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MEMORANDUM FOR: BWIP Group Coordinators

FROM: John T. Greeves, Section Leader
Design Section
High-Level Waste Technical
Development Branch
Division of Waste Management

SUBJECT: RELEASE RATE FROM THE ENGINEERED SYSTEM APPENDIX W

The Design Group has prepared four appendices for the BWIP SCA. These are:

Appendix	Title
V	Stability of Openings
W	Release Rate
X	Retrievability Systems
Y	Underground Testing

Attached is a copy (Draft) of the Release Rate Appendix. This topic touches on almost all team responsibilities. We can not afford to have inconsistencies in appendices (i.e., take this question up now, not later when it is too late). Please review the attached and let me know if you have technical comments on this material. I would be pleased to review related material in your SCA products.

The rest of the design appendices (V,X and Y) are available if you wish to review them. Please see me for copies.

"ORIGINAL SIGNED BY"

John T. Greeves, Section Leader
Design Section
High-Level Waste Technical
Development Branch
Division of Waste Management

OFC	WMHT	WMHT				
NAME	JTGreeves	HJMiller				
DATE	12/8/82	12/ /82				

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30136

Document Name:
APPENDIX W
RELEASE RATE FROM THE ENGINEERED SYSTEM
(Preliminary Draft 11/24/82)
(First Revision 11/29/82)

Requestor's ID:

Author Name:
Talbot

Document Comments:

Copies: (Greeves)
Natarajan
Rhoderick
Verma
Wise
Gordon
Weber
Logsdon

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APPENDIX W

RELEASE RATE FROM THE ENGINEERED SYSTEM

(PRELIMINARY DRAFT)

1 INTRODUCTION

A geologic repository for long term disposal of nuclear waste materials is comprised of engineered facility located at depth in a stable, well characterized geological ~~system~~. Isolation of the wastes from the biosphere is to be achieved by a combination of long radionuclide transport time through the geologic medium backed up by an engineered design having a predictable radionuclide containment time and release rate from the engineered system.

The purpose of this Appendix is to examine the intent of the radionuclide release criteria as defined in the current NRC/EPA regulations, how release rates are determined, and the current uncertainties associated with that determination for the Hanford site. The specific regulatory requirements are summarized in Section 2. Definitions of the engineered system and components are outlined in Section 3. The determination of release rates, including performance criteria ~~and~~ data and modeling requirements is presented in Section 4. Areas of concern for the Hanford site, based on existing studies, are discussed in Section 5.

2 REGULATORY REQUIREMENTS

2.1 Performance Objectives

The overriding performance objective [60.111 (b) (1)] for a repository is to meet the EPA criteria established in proposed draft 40 CFR Part 191 (Draft 21). The criteria specified by the EPA are in terms of a maximum cumulative release to the accessible environment, for each radionuclide, for a period 10,000 years after disposal. For releases involving more than one radionuclide, the allowed release for each radionuclide is reduced to the fraction of its limit that insures that the overall limit is not exceeded. Cumulative release limit criteria for high level waste are specified in Table 2-1.

The EPA defines accessible environment to include the atmosphere, land surfaces, surface waters, oceans, and parts of the lithosphere that are more than ten kilometers in any direction from the original location of the radioactive wastes in a disposal system. The NRC has recognized that there are large uncertainties involved in predicting radionuclide transport processes through the portion of the geologic setting that is significantly affected by construction of the subsurface facility, or by the heat generated by the emplacement of radioactive waste. The proposed NRC technical rule 10 CFR Part 60 therefore also includes specific performance objectives for two parts of the engineered system, the waste package and the underground facility, in addition to a criteria for pre-waste emplacement groundwater travel time through the far field to the accessible environment.

