5 rem or greater at or beyond the nearest boundary of the controlled area at any time until the completion of permanent closure.

isolation -- means inhibiting the transport of radioactive material in the subsurface so that the amounts and concentrations of this material entering the accessible environment will be kept within prescribed limits. (DOE, 1983)

license application — a document showing that the nuclear facility and its safety-related systems, with reasonable assurance, can be operated without undue risk to the health and safety of the public and with adequate provisions for the protection of property and the environment.

licensing — the process of obtaining the permits and authorizations from responsible federal, state, and local regulatory agencies required to site, construct, operate, and decommission a repository. Includes preparing required documentation, submitting it to the appropriate agencies, responding to agency requests for additional information, and testifying as necessary at public hearings. Within the licensing framework, as defined in statutory requirements, approved permits or licenses must be available prior to the commencement of the activity involved.

model — means conceptual definitions and associated mathematical representations that simulate the response of a repository system under natural or perturbed conditions. An example is a hydrologic model to predict ground-water travel or radionuclide transport from the waste emplacement area to the accessible environment.

multibarrier system — concept of using the waste form, the container (canister), the overpack, the emplacement medium, and surrounding geologic media as multiple barriers to isolate the waste from the biosphere. A multi-barrier system is a system of barriers, operating independently or relatively independently, which acts to contain and/or isolate nuclear waste.

NRC — U.S. Nuclear Regulatory Commission.

NWTS Program — National Waste Terminal Storage Program.

ONI — Office of NWTS Integration.

ONWI — Office of Nuclear Waste Isolation.

Pasco Basin — a structural and topographic basin within the western Columbia Plateau. The Hanford Site is located within the Pasco Basin.

pathway — (as related to waste management) possible or potential routes by which wastes might reach the accessible environment.

performance assessment — performance assessment is the prediction of component and system behavior relative to the ability to contain and isolate wastes in accordance with applicable standards and requirements. Performance assessment includes both preclosure and postclosure analyses.

performance confirmation — (NRC, 1981a) the program of tests, experiments, and analyses which is conducted to evaluate the accuracy and adequacy of the information used to determine assurance that the performance objectives for the period after permanent closure can be met.

permanent closure — (NRC, 1981a) final backfilling of the underground facility and the sealing of shafts and boreholes.

permeability (permeable) (K) — a material's or rock's capacity for transmitting a fluid under a hydraulic gradient. It is approximately equivalent to hydraulic conductivity.

pH — a measure of the relative acidity or alkalinity of solution; a neutral solution has pH of 7, acids have pH's of less than 7, and alkalies have pH's of greater than 7. pH = -log H^+ where H^+ is the hydrogen ion activity in solution.

porosity — usually expressed as a percentage of the volume, Vp, of the pore space in a rock to the volume, Vr, of the rock, the latter volume including rock material plus void space.

$$\text{porosity} = n = \frac{V_v}{V_T}, \text{ where } V_v = \text{volume of voids and } V_T = \text{total volume}$$

preclosure period — the period of time from the inception of construction activities, including waste emplacement and monitoring through the end of permanent closure activities.

postclosure — the period of time beginning at the end of the operations phase and ending 10,000 yr later.

PWR — pressurized water reactor.

radionuclide retardation factor — a characteristic (usually chemical) of the hydrological or geochemical regime that slows the migration or transport of a radionuclide by sorption or other processes. The radionuclide retardation factor gives the ratio of the groundwater velocity to the solute velocity.

reasonably achievable (to the extent) — that which is shown to be reasonable considering the costs and benefits of potential mitigative measures or reasonable courses of action in accordance with requirements of NEPA (1970) and CEQ (1978). (See also as low as reasonably achievable (ALARA).)

reasonably forseeable releases — (as used by the EPA (1981)) releases of radioactive wastes to the accessible environment that are estimated to have more than one chance in 100 of occurring within 10,000 yrs.

repository (federal) — a federally owned and operated facility for storage or disposal of specific types of waste from DOE sites and/or commercial nuclear operations.

repository subsystem — the configuration of man-made features designed to act in harmony with the natural system to provide long-term containment and isolation of nuclear wastes and to provide for receipt, inspection handling, emplacement, and potential retrieval of wastes during the operating phase.

risk — the product of probability and consequence of an event.

Safety Analysis Report — a safety document showing that the facility and its safety-related systems can be operated with reasonable assurance of no undue risk to the health and safety of the public and with adequate provisions for the protection of property and the environment.

scenario — a particular chain of hypothetical circumstances often used in performance analysis to model possible events.

sensitivity analysis — a sensitivity analysis is a systematic modeling procedure in which the model parameters (coefficients, boundary conditions, source terms, etc.) are varied over some range of interest and the response of model is observed. The objective of a sensitivity analysis are: (1) to identify the most important parameters influencing the model predictions; and (2) to relate the change in model output to unit changes in model input.

site qualification — all scientific and engineering investigations designed to ascertain that a specific site has characteristics that will permit a repository facility to be licensed at that site.

site subsystem — the zone between the accessible environment and the disturbed rock zone. (Comparable to NRC's "controlled area" and the geologic setting.)

sorption — the binding, on a microscopic scale, of one substance to another, such as by adsorption or ion exchange. In this document, the word is especially used in the sorption of solutes, such as dissolved radionuclides, onto aquifer solids or waste package materials. This occurs by means of close-range chemical or physical forces.

sorptive capacity — the measure of a material's ability to sorb specific constituents from a liquid as it passes through the material.

subsurface facility — the underground portions of the geologic repository operations area including openings, backfill materials, shafts, tunnels, and boreholes, as well as shaft, tunnel and borehole seals until the time of preliminary closure.

— (as defined in 10 CFR 60 (NRC, 1981b)) the underground portions of the geologic repository operations area including openings, backfill materials, shafts, and boreholes as well as shaft and borehole seals.

<u>terminal storage</u> -- isolation and storage of radioactive waste operations for which no subsequent waste treatment or transportation operations are anticipated.

<u>transmissivity</u> -- a coefficient relating the volumetric flow through a unit width of material to the driving force (hydraulic potential); a function of both the porous medium, fluid properties (including viscosity), and saturated thickness of the aquifer. Mathematically, it is the product of hydraulic conductivity and the thickness of the zone of the aquifer being measured. It is measured in square feet per day or equivalent units.

<u>unanticipated processes and events</u> -- (NRC, 1981a) those processes and events affecting the geologic setting that are judged not to be reasonably likely to occur during the period the intended performance objective must be achieved, but which are nevertheless sufficiently credible to warrant consideration. Unanticipated processes and events may be either natural processes or events or processes and events initiated by human activities other than those activities licensed under this part. Processes and events initiated by human activities may only be found to be sufficiently credible to warrant consideration if it is assumed that: (1) the monuments provided for by this part are sufficiently permanent to serve their intended purpose: (2) the value to future generations of potential resources within the site can be assessed adequately under the applicable provisions of this part; (3) an understanding of the nature of radioactivity, and an appreciation of its hazards, has been retained in some functioning institutions; (4) institutions are able to assess risk and to take remedial action at a level of social organization and technological competence equivalent to, or superior to, that which was applied in initiating the processes or events concerned; and (5) relevant records are preserved, and remain accessible, for several hundred years after permanent closure.

<u>uncertainty analysis</u>-- (as used in modeling). An uncertainty analysis is a statistically based procedure which provides uncertainty bonds in model prediction. The analysis approach generally requires a characterization of the uncertainty in model input data (in terms of means and variances, and quantifies the propagation of uncertainty in uncertainty of such variables as groundwater travel time, radionuclide concentration, and dose water.)