In addition, there are specific regulatory requirements for the development of engineered barriers, which can be grouped into four areas:

- Engineered System Design Requirements
- Analysis of the Performance of the Engineered System
- Verification of Data and Models Used in Analysis
- Confirmation of Engineered System Performance

TABLE 2-1

CUMULATIVE RELEASES TO THE ACCESSIBLE ENVIRONMENT FOR 10,000 YEARS AFTER DISPOSAL*[b]

Radionuclide	Release Limit[a] (curies per 1000 MTHM)
Americium-241	10
Americium-243	4
Carbon-14	200
Cesium-135	2000
Cesium-137	500
Neptunium-237	20
Plutonium-238	400
Plutonium-239	100
Plutonium-240	100
Plutonium-242	100
Radium-226	3
Strontium-90	80
Technetium-99	2000
Tin-126	80
Any other alpha-emitting radionuclide	10
Any other radionuclide which does not emit alpha particles	500

*Limiting values for a mixture of radionuclides

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 years should be limited so that:

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

(a) The release limits also apply to each unit of transuranic wastes containing three million curies of alpha-emitting transuranic nuclides.

(b) These release limits shall be met for all anticipated processes and events, defined as those estimated to occur with a frequency of 0.01 or more over 10,000 years. For very unlikely events, those with a frequency of occurence of between 10^{-2} and 10^{-5} over 10,000 years, the acceptable release limits are 10 times all values in this table.

The sequential nature of these four steps is shown on Figure 2-1. The regulatory criteria for each of these areas and the additional performance objectives for the engineered system specified in 10 CFR Part 60 area briefly discussed below.

2.2 Engineered System Design Requirements

The proposed rule imposes three major performance objectives on engineered barriers for anticipated processes and events. These are:

- o Contain wastes for 1000 years (60.113)
- o Control rate of release after 1000 years (1 part in 100,000 per year, maximum) (60.113)
- o Develop engineered barriers in consonance with retrieval plans (60.133)

The rule imposes only one major requirement on the actual design process (as opposed to design criteria). This is to require a quality assurance program based upon Appendix B of 10CFR60 (60.152).

2.3 Design Analysis

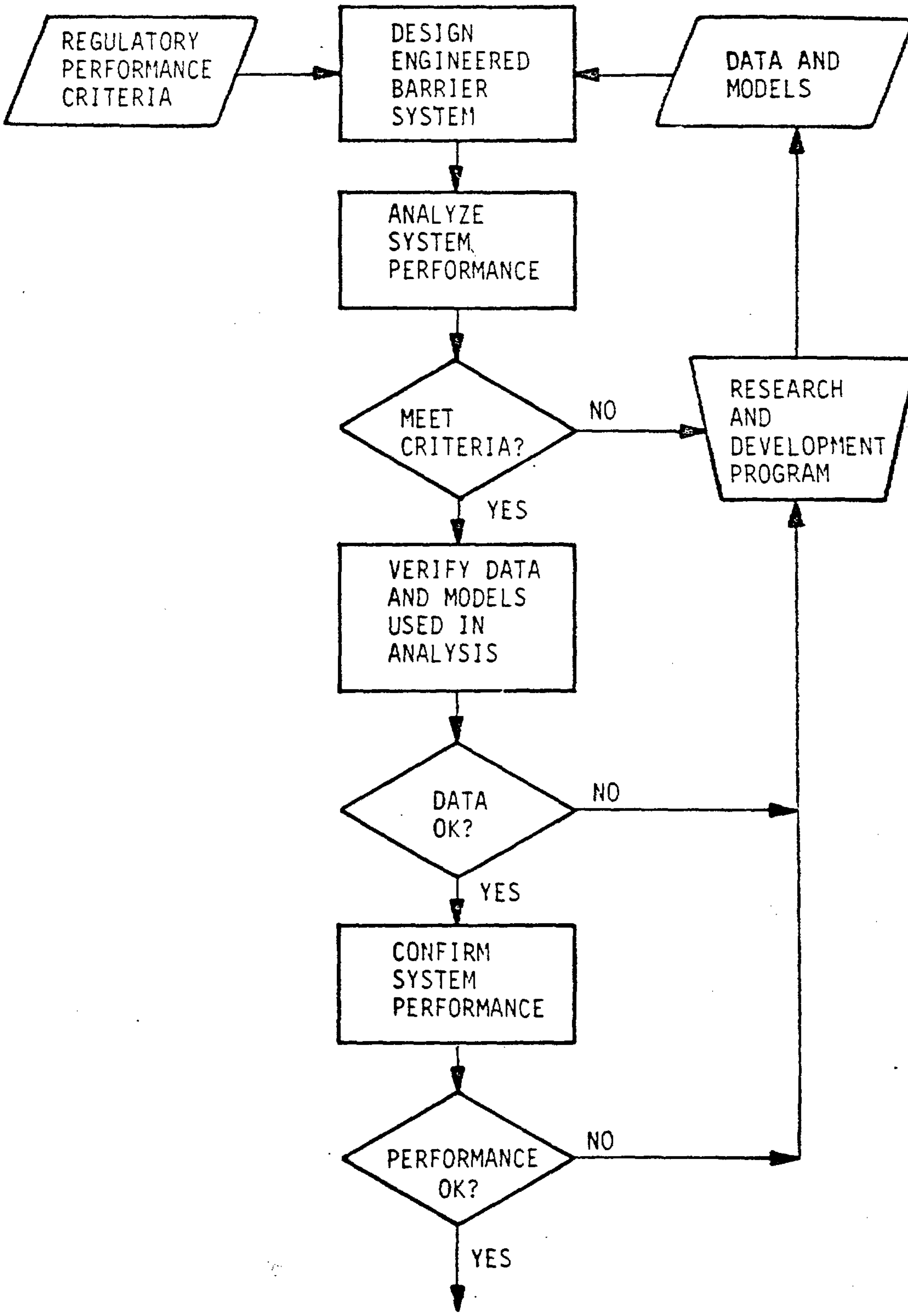
The rule imposes four major design analysis requirements. These are:

- o Analyze the effectiveness of engineered barriers (60.21)
- o Analyze the expected performance of engineered barriers (60.21)
- o Consider expected thermal and thermomechanical response of the host rock and groundwater system in the analysis (60.133)
- o The analysis must provide reasonable assurance that the performance of the engineered barriers will be in conformance with the criteria and objectives (60.101)

2.4 Data and Model Verification

The rule imposes two requirements on the verification of data and methods used in design and analysis. Fulfillment of these requirements must be documented in the SAR. The requirements are that:

DEVELOPMENT SEQUENCE FOR ENGINEERED BARRIERS Figure 2-1



Rev. Dwg. No. 823-1080 Date 10-14-82 Eng. [illegible]

- An explanation must be submitted of the measures used to confirm the models used in the analysis (60.21)
- A justification must be submitted on the selection of the variables and conditions used in design and analysis (60.21)

2.5 Performance Confirmation

The proposed rule requires that, before and during repository operation, a performance confirmation program be conducted which indicates that the engineered systems are functioning as intended and anticipated (60.140).

The proposed rule makes recognition that confirmation of the performance of an engineered system that is designed to function over thousands of years "is not to be had in the ordinary sense of the word. For such long-term objectives and criterion, what is required is reasonable assurance, making allowance for the time period, hazards and uncertainties involved, that the outcome will be in conformance with those objectives and criteria."

3 DEFINITION OF ENGINEERED SYSTEM

3.1 Definition of Engineered System Components

Definitions for specific features of the engineered system are provided in 10 CFR 60.2, as follows:

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

Engineered Barriers System means the waste packages and the underground facility.

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

Waste Package means the waste form and any containers, shielding, packing and other components surrounding the waste form.

There are two boundaries of interest for assessment of release rates from the engineered system:

(1) The outer limit of the waste package.
(2) The boundary between the underground facility and the geologic setting.

The present definition of the waste package includes the tailored backfill placed in the storage hole around the waste canister; thus the waste package boundary is located at the edge of the emplacement hole. The boundary between the underground facility and the geologic setting is currently interpreted to be the edge of the mined openings or a short distance beyond the openings.