<u>uncertainty analysis</u> -- (data evaluation) A statistically based procedure applied to laboratory or field data (hydrologic, geologic, and/or chemical, among others) to obtain a description of its spacial or other variability. Other description in general provided in terms of a standard statistical distribution such as a normal or log normal distribution and can be expressed in terms of prevision and/or accuracy.

validation of computer codes — the method of assessing that the code indeed reflects the behavior of the real world (i.e., that the map is an adequate accurate description of the territory).

verification of computer codes/models — testing a code with analytical solutions for idealized boundary value problems. A computer code will be considered verified when it has been shown to solve the boundary value problems with sufficient accuracy. This testing process provides a check on both the computer coding and the numerical approximations to the mathematical model.

very unlikely releases — (EPA, 1982) releases of radioactive wastes to the accessible environment that are estimated to have a chance of occurring within 10,000-yr of less than one in 100 and more than one in 10,000.

waste isolation system — the entire repository, or mined geological disposal system consisting of the site, waste package, and repository subsystem. The waste isolation system is bounded by the accessible environment. The terms "mined geologic disposal system" (NWTS, DOE/NWTS-2, 1982) and "waste isolation system" (BWIP) are used interchangeably.

waste package — the sealed canister and overpack (if present), which includes the waste form, as well as the enclosing envelope that separates the waste from the unexcavated rock and the repository backfill. The enclosing envelope may include the canister, buffer or shielding, overpack, and discrete backfill in the emplacement hole, and any other structures, enclosures, or materials reaching to the surface of the rock (borehole emplacement) or tunnel wall (for tunnel emplacement).

REFERENCES

CEQ, 1978, Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act, Title 40, Code of Federal Regulations, Parts 1500-1508, Council on Environmental Quality, Washington, D.C., also in Federal Register, Vol. 43, pp. 55978.

DOE/NWTS-2, 1982, National Waste Terminal Storage Program, NWTS Performance Assessment Plan, Draft 3, U.S. Department of Energy, Washington, D.C., June 1982.

DOE, 1983, "Department of Energy, 10 CFR 960, Nuclear Waste Policy Act of 1982: Proposed general guidelines for the recommendation of sites for Nuclear Waste Repositories, "Federal Register, Vol. 48, No. 26, pp. 5670- 5682, Feb. 7, 1983.

EPA, 1982, "Environmental Protection Agency, 40 CFR 191, Environmental Standards and Federal Radiation Protection Guidance for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes," Federal Register, Vol. 47, No. 250, December 29, 1982, Proposed Rule.

NEPA, 1970, National Environmental Policy Act of 1969, Public Law 91-190, 83 Stat. 852, 42 USC 4321, Sections 102(2)(C) and (E), United States Congress, Washington, D.C., January 1, 1970.

NRC, 1980a, Domestic Licensing of Production and Utilization Facilities, Title 10, Code of Federal Regulations-Energy, Part 50, U.S. Nuclear Regulatory Commission, Washington, D.C.

NRC, 1980b, Standards for Protection Against Radiation, Title 10, Code of Federal Regulations-Energy, Part 20, U.S. Nuclear Regulatory Commission, Washington, D.C.

NRC, 1981a, Disposal of High-Level Radioactive Wastes in Geologic Repositories: Proposed Licensing Procedures, Title 10, Code of Federal Regulations-Energy, Part 60, Subparts A-D, U.S. Nuclear Regulatory Commission, Washington, D.C., March 6, 1981.

NRC, 1981b, "Nuclear Regulatory Commission, 10 CFR 60, Disposal of High Level Radioactive Wastes in Geologic Repositories," Federal Register, Vol. 46, No. 130, July 8, 1981, Proposed Rules.

APPENDIX C

PERFORMANCE CRITERIA FOR A NUCLEAR WASTE REPOSITORY IN BASALT (EXCERPTS)

PREEMPLACEMENT

10 CFR 60.113 (NRC, 1982)	(2) Geologic setting. The geologic repository shall be located so that pre-waste emplacement groundwater travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment shall be at least 1,000 yr or such other travel time as may be approved or specified by the Commission.

PRECLOSURE

10 CFR 60.111 (NRC, 1982)	(a) Protection against radiation exposures and releases of radioactive material. The geologic repository operations area shall be designed so that until permanent closure has been completed, radiation exposures and radiation levels, and releases of radioactive materials to unrestricted areas, will at all times be maintained within the limits specified in Part 20 of this chapter and such generally applicable environmental standards as may have been established by the Environmental Protection Agency.
40 CFR 191.03 (EPA, 1982)	Standards for normal operations. Operations covered by this Subpart should be conducted so as to reduce exposures to members of the public to the extent reasonably achievable, taking into account technical, social, and economic considerations. As an upper limit, except for variances in accordance with 191.04, these operations shall be conducted in such a manner as to provide reasonable assurance that the combined annual dose equivalent to any member of the public due to: (i) operations covered by Part 190, (ii) planned discharges of radioactive material to the general environment from operations covered by this Subpart, and (iii) direct radiation from these operations; shall not exceed 25 millirems to the whole body, 75 millirems to the thyroid, or 25 millirems to any other organ.

POSTCLOSURE

10 CFR 60.113 (NRC, 1982)	(A) Containment of HLW within the HLW waste package will be substantially complete for a period of 1,000 yr after permanent closure of the geologic repository, or such other period as may be approved or specified by the Commission.
10 CFR 60.112 (NRC, 1982)	Overall system performance objective for the geologic repository after permanent closure. The geologic setting shall be selected 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 environmental standards as may have been established by the Environmental Protection Agency with respect to either anticipated processes and events or unanticipated processes and events. For disposal in the saturated zone, both the partial and complete filling with groundwater of available void spaces in the underground facility shall be included among the anticipated processes and events.
10 CFR 60.113 (NRC, 1982)	(B) The release rate of any radionuclide 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 yr following permanent closure, or such other fraction of the inventory as may be approved or specified by the Commission; provided, that this requirement does not apply to any radionuclide which is released at a rate less than 0.1% of the calculated total annual release at 1,000 yr following permanent closure.
40 CFR 191.13 (EPA, 1982)	Projected Performance Requirements (a) Disposal systems shall be designed to comply with the projected performance requirements of this section. If performance assessments are used to determine compliance with these projected performance requirements, these assessments should consider realistic projections of the protection provided by all of the engineered and natural barriers of a disposal system. These requirements are upper limits. In accordance with Appendix A, the implementing agency should establish siting and design objectives which will reduce releases as far below these limits as reasonably achievable.

(b) Disposal systems for high-level or transuranic wastes shall be designed to provide a reasonable expectation that, for 10,000 yr after disposal: (1) Reasonable foreseeable releases of waste to the accessible environment are projected to be less than the quantities calculated according to Appendix B. (2) Very unlikely releases of waste to the accessible environment are projected to be less than ten times the quantities calculated according to Appendix B.

10 CFR 60.113 (NRC, 1982)	Performance of particular barriers after permanent closure. (a) General provisions. (1) Engineered barrier system. (i) The engineered barrier system shall be designed so that assuming anticipated processes and events, (a) containment of HLW will be substantially complete during the period when radiation and thermal conditions in the underground facility are dominated by fission product decay; (b) any release of radionuclides from the engineered barrier system shall be a gradual process which results in small fractional releases to the geologic setting over long times.
10 CFR 60.134 (NRC, 1982)	Design of seals for shafts and boreholes. (a) General design requirement. Seals for shafts and boreholes shall be designed so that following permanent closure they do not become pathways that will compromise the geologic repository's ability to meet the performance objectives of 60.112 and 60.113. (b) Selection of materials and placement methods. Materials and placement methods for seals shall be selected to reduce, to the extent practicable, (1) the potential for creating a preferential pathway for groundwater; or (2) radioactive waste migration through existing pathways.

Table C-1. Cumulative Release Limits to the Accessible Environment for 10,000 Yr. (40 CFR 191) (EPA, 1982)

Radionuclide	Release limit[a] (Ci per 1,000 MTHM)
^{241}Americium	10
^{243}Americium	4
^{14}Carbon	200
^{135}Cesium	2000
^{137}Cesium	500
^{237}Neptunium	20
^{238}Plutonium	400
^{239}Plutonium	100
^{240}Plutonium	100
^{242}Plutonium	100
^{226}Radium	3
^{90}Strontium	80
^{99}Technetium	10,000
^{126}Tin	80
Any other alpha-emitting radionuclide	10
Any other radionuclide that does not emit alpha particles	500

[a]For each isotope.
MTHM = Metric tons heavy metal.