The engineered system components may be evaluated at several levels of detail, using alternative models, which are consistent with the environmental scale in which they are intended to function. These environments include:

- Repository-scale environment.
- Room-scale environment.
- Waste package-scale environment.

The repository-scale environment is used to model near field geologic, hydrologic and geochemical conditions, including the effects of geologic processes and events. Properties of the underground facility and waste packages (hydraulic conductivity, density, thermal load etc.) are represented by equivalent values averaged over the area or volume of the facility, based on the waste storage configuration, volume of rock excavated, type of backfill material etc. This scale of analysis provides input to far field waste transport assessments and establishes boundary conditions for more detailed analyses.

The room-scale environment is used to model performance within the underground facility, including construction/thermal induced stress effects, local groundwater flow, geochemical and hydrochemical effects, and the contribution of storage room barrier materials to limiting radionuclide release to the geologic setting. Releases from each storage room are aggregated to determine cumulative releases for repository scale modeling. Boundary conditions for waste-package modeling are established.

The waste package-scale environment is used to determine the waste package life and subsequent release of radionuclides from the waste package into the underground facility. This includes a detailed evaluation of metal corrosion rates, water seals (backfill), and dissolution or leaching of the waste form under the anticipated range of geochemical/hydrochemical conditions, and all possible waste transport processes (diffusion, advection, colloidal etc.) through the waste package materials.

3.2 Engineered System Components

3.2.1 Objectives

The design objectives of the engineered system are (1) to supplement the waste form in meeting the NRC release limits to the geologic setting, and (2) to supplement the waste form and the geologic setting in meeting the EPA limits of release of radionuclides to the accessible environment. The engineered system must meet these two objectives throughout the repository lifetime. The objectives must be shown to be fulfilled for the anticipated thermal and radiation environments and within the structural, hydrologic and geochemical environments expected in the repository. Additionally, the engineered system must be shown to meet the design objectives ~~the~~ for those anticipated processes and events which will influence repository performance.

Because the engineered system must perform in an environment of considerable uncertainty, with potential performance uncertainties of individual components, basic principles must be adhered to in their design. These include:

- Engineered barriers should be selected and designed on the basis of established principles in geotechnical, mining, chemical and nuclear engineering.

- Design of engineered features should not be based on the results of unproven theories or concepts but should be based on testing and proven performance.

- The design and selection of engineered features should be based on the major factors affecting performance on the repository scale and major system interaction effects on room and waste package scales.

- Engineered barrier design and assessment should take into account that barrier and barrier system performance will be to some extent site-specific.

The design objectives and principles require that the engineered barrier design criteria address both deterministic and stoichastic (event scenario) considerations. On the deterministic side, the engineered barriers must contribute to system performance whereever other features of the geologic repository cannot (such as providing for sorption of a specific nuclide not sorbed well by the host rock). Considering the stoichastic events the engineered barrier system must provide redundant functions in case of failure in the engineered or geologic systems. For example, premature failure of a waste package should not result in an above-limit release through total dependency on a diffusion process or on the sorption properties of a backfill.

3.2.2 Functions of Components

The engineered system can provide the following functions in meeting its design objectives:

- Irreversible sorption of radionuclides (permanent retention by ion-exchange).
- Retardation by equilibrium sorption (temporary holdup which allows decay time).
- Dispersion (reducing peak discharge, spread releases over time).
- Permanent bonding within the barrier (e.g., formation of secondary mineral species).
- Restrict transport to diffusion and limit the diffusivity (i.e., reduce water flow).
- Provide low permeability barrier to water (solution) transport.
- Radionuclide holdup by filtering (some backfills behave as semi-permeable membranes).
- Provide reinforcement or defense to withstand crushing forces from rock movement or pore water pressure.
- Buffer local water chemistry (Eh, pH) - to reduce adverse chemical reactions and/or encourage desirable chemical reactions.
- Provide repository structural support thus relieving stress concentration in the waste package region.
- Retard escape of corrosion products (tends to reduce corrosion rates).
- Retard influx of oxidants (related to Eh control).
- Provide low resistance heat transfer paths.