NOTE: In cases where a mixture of radionuclides is projected to be released, the limiting values shall be determined as follows: For each radionuclide in the mixture, determine the ratio between the cumulative release quantity projected over 10,000 yr and the limit for that radionuclide as determined from Table C-1. The sum of such ratios for all the radionuclides in the mixture may not exceed one.

For example, if radionuclides A, B, and C are projected to be released in amounts Q_a, Q_b, and Q_c, and if the applicable Release Limits are RL_a, RL_b, and RL_c, then the cumulative releases over 10,000 shall be limited so that the following relationship exists:

$$\frac{Q_a}{RL_a} + \frac{Q_b}{RL_b} + \frac{Q_c}{RL_c} \quad 1$$

REFERENCES

EPA, 1982, "Environmental Protection Agency, 40 CFR 191, Environmental Standards and Federal Radiation Protection Guidance for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes," Federal Register, Vol. 47, No. 250, December 29, 1982, Proposed Rule.

NRC, 1982, Disposal of High-Level Radioactive Wastes in Geologic Repositories, Title 10, Code of Federal Regulations-Energy, Part 60, Subpart E, U.S. Nuclear Regulatory Commission, Washington, D.C., November 18, 1982, Final Draft.

APPENDIX D

PROPOSED GENERAL GUIDELINES FOR THE RECOMMENDATION OF SITES FOR NUCLEAR WASTE REPOSITORIES (DOE, 1983)

SYSTEM GUIDELINE
960.3.1
(DOE, 1983)

Performance Before Permanent Closure

The repository operations area shall be sited and designed to comply with the limits established by the Nuclear Regulatory Commission in 10 CFR 20 and by the Environmental Protection Agency in the proposed 40 CFR 191, Subpart A, Environmental Standards for Management and Storage. A site shall be disqualified if during site investigation it becomes clear that the site, together with state-of-the-art engineered systems and controls, will preclude a repository at that site from complying with 10 CFR 20 and the proposed 40 CFR 191, Subpart A.

a. Favorable Conditions

1. A combination of meteorological conditions and low population densities such that few, if any, members of the general public would be exposed to radiation due to emissions during repository operation.

2. Absence of contributing radioactive releases from other nuclear facilities governed by 40 CFR 190 or the proposed 40 CFR 191 that would require consideration in accordance with 40 CFR 191.03.

b. Potentially Adverse Conditions

1. Presence of other nuclear facilities governed by the proposed 40 CFR 191 with actual or projected releases at or near the maximum value permissible under those standards.

2. Proximity to populated areas that could be routinely affected by repository effluents considering prevailing meteorological conditions.

SYSTEM GUIDELINE
960.3.2

Performance After Permanent Closure

The site and engineered systems shall provide reasonable assurance that, after the permanent closure of the repository, credible postulated releases of radioactive materials to the accessible environment will not exceed the quantities of radioactive materials that may enter the environment as specified in the proposed 40 CFR 191, Subpart B, Environmental Standards for Disposal.

A site shall be disqualified if the characteristics that influence radionuclide transport are too complex to allow reasonable confidence of compliance with the proposed 40 CFR 191.13 when considered in conjunction with state-of-the-art engineered systems, including those required under 10 CFR 60.113.

a. Favorable Conditions

1. Ground-water travel times to the accessible environment of more than 10,000 years.

2. Geochemical conditions or ground-water volumetric flow limits that limit radiouclide releases.

3. A geologic setting that is easily characterized or modeled with existing performance-assessment techniques.

b. Potentially Adverse Conditions

Geologic settings, site geometries and characteristics, and radionuclide-transport characteristics that are extremely difficult to characterize and model.

PROGRAM GUIDELINE
960.4.1

Conduct of Site Investigations

Studies to identify potential repository sites will consider several geologic media, different hydrogeologic settings, and lands already dedicated to the nuclear activities of the Federal Government. To the extent practicable, sites recommended for detailed characterization shall be in different geologic media.

PROGRAM GUIDELINE 960.4.2

Consultation with States and Affected Indian Tribes

The DOE shall provide to State officials and to the governing bodies of any affected Indian Tribe timely and complete information regarding both plans and results concerning all phases of site evaluation, investigation, and characterization and the development of a geologic repository. Written responses to written requests for information from officials of affected states or Indian tribes will be provided within no more than 30 days.

In performing any aspect of the geologic repository progrm, the DOE shall consult and cooperate wth the governor and the legislature of an affected State and the governing body of an affected Indian tribe in an effort the resolve concerns regarding public health and safety, environmental, and economic impacts of any proposed repository.

If requested, or after notifying states or Indian tribes that potentially acceptable sites have been identified within a State or tribal land, the DOE shall seek to enter into binding written agreements to specify procedures for consultation and cooperation with the affected State or Indian tribe.

PROGRAM GUIDELINE 960.4.3

Environmental Impact Considerations

Environmental impacts shall be given due consideration throughout the site-characterization and site-selection processes. The environmental assessments that accompany the nomination of sites shall include the following items as specified by Section 112 of the Act:

(i) an evaluation as to whether the site under consideration is suitable for site characterization under these siting guidelines;

(ii) a preliminary evaluation as to whether the site under consideration would be suitable for a repository by comparison to those siting guidelines that can be invoked without the results of site characterization;

(iii) an evaluation of the effects of site characterization activities on the public health and safety and the environment;

(iv) a reasonable comparative evaluation of the site under consideration with other sites and locations that have been considered;

(v) a description of the decision process which led to the site being recommended;

(vi) an assessment of the regional and local impacts of locating a geologic repository at the site being recommended.

A final environmental impact statement will be submitted in support of a decision to recommend a site to the President as suitable for the construction of a geologic repository. Written in accordance with Section 114(f) of the Act, this statement will be based on the requirements of the National Environmental Policy Act and will be the vehicle for evaluating the environmental acceptability of the recommended site in comparison to the available alternatives.

PROGRAM GUIDELINE
960.4.4

Regional Distribution

After the selection of the first repository site, a major consideration in siting additional repositories shall be of regional distribution. The DOE shall consider the advantages of regional distribution in the siting of repositories to the extent that technical, policy, and budgetary considerations permit.

The DOE shall develop a regionally sited repository system insofar as technical, policy, and budgetary considerations permit. Features of the repositories shall be standardized to the extent practicable to facilitate safe and economical development and operation.

PROGRAM GUIDELINE
960.4.5

Schedule for the First Repository

The DOE shall nominate at least five sites determined suitable for site characterization and subsequently recommend to the President at least three of the these nominated sites for detailed characterization as candidate sites. No later

than March 31, 1987, the President shall submit to the Congress a recommendation of one site from the three sites initially characterized that the President considers qualified for application for a construction authorization for repository.

PROGRAM GUIDELINE
960.4.6

Schedule for the Second Repository

The DOE shall nominate at least five sites determined suitable for site characterization and subsequently recommend to the President at least three of these nominated sites for characterization as candidate sites. Not later than March 31, 1990, the President shall submit to the Congress a recommendation of a second site from any sites already characterized that the President considers qualified for a construction authorization for a second repository.

TECHNICAL GUIDELINE
960.5.1

Site Geometry

The geologic repository shall be located in a geologic setting that physically separates the radioactive wastes from the accessible environment and that has a volume of rock adequate for placement of the underground facility.

TECHNICAL SUBGUIDELINE
960.5.1.1

Depth of Underground Facilities

The site shall allow the underground facility to be placed at a minimum depth such that reasonably foreseeable human activities and natural processes acting at the surface will not lead to a projection of radionuclide releases greater than those discussed in Section 960.3.2.

The site shall be <u>disqualified</u> if site conditions do not allow all portions of the underground facility except the shafts to be at least 200 meters from the directly overlying ground surface.

a. <u>Favorable Conditions</u>

1. Site conditions permitting the emplacement of waste at a minimum depth of 300 meters from the ground surface (10 CFR 60.122(b)(6)).

2. A geologic setting where the nature and rates of the geomorphic processes that have been operating during the past million years would, if continued in the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste (10 CFR 60.122(b)(1).

b. Potentially Adverse Conditions

A geologic setting that shows evidence of extreme erosion during the past million years (10 CFR 60.122(c)(17)).

TECHNICAL SUBGUIDELINE
960.5.1.2

Thickness and Lateral Extent of Host Rock

The thickness and lateral extent of the host rock shall accommodate the underground facility and ensure that impacts induced by construction of the repository and by waste emplacement will not lead to a projection of radionuclide releases greater than those discussed in Section 960.3.2.

a. Favorable Conditions

The host rock is sufficient extent to allow significant latitude in terms of depth, configuration, or location of the underground facility.

b. Potentially Adverse Conditions

A volume of rock with physical properties adequate for the underground facilities but laterally restricted to a small portion of the site.

TECHNICAL GUIDELINE
960.5.2

Geohydrology

The geohydrologic regime in which the site is located shall be compatible with waste containment, isolation, and retrieval.

TECHNICAL GUIDELINE
960.5.2.1

Present and Future Hydrologic Condition

The present and probable future geohydrologic regime of the site shall be capable of preventing radionuclide transport from the respository to the accessible environment in amounts greater than those discussed in Section 960.3.2.

The site shall be disqualified if the average pre-waste-emplacement ground-water travel time along the path of likely radionuclide travel from the disturbed zone to the accessible environment is less than 1,000 years.

a. Favorable Conditions

1. The nature and rates of hydrologic processes operating within the geologic setting during the last million years would, if continued in the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste (10 CFR 60.122(b)(1)).

2. For disposal in the saturated zone, hydrologic conditions that provide a host rock with a low horizontal and vertical permeability; a downward or predominantly horizontal hydraulic gradient in the host rock; and a low vertical permeability and low hydraulic potential between the host rock and the surrounding hydrogeologic units; or a pre-waste-emplacement ground-water travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment that substantially exceeds 1,000 years (10 CFR 60.122(b)(2)).

3. For disposal in the unsaturated zone, hydrogeologic conditions that provide a low and nearly constant moisture content in the host rock and the surrounding hydrogeologic units; or a water table sufficiently below the underground facility such that the capillary fringe does not encounter the host rock; or a laterally extensive low-permeability hydrogeologic unit above the host rock that would divert the downward infiltration of water

beyond the limits of the underground facility; or a host rock with a high saturated permeability and an effective porosity that provides for free drainage; or a climatic regime in which precipitation is a small percentage of the potential evapotranspiration (10 CFR 60.122(b)(3)).

b. Potentially Adverse Conditions

None specified.

TECHNICAL SUBGUIDELINE
960.5.2.2

Hydrologic Modeling

The geohydrologic regime shall be capable of being characterized with sufficient certainty to permit modeling to show that present and probable future conditions would lead to a projection of radionuclide releases less than those specified in Section 960.3.2.

a. Favorable Conditions

Sites that have simple stratigraphic and hydrogeologic sequences and a lack of structural, tectonic, or cross-cutting igneous features such that the geohydrology can be readily characterized and modeled with reasonable certainty.

b. Potentially Adverse Conditions

1. Potential for foreseeable human activities to adversely affect the ground-water flow system, such as ground-water withdrawal, extensive irrigation, the subsurface injection of fluids, underground pumped storage, military activities, or the construction of large-scale surface-water impoundments (10 CFR 60.122(c)(2)).

2. Potential for natural phenomena like landslides, subsidence, or volcanic activity of such a magnitude that they could create large-scale surface-water impoundments that could change the regional ground-water flow system (10 CFR 60.122(c)(3)).

3. Potential for the water table to rise sufficiently to cause the saturation of waste-emplacement areas in the unsaturated zone (10 CFR 60.122(c)(4)).

4. Potential for structural deformation--such as uplift, subsidence, folding, or faulting--that may adversely affect the regional ground-water flow system (10 CFR 60.122(c)(5)).

5. Potential for changes in hydrogeologic conditions that would increase the transport of radionuclides to the accessible environment, such as changes in the hydraulic gradient, average interstitial velocity, storage coefficient, hydraulic conductivity, natural recharge, potentiometric levels, and discharge points (10 CFR 60.122(c)(6)).

6. Potential for adverse changes in hydrologic conditions resulting from reasonable foreseeable climatic changes (10 CFR 60.122(c)(7)).

TECHNICAL SUBGUIDELINE
960.5.2.3

Shaft Construction

The geohydrologic regime of the site shall allow the construction of repository shafts and maintenance of the integrity of shaft liners and seals.

a. Favorable Conditions

Absence of large highly transmissive aquifers between the host rock and the land surface.

b. Potentially Adverse Conditions

Rock or ground-water conditions that would require complex engineering measures in the design and construction of the underground facility or in the sealing of boreholes and shafts (10 CFR 60.122(c)(a).

TECHNICAL SUBGUIDELINE
960.5.2.4

Dissolution Features

The site shall be such that any subsurface rock dissolution that may be occurring or is likely to occur would lead to a projection of radionuclide releases greater than those discussed in Section 960.3.2.

The site shall be disqualified if it can be shown that active dissolution fronts would cause significant interconnection of the underground facility to the site hydrogeologic systems during the first 10,000 years.

a. Favorable Conditions

No evidence that the host rock within the operations area was subject to dissolution during the past million years.

b. Potentially Adverse Conditions

Evidence of dissolution such as breccia pipes or dissolution cavities (10 CFR 60 122(c)(11)).

TECHNICAL GUIDELINE
960.5.3

Geochemistry

The site shall have geochemical characteristics compatible with waste containment, isolation, and retrieval. The site shall be such that the chemical interactions among radionuclides, rock, ground water, and engineered components would not lead to a projection of radionuclide releases greater than those discussed in Section 960.3.2.

a. Favorable Conditions

1. The nature and rates of the geochemical processes operating within the geologic setting during the past million years would, if continued in the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste (10 CFR 60.122(b)(1)).

2. Geochemical conditions that promote the precipitation or sorption of radionuclides; inhibit the formation of particulates, colloids, and inorganic and organic complexes that increase the mobility of radionuclides; or inhibit the transport of radionuclides by particulates, colloids, and complexes (10 CFR 60.122(b)(4)).

3. Mineral assemblages that, when subjected to the expected thermal loading, will remain unaltered or will be altered to mineral assemblages with equal or increased capability to inhibit radionuclide transport (10 CFR 60.122(b)(5)).

b. Potentially Adverse Conditions

1. Ground-water conditions in the host rock--including chemical composition, high ionic strength, or oxidizing or reducing conditions and pH--that could increase the solubility or chemical reactivity of the engineered barrier systems (10 CFR 60.122(c)(8)).

2. Geochemical processes that would reduce the sorption of radionuclides, result in the degradation of the rock strength, or adversely affect the performance of the engineered barrier systems (10 CFR 60.122(c)(9)).

3. For disposal in the saturated zone, ground-water conditions in the host rock that are not chemically reducing (10 CFR 60.122(c)(10)).

TECHNICAL GUIDELINE
960.5.4

Rock Characteristics

The site shall have geologic characteristics compatible with waste containment, isolation, and retrieval.

TECHNICAL SUBGUIDELINE
960.5.4.1

Physical Properties

The site shall provide a geologic system that is capable of accommodating the geomechanical, chemical, thermal, and radiation-induced stresses that are expected to be caused by interactions between the waste and the host rock.

a. Favorable Conditions

None specified.

b. Potentially Adverse Conditions

Potential for such phenomena as thermally induced fractures, hydration and dehydration of mineral components, brine migration, or other physical, chemical, or radiological phenomena that could lead to projections of radionuclide releases greater than those discussed in Section 960.3.2.

TECHNICAL SUBGUIDELINE
960.5.4.2

Operational Safety

The site shall be such that the construction, operation, and closure of underground areas will not cause undue hazard to repository personnel.

The site shall be disqualified if the applicable safety requirements of the DOE and NRC could not be met.

a. Favorable Conditions

None specified.

b. Potentially Adverse Conditions

1. Rock conditions that would require complex engineering measures in the design and construction of the underground facility or in the sealing of boreholes and shafts (10 CFR 60.122(c)(21)).

2. Geomechanical properties that would not permit underground openings to remain stable until permanent closure (10 CFR 60.122(c)(22)).

TECHNICAL GUIDELINE
960.5.5

Tectonic Environment

The site shall be located in a geologic setting where the effects of current or reasonably foreseeable tectonic phenomena will not lead to a projection of radionuclide releases greater than those discussed in Section 960.3.2.

TECHNICAL SUBGUIDELINE
960.5.5.1

Faulting and Seismicity

The site shall be located in a geologic setting where faults that might affect waste isolation, if any, can be identified and shown to have hydrologic properties and seismic potentials that will not lead to a projection of radionuclide releases greater than those discussed in Section 960.3.2.

a. Favorable Conditions

1. The nature and rates of faulting, if any, operating within the geologic setting during the past million years would, if continued in the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste (10 CFR 60.122(b)(1))

2. The nature and rates of faulting, if any, operating within the geologic setting during the past million years would, if continued into the future, have less than one chance in 10,000 over the next 10,000 years of leading to releases of radioactive waste to the accessible environment (proposed 40 CFR 191.13).

b. Potentially Adverse Conditions

1. Faults in the geologic setting that may adversely affect the regional ground-water flow system (10 CFR 60.122(c)(5)).

2. Evidence of active faulting within the geologic setting during the past million years (10 CFR 60.122(c)(12)).

3. Historical earthquakes that, if repeated, could affect the site significantly (10 CFR 60.122(c)(13)).

4. Indications, based on correlations of earthquakes with tectonic processes and features (e.g., faults), that either the frequency of occurrence or the magnitude of earthquakes may increase (10 CFR 60.122(c)(14)).

5. More frequent occurrences of earthquakes or earthquakes of higher magnitude than are typical of the region in which the geologic setting is located (10 CFR 60.122(4)(15)).

TECHNICAL SUBGUIDELINE 960.5.5.2

Igneous Activity

The site shall be located in a geologic setting where centers of Quaternary igneous activity during the past million years, if any, can be identified and shown to have no effects that will lead to a projection of radionuclide releases greater than those discussed in Section 960.3.2.

a. Favorable Conditions

1. The nature and rates of igneous processes within the geologic setting during the past million years would, if continued into the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste (10 CFR 60.122(b)(1)).

2. The nature and rates of igneous activity, if any, in the geologic setting during the past million years would, if continued into the future, have less than one chance

in 10,000 over the next 10,000 years of leading to releases of radioactive material to the accessible environment (proposed 40 CFR 191.13)

b. Potentially Adverse Conditions

1. The presence in the geologic setting of intrusive dikes, sills, or stocks that may adversely affect the regional ground-water flow system (10 CFR 60.122(c)(5)).

2. Evidence of igneous activity within the geologic setting during the past million years (10 CFR 60.122(c)(16)).

TECHNICAL SUBGUIDELINE
960.5.5.3

Uplift, Subsidence, and Folding

The site shall be located in a geologic setting where significant uplift, subsidence, or folding, if any, that has occurred during the past million years can be identified and shown to have hydrologic, seismic, and erosional implications that will not lead to a projection of releases of radionuclides greater than those specified in Section 960.3.2.

a. Favorable Considerations

1. The nature and rates of uplift, subsidence, and folding within the geologic setting during the past million years would, if continued into the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste (10 CFR 60.122(b)(1)).

2. The nature and rates of tectonic deformation in the geologic setting during the past million years would, if continued into the future, have less than one chance in 10,000 over the next 10,000 years of leading to releases of radioactive material to the accessible environment (proposed 40 CFR 191.13).

b. Potentially Adverse Considerations

1. The occurrence in the geologic setting of folds that may adversely affect

the regional ground-water flow system (10 CFR 60.122(c)(5)).

2. Evidence of active uplift, subsidence, or folding within the geologic setting during the past million years (10 CFR 60.122(c)(12)).

TECHNICAL GUIDELINE
960.5.6

Human Intrusion

The site shall be located to reduce the likelihood that past, present, or future human activities would cause unacceptable impacts on meeting the isolation guidelines discussed in Section 960.3.2.

TECHNICAL SUBGUIDELINE
960.5.6.1

Natural Resources

The site shall be such that the exploration history or relevant past use of the site or adjacent areas can be determined and can be shown to have no unacceptable impact on meeting the isolation guidelines discussed in Section 960.3.2. The site features shall make human intrusion unlikely or, in combination with engineered systems, mitigate the consequences of intrusion to within the limits discussed in Section 960.3.2.

a. Favorable Conditions

Natural-resource concentrations that are not significantly greater than the average condition for the region.

b. Potentially Adverse Conditions

1. The presence of naturally occurring materials, whether identified or undiscovered, within the site in such form that (a) economic extraction is currently feasible or potentially feasible during the foreseeable future or (b) such materials have greater gross value or net value than the average for other areas of similar size that are representative of, and located in, the geologic setting (10 CFR 60.122(c)(18)).

2. Evidence of subsurface mining for resources within the site (10 CFR 60.122(c)(19)).

3. Evidence of drilling for any purpose other than repository-site characterization (10 CFR 60.122(c)(20)).

TECHNICAL SUBGUIDELINE 960.5.6.2

Site Ownership and Control

The site shall be located on land for which the Federal Government can obtain ownership, control access, and obtain all surface and subsurface rights required under 10 CFR 60.121 to ensure that surface and subsurface activities at the site will not lead to a projection of radionuclide releases greater than those discussed in Section 960.3.2.

a. Favorable Conditions

Present ownership and control of land and rights as required by 10 CFR 60.121.

b. Potentially Adverse Conditions

Land-use conflicts involving land dedicated by the Federal Government for potentially incompatible purposes.

TECHNICAL GUIDELINE 960.5.7

Surface Characteristics

The site and its surrounding area shall be such that surface characteristics or conditions can be accommodated by engineering measures and can be shown to have no unacceptable effects on repository operation and waste isolation as discussed in Sections 960.3.1 and 960.3.2.

TECHNICAL SUBGUIDELINE 960.5.7.1

Surface-Water System

The site shall be such that the surficial hydrologic system, both during expected climatic cycles and during extreme natural phenomena, will not cause unacceptable impacts on repository operation or waste isolation as discussed in Sections 960.3.1 and 960.3.2.

a. Favorable Conditions

None specified.

b. Potentially Adverse Conditions

1. Potential for foreseeable human activities to adversely affect the ground-water flow system, such as extensive irrigation or the construction of large-scale surface-water impoundments (10 CFR 60.122(c)(1)).

2. Potential for flooding the underground facility, whether through the occupancy and modification of floodplains or through the failure of existing or planned man-made surface-water impoundments (10 CFR 60.122(c)(2)).

TECHNICAL SUBGUIDELINE 960.5.7.2

Terrain

The site shall be located in an area where the surface terrain features do not unacceptably affect repository operation.

a. Favorable Conditions

Generally flat terrain.

b. Potentially Adverse Conditions

Road and rail access routes that encounter steep grades, sharp switchbacks, slope instability, or other potential sources of hazard to incoming waste shipments.

TECHNICAL SUBGUIDELINE 960.5.7.3

Meteorology

The site shall be located where anticipated meteorological conditions would not result in the projection of unacceptable effects on repository operations.

a. Favorable Conditions

None specified.

b. Potentially Adverse Conditions

None specified.

TECHNICAL SUBGUIDELINE
960.5.7.4

Offsite Hazards

The site shall be such that present and projected effects from nearby industrial, transportation, and military installations and operations including atomic energy defense activities, can be accommodated by engineering measures and can be shown to have no unacceptable impacts on repository operation.

a. Favorable Conditions

Siting on lands already committed for DOE nuclear reservations.

b. Potentially Adverse Conditions

1. The presence of nearby potentially hazardous facilities.

2. The presence of nearby facilities that could be adversely affected by repository construction or operation.

TECHNICAL GUIDELINE
960.5.8

Population Density and Distribution

The site shall be located to limit the potential risk to the population. The site shall be so located that risk to the population from repository operation does not exceed system-performance guidelines.

A site shall be disqualified if it would fail to comply with EPA's standard for radiation doses received by members of the public as a result of the management and storage of these wastes (proposed 40 CFR 191, Subpart A).

TECHNICAL SUBGUIDELINE
960.5.8.1

Population Near Site

The site shall be located away from population concentrations and urban areas. A site shall be

<u>disqualfied</u> if any surface facility of a repository would need to be located (1) in a highly populated area or (2) adjacent to an area one mile by one mile having a population of not less than 1,000 individuals.

a. <u>Favorable Conditions</u>

Remoteness from population centers (10 CFR 60.122(a)(7)).

b. <u>Potentially Adverse Conditions</u>

A population density and distribution such that projected releases could result in the exposure of many people.

TECHNICAL SUBGUIDELINE
960.5.8.2

Transportation

The cost and other impacts of transporting radioactive waste to a repository shall be considered in selecting the repository sites. Consideration shall be given to the proximity of locations where radioactive waste is currently generated or temporarily stored and the transportation and safety factors involved in moving such waste to a repository.

a. <u>Favorable Conditions</u>

Ability to select transportation routes that minimize risk to the general population.

b. <u>Potentially Adverse Conditions</u>

Site locations requiring the concentration of transportation routes through highly populated areas.

TECHNICAL GUIDELINE
960.5.9

Environmental Protection

The site shall be such that a repository can be constructed and operated in a manner that provides reasonable assurance that the environment will be adequately protected, for this and future generations. The site shall be located so as to reduce the likelihood and consequences of

potential environmental impacts, and these impacts shall be mitigated to the extent reasonably achievable.

A site shall be disqualified if a repository would result in an unsatisfactory adverse environmental impact that threatens the health or welfare of the public or the quality of the environment and cannot be mitigated. A site shall be disqualified if it is located within the boundaries of a significant nationally protected natural resource, such as a National Park, National Wildlife Refuge, or Wilderness Area, and its presence conflicts irreconcilably with the previously designated use of the site.

a. Favorable Conditions

1. Ability to meet all procedural and substantive environmental requirements applicable to the site, at the Federal, State, and local level, with assurance and within time constraints.

2. Adverse environmental impacts, to present and future generations, can be avoided or reduced to an insignificant level through the application of reasonable mitigating measures.

b. Potential Adverse Conditions

1. Probable conflict with applicable Federal, State, or local environmental requirements.

2. Significant adverse environmental impacts that cannot be avoided or minimized.

3. Proximity to, or direct adverse environmental impacts of the repository or its support systems on, a component of the National Park System, the National Wildlife Refuge System, the Wild and Scenic River System, the National Wilderness Preservation System, or National Forest Land.

TECHNICAL GUIDELINE
960.5.10

Socioeconomic Impacts

The location of the site shall be such that any significant adverse social and/or economic impacts on communities and regions resulting from repository construction, operation, and decommissioning or the transportation of radioactive waste to the site can be accommodated by mitigation or compensation.

a. Favorable Considerations

1. Locally available labor.

2. Potential for repository-related increases in local employment, increases in business sales, increases in government revenues, or improvements in community services.

b. Potentially Adverse Factors

1. The existence of, or the potential for, a lack of the necessary labor force or a lack of local suppliers.

2. A projected substantial decrease in community services due to repository development.

3. Conditions where the development, construction, operation, or decommissioning of a repository may require any purchase or acquisition of water rights that will have a significant adverse effect on the present or future development of the area.

REFERENCES:

DOE, 1983, "Department of Energy, 10 CFR 960, Nuclear Waste Policy Act of 1982: Proposed General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories, "Federal Register, Vol. 48, No. 26, pp. 5670-5682, February 7, 1983.

APPENDIX E

TRANSPORT PATHWAY DESCRIPTION AND PARAMETER CHARACTERISTICS

E.1 TRANSPORT PATHWAY DESCRIPTION

The purpose of this section is to identify and briefly review the features that directly affect radionuclide migration, to develop a general, integrated picture of the system from a performance assessment point of view. A proper understanding and quantification of some of these features arises in part through development of what is termed a conceptual model. The conceptual model is simply a synthesis of available direct and indirect information that gives an understanding of the present and past behavior of a system, as well as some insight into future behavior. While the scope of this discussion does not include a detailed review of conceptual model development, the performance of conceptual modeling is acknowledged. The emphasis here is on what information is needed, why it is needed, and how it will be used to conduct a performance assessment. How the information is generated or synthesized from indirect sources is beyond the scope of this report.

E.2 GEOLOGIC CHARACTERISTICS

A discussion of the geologic characteristics of the reference repository location (RRL) is presented in Chapter 3 of the Site Characterization Report (SCR) (Rockwell, 1982). The material presented here was primarily extracted from that report.

The geologic features of direct importance to performance assessment are:

- Depth of repository horizon
- Layered nature of basalt
- Intraflow structure
- The existence and nature of folds or faults
- Tectonic stability
- Potential for renewed volcanic activity.

The Columbia River Basalt Group, as a whole, covers an area of 200,000 km^2 and has an estimated volume of 325,000 km^3 (Reidel, 1981). Individual flows range from a few tens of centimeters (rarely) to more than 100 m thick, averaging 30 to 40 m (Swanson and Wright, 1978). The RRL is located in the western part of the Pasco Basin in the gently sloping Cold Creek syncline. In this area, there is a thick sequence of Columbia River basalt. At present, three basalt flows within the Grande Ronde Basalt

are being considered as candidate repository horizons: the Umtanum flow, the Cohassett flow, and the McCoy Canyon flow. Final selection of a single candidate horizon will follow additional characterization and performance assessment optimization studies. In any case, the repository depth would exceed 900 m below land surface.

The basalt flows were emplaced as a series of layers, with each flow experiencing some solidification before deposition of the next flow. Flows generally exhibit a jointing pattern that is characteristic of lava upon cooling. Intraflow structures, as used here, refer to internal units, including jointing habit, within a flow with relatively uniform abundance and geometry of fractures, but also include size and abundance of vesicles, flow top breccia, and the occurrence of pillows. Intraflow structures may be present within a flow. The intraflow structures may vary greatly in lateral extent and thickness, may be absent from any given flow, or may occur repeatedly within a single flow.

The vast majority of fractures in the Grande Ronde Basalt are joints created by thermal contraction during cooling of individual flows (Long, 1978). Qualitatively, the dominant fracture patterns range from well-formed, regular, polygonal solids to irregular, elongate-to-equant blocks, with a complete gradation between the two.

The great majority of fractures in drill core have narrow "apertures" (≤0.5 mm) filled with multiple generations of secondary minerals. Information from fracture logging of drill core was used to calculate the volume percent of fracture openings (filled or unfilled) in the core. The total volume percent of fractures was ≤0.4, whereas the volume of unfilled fractures ranged from 0.025 to 0.059 volume percent. These results suggest that the volume of unfilled fractures, particularly in the dense interior of Grande Ronde Basalt flows, is small, and thus the total fracture porosity of these rocks is comparably small. Lower fracture porosity can be expected to result in lower hydraulic conductivity.

The RRL is located in the Cold Creek syncline of the Pasco Basin, which is part of the Yakima Fold Belt subprovince. This subprovince is dominated by generally east-west trending anticlinal ridges and synclinal valleys. These folds are typically asymmetrical on the north limbs with low-angle reverse or thrust faults present on the north limbs of the anticlines. Locally, cross structures are present.

Structural analysis of the Yakima fold belt structures shows that any dipping basalt might be expected to contain small breccia zones or faults. Within the Cold Creek syncline, discrete shear zones or faults a few centimeters to 1 m wide may be present. Brecciation is a dilation process that would locally increase the permeability and porosity until the breccia is sealed with a precipitated cement.

Historical data indicate that the site is an area of low seismicity. Microearthquake activity is largely shallow, confined to a crust of 30-km thickness, and is characterized by swarms of low-magnitude earthquakes

that occur in and below the basalt. Focal mechanisms of individual and composite shallow and deep events indicate reverse faulting along nearly east-west planes under nearly horizontal, nearly north-south compression.

The potential for renewal of basaltic volcanism similar to the Columbia River basalt fissure eruptions is extremely low. Effects of volcanism from sources in the Cascades and the Northern Basin and Range province are considered minimal and of very low probability.

E.3 WASTE EMPLACEMENT CHARACTERISTICS

The characteristics of repository construction and waste emplacement that directly affect long-term performance are: (1) waste package and repository design, (2) altered site conditions and properties due to underground construction, (3) waste package and very near-field release, and (4) waste-related effects.

Waste Package and Repository Design

The repository geometry will affect the heat load, waste package and backfill design, and the alteration of the near-field basalt parameters. The waste package conceptual design consists of a waste form, metal canister, and surrounding backfill. The waste package system is being designed to provide short-term containment and retrievability and to reinforce the natural barriers.

Altered Conditions Due to Construction and Emplacement

Construction, operation, and decommissioning of a repository results in physical modification of the host rock. Voids are created by shaft, tunnel, storage room, and canister borehole excavation. Initial displacements occur in the rock surrounding the openings, due to excavation and installation of rock support systems. During and after closure, interaction of the host rock with backfill and sealing materials may cause additional displacement. Recoverable and permanent displacements will influence the hydraulic conductivity in the disturbed rock zone immediately adjacent to the openings.

Waste Package and Very Near-Field Release

Appropriate design of the engineered system will help to control the radionuclide release. An engineered system will also provide reinforcement to the natural geologic barrier and protection during the preclosure phases of the repository. Of significance in determining the performance of the engineered system are the:

- Nature of the waste form
- Nature of the waste canister
- Nature of any backfill material

- Temperature around the engineered systems
- Chemistry of the surrounding groundwater
- Rate and direction of engineered system penetration by groundwater
- Effects of radiation on the engineered materials, groundwater, and perhaps on the basalt in the immediate vicinity of the waste packages.

E.4 WASTE-RELATED EFFECTS

Associated with the waste are two phenomena that can affect the engineered and natural basalt system: (1) a changing temperature field due to waste heat generation and (2) a radiation flux. Increased temperature can alter the chemical reaction rates and may result in localized steam generation, depending on water availability and pressure. Radiation may affect material properties.

E.5 HYDROGEOLOGIC CHARACTERISTICS

The hydrogeology of the RRL and surrounding area is discussed in detail in Chapter 5 of the SCR (Rockwell, 1982). The features that directly affect the long-term performance of the site are:

- Groundwater occurrence relative to potential repository locations
- Groundwater flow patterns
- Groundwater flow rates and hydraulic characteristics of basalts
- Groundwater velocity and travel times.

Groundwater Occurrence Relative to Potential Repository Locations

As mentioned in the section on "Geologic Characteristics," the Grande Ronde Basalt at the RRL is the focus of siting studies. All three candidate repository horizons in the Grande Ronde Basalt at the RRL are deep within the saturated groundwater zone. The water table surface is within the sedimentary blanket overlying the uppermost basalt unit hundreds of meters above the Grande Ronde Basalts.

Groundwater Flow Patterns

Groundwater flow is influenced by a number of factors, including topography, structure, stratigraphy, and the hydrologic properties of the rock through which the groundwater moves.

Overall, groundwater moves from areas of recharge to discharge. Recharge areas are usually basalt outcrops surrounding the Pasco Basin or in other areas of the Columbia Plateau where basalts lie at or near ground level. Groundwater then moves down a hydraulic gradient to discharge into either an overlying aquifer or a surface water body.

Hydrogeologically, the dense interiors of basalt flows act as confining units for groundwater contained in the more permeable flow tops. The relatively high ratio of horizontal hydraulic conductivity of the flow tops to inferred vertical conductivity of the basalt flow interiors (around 100 to 1,000 or more) promotes horizontal movement of groundwater through the flow tops. In general, vertical movement of groundwater is inhibited except in areas of structural deformation close to fold hinge lines, where subvertical fractures may occur. Such fractures are not expected in the Cold Creek syncline because it is a broad, relatively flat-bottomed fold that shows little evidence of strain.

Adequate knowledge of the groundwater flow patterns is necessary to determine the orientation and length of the radionuclide transport pathway.

Hydraulic Characteristics of Basalt

The volumetric flow rate of groundwater moving through the system is a function of the ability of the rock to conduct flow along a set of interconnected void spaces. The coefficient that is used to represent this characteristic in an equivalent porous media system is referred to as hydraulic conductivity. Hence, a determination of the hydraulic conductivity or at least bounding estimates of the same are necessary to calculate the groundwater volumetric flow rates and velocities. Hydraulic conductivities have been measured at a number of discrete well sites on the Hanford Site and vicinity. Measurements have been obtained for individual horizons (primarily interbeds and flow tops) and for composite zones encompassing a series of flow tops and entablature/colonnades. Results are summarized in Chapter 5 of the SCR (Rockwell, 1982) and generally show decreasing hydraulic conductivity with depth. Possible explanations for this decrease are greater secondary mineralization with depth and/or a reduction in fracture aperture due to increased lithostatic loading.

Calculation of the groundwater velocity in an equivalent porous medium also requires definition of the effective porosity that is defined as the volumetric fraction of rock made up of interconnecting voids. Effective porosity may be substantially less than the total porosity (fraction of volume represented by total void spaces whether interconnected or not).

Repository Related Processes

In addition to the natural hydrogeologic processes occurring prior to repository construction and waste emplacement, other processes occur because of the influence of the repository. As mentioned earlier, rock displacements will alter the hydraulic conductivity of the basalt in the immediate vicinity of the rock openings. Hydraulic conductivity may be

increased or decreased by recoverable displacements, but will generally be increased by the permanent component. Repository shafts extend from the surface facilities to the major subsurface excavations in the candidate horizon. They penetrate all of the geologic strata overlying the repository and are a potential pathway for radionuclide release to the environment. The current repository conceptual design is a planar structure extending laterally a distance of 3.4 by 1.8 km within a candidate horizon. Isolation capability in the strata overlying the repository is provided by the low vertical hydraulic conductivity in the entablature and colonnade portions of the basalt flows. Shaft seal structures are intended to limit vertical conductivity increases due to shaft penetration of the strata, including conductivity changes in the disturbed rock zone adjacent to the shaft. Vertical groundwater movement across a basalt flow will be made up of two components:

- Vertical flow through the low conductivity entablature and colonnade summed over an area equal to the lateral extent of the repository
- Vertical flow at the shaft penetrations limited to the shaft seal conductivity and the conductivity of the surrounding disturbed rock zone.

Comparisons of the magnitudes of these components will allow specification of appropriate design parameters for the shaft seals.

Postclosure groundwater flow in the very-near field is perturbed by the construction-related permeability changes within the repository horizon. For current candidate horizons, the ratio of repository void space volume to the volume of the competent intraflow structure (entablature and colonnade) is a small percentage. This includes backfilled and sealed voids and portions of the disturbed rock zone where hydraulic conductivity has been increased. Groundwater flow through the immediate volume of the rock stratum enclosing the repository depends on this void ratio and the relative hydraulic conductivity of engineered backfill and seal materials to that of the structurally unmodified host rock. Comparisons of the relative contributions of the respective flow components will allow formulation of an appropriate design specification for the repository backfill and seals.

Apart from the changes arising from construction (disturbing the rock, dewatering the area near the tunnels and shafts, etc.), the most significant long-term effect of the repository is related to the thermal field induced by the heat generated from the waste. The waste-induced thermal field will influence (1) the mechanical behavior of the rock and hence the hydraulic properties, (2) the groundwater flow through buoyancy effects, and (3) the hydraulic conductivity by altering the groundwater properties.

The waste form acts as a heat source and induces a changing temperature field in the rock surrounding the repository. This in turn causes a time-dependent stress increment and associated displacements around the openings due to constrained thermal expansion. Such displacements cause changes in the hydraulic conductivity.

Groundwater flow in a nonisothermal regime is dependent on the temperature of the water/rock system. This coupling is particularly important in the near-field zone because fluid density decreases with increasing temperature, creating a thermal buoyancy effect. The perturbation caused by thermal bouyancy causes an increased upward component in groundwater flow toward the surface. The maximum effect occurs in a zone bounded by the repository perimeter and extending several hundred meters upward from the cardidate horizon. Because hydraulic conductivity is a function of the density and viscosity of the water as well as the intrinsic rock properties, temperature-related changes in density and viscosity will alter the hydraulic conductivity. Over the temperature range expected in the vicinity of the repository, the fluid density changes by only a few percent; however, the fluid viscosity decreases by 2 to 5 times. Consequently, the hydraulic conductivity and thus the groundwater velocity can change by a significant amount in the affected zone.

Groundwater Velocities and Travel Times

It is generally recognized that the most probable mode by which radionuclides could be released from a repository facility is through the groundwater system. Adequate knowledge of the groundwater flow patterns, together with at least bounding estimates of the hydraulic conductivity and effective porosity distributions, will permit calculation of the groundwater velocities and travel times from a potential repository location to the accessible environment.

E.5 GEOCHEMICAL CHARACTERISTICS

Background

The geochemical characteristics of the basalt and associated groundwater are quite significant in determining the availability and rate of radionuclide migration towards the accessible environment. The most important characteristic is the Eh-pH regime established by the basalt-groundwater system. Eh is a measure (in volts) of the electrical potential necessary to cause oxidation or reduction of a metal; pH is a measure of the acidity or basicity of a system. These two variables control the stability and solubility of solid phases in contact with the groundwater and the form a substance will assume in the groundwater. Therefore, they can affect the stability of the waste package and the transport of hazardous radionuclides from the package.

Reducing Conditions (Eh)

The iron-bearing minerals in the basalt suggest an Eh range for the repository of -0.45 to +0.07 V (i.e., a reducing environment). This reducing environment is conducive to metal stability, and thus can greatly increase the lifetime (corrosion resistance) of metal canister materials used to contain the nuclear waste. In addition, a strongly reducing environment favors the formation of insoluble actinides and transuranic oxides and, therefore, limits their transport to the accessible

environment. For example, the solubilities of uranium, neptunium, and plutonium in the reducing conditions of the basalt geohydrologic system are sufficiently low to keep the release of these hazardous radionuclides well below the release limits established by the EPA for a nuclear waste repository (EPA, 1982).

Alkaline Conditions

The Umtanum basalt groundwater chemistry is dominated by silica (present as silicic acid) that results in a basic groundwater. The pH of groundwater sampled from the Grande Ronde Basalt is 9.5 ± 0.5 at 25°C. The pH of groundwater in Grande Ronde Basalt is controlled at elevated temperature by a set of complex ionic relationships. Analyses to date indicate that the pH of the groundwater at elevated temperatures remains above the corresponding neutral point pH; thus, a basic solution is maintained at elevated temperatures.

Retardation by Sorption

A second significant geochemical characteristic is exhibited in the sorptive capacity of the basalt for the radionuclides. Sorption of radionuclides onto geologic materials is one of the major mechanisms for retarding the migration of hazardous radionuclides to the accessible environment. Basalts have been shown to have high sorptive capacity (retardation capacity) for such hazardous radionuclides as cesium, strontium, radium, and americium. Furthermore, the basalts contain a small, but significant, amount of secondary minerals (clays, zeolites, and silica phases) that generally have a much greater radionculide sorptive capacity. These secondary minerals are found lining and filling the vesicles, vugs, and fractures of the basalt that often comprise the dominant groundwater pathways in the basalt. Therefore, these secondary minerals are a primary sorptive medium for radionuclides and greatly increase the radionuclide retardation capabilities of the basalt.

Hydrothermal Interactions

The hydrothermal interactions that can occur between the basalt, groundwater and nuclear waste have been found to limit the availability and/or migration potential of many radionuclides. The primary basalt minerals (plagioclase, pyroxene) are found to be relatively stable (unreactive) under the expected repository temperature and pressure conditions. The more reactive portion of the basalt, however, has been found to be highly efficient in removing cesium and strontium from solution. In addition, the basalt hydrothermal alteration products are high sorptive-capacity minerals such as clays and zeolites. Hydrothermal alteration appears to increase the retardation capability of the basalts, which would make them geochemically compatible with the thermal regime induced by the emplacement of nuclear waste.

Temperature Effects

Radionuclide solubility and sorption on basalt are also functions of temperature. Solubility limits and sorption generally increase with increasing temperature.

Radionuclide Mass Transport

The concentration of a particular radionuclide as a function of time and space depends on the release rate from the engineered system, groundwater velocity, the degree of chemical retardation, solubility in the groundwater, radioactive decay, dispersion, and possible precursor decay.

Radioactive decay rates have been measured in the laboratory and are well documented in the literature. Dispersion is the macroscopic expression of several phenomena including tortuous pathways, diffusion, lack of complete fracture interconnection, and small-scale heterogeneities. For these reasons, a chemically unretarded radionuclide can be expected to spread and occupy a larger volume at a lower concentration than would otherwise be expected from simple advective groundwater flow.

Disruptive Conditions

In addition to determining whether the RRL meets the criteria and guidelines under present conditions, the impact of future changes and disruptive events requires consideration. Consequently, effort will be devoted to identification of credible processes and/or events that could alter the waste isolation characteristics of the site. Once a process or event is identified, the degree of alteration of important chemical or physical parameters will be bounded. A tectonic fault through the repository has been postulated as a plausible disruptive event. The orientation of such a fault would be significant as well as the hydraulic and chemical properties of the gouge zone and any damaged rock. Estimating the nature and amount of waste package disruption would also be part of a disruptive fault analysis.

REFERENCES

EPA, 1982, "Environmental Protection Agency, 40 CFR 191, Environmental Standards and Federal RAdiation Protection Guidance for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes," Federal Register, Vol. 47, No. 250, December 29, 1982, Proposed Rule.

Long, P. E., 1978, Characterization and Recognition of Intraflow Structures, Grande Ronde Basalt, RHO-BWI-LD-10, Rockwell Hanford Operations, Richland, Washington.

Reidel, S. P., Long, P. E., Myers, C. W., and Mase, J., 1981, New Evidence for Greater than 3.2 Kilometers of Columbia River Basalt Beneath the Central Columbia Plateau, RHO-BWI-SA-162A, Rockwell Hanford Operations, Richland, Washington.

Rockwell, 1982, Site Characterization Report for the Basalt Waste Isolation Project, (DOE/RL 82-3) 3 vol., Rockwell Hanford Operations for the U.S. Department of Energy, Richland, Washington, November, 1982.

Swanson, D. A., and Wright, T. L., 1978, "Bedrock Geology of the Northern Columbia Plateau and Adjacent Areas," in The Channeled Scabland, A Guide to the Geomorphology of the Columbia Basin, Baker, V. R. and Nummadeal, D., eds., Office of Space Administration, National Aeronautics and Space Administration, Washington, D.C., pp. 35-57.