4 ASSESSMENT OF RELEASE RATES

Release rates for radionuclides, from both the waste package and the underground facility, are calculated quantities that are dependent on many complex, interdependent processes and parameters. These include the groundwater flow rates, radionuclide solubility, radionuclide transport processes such as diffusion, advection, colloidal transport, species retardation or irreversible sorption, chemical bonding, radionuclide decay and many others. Each of these processes and parameters has an uncertainty associated with its value, thus the calculated release rates must also have a potentially large uncertainty. The contribution of both the waste package and the engineered system to controlling radionuclide release, including data and modeling requirements, are discussed below.

4.1 Release From the Waste Package

The proposed release rate criteria is applied after assumed failure of the waste package (i.e., after 1000 years). There are three factors of interest:

(1) Waste package life
(2) Solubility or leachability of the waste form
(3) Radionuclide transport through remnants of the waste package barrier materials.

Package life is important when considering the total mass of short-lived nuclides that will be released to the environment. The range of half-lives of the nuclides in the waste is from approximately 30 years to greater than one billion years. Thus, if the package can survive to a time that is many half-lives of a particular nuclide, then that nuclide mass in inventory might have decayed to a sufficiently small quantity to be of no consequence upon total release to the environment.

In order to assess the importance of package life with respect to a particular nuclide, five quantities must be considered: inventory at emplacement, half-life, package failure time, total mass released from the package, and the consequence of this released mass. In essence, package life participates directly in the material balance of nuclide release. The first three quantities listed here determine the inventory at the time of package failure. The total mass released from the package can be equal to the inventory at the time of failure if the transport processes are fast compared to the nuclide half-life. However, if the transport processes are slow, an additional fraction of the nuclide mass will decay in inventory, thus decreasing the total mass released. The transport process itself will dilute and allow further decay of the released mass, and a final conclusion must then be determined on the consequence of the mass released to the environment.

Package life then is important in determining how much of a particular nuclide might reach the environment. For long-lived nuclides such as uranium-238, a package life of one thousand years is not significant because the fraction of uranium decayed will be on the order of 1.5×10^{-7} to 1.5×10^{-6}. For short-lived nuclides such as Cs-137, package life is important because the fraction remaining at the end of package life will be less than 10^{-10} of its inventory at emplacement and the mass available for release will be of little significance.

The waste package and engineered barrier system will be designed to delay the intrusion of groundwater and thus postpone the inception of dissolution or leaching of the radionuclides from the waste form. After the waste package is breached, radionuclide release is limited by the finite leach rate of radionuclides from the waste form. In addition to leaching, the release may be limited by the solubility of the radionuclides, particularly for the actinides. In this case the release rate would be lower than the leach rate. Other factors, such as irreversible precipitation, may further reduce the rate of release from the waste package.

Failure of all waste packages in the repository will not, in practice, occur at the same time so that the release from the waste packages will be distributed over time. Furthermore, once a waste package has been breached, the radionuclides must migrate out through the engineered barriers before release is possible and some of these barriers may be designed to absorb or otherwise affect this migration. Therefore the actual release from the waste package will be spread over time due to a variety of factors.

4.2 Release From the Engineered System

Once radionculides are released from the waste package into underground facility, the singular function of the engineered barriers is to maximize the residence of radionculides within the engineered facility and thus allow decay of the nuclides to occur. This has the effect of reducing the rate at which nuclides may be released to the geologic setting. It is this release rate that is specified in 10CFR60.113.

This delay within the engineered barriers may be accomplished in a number of ways, including irreversible and equilibrium sorption, permanent bonding, filtering, and chemical control. In general, each nuclide must be specifically examined because of its individual chemical properties. Accomplishing this delay in nuclide travel time requires specific ~~conditions~~ consideration of the hydrological system, and the geometry and hydrological properties of the engineered barrier system. The current design of horizontal waste package emplacement for the basalt repository, coupled with a vertical hydrologic flowpath through the host rock means that all delay must be accomplished within the few inches of engineered backfill that is placed around the waste package and against the host rock. This is clearly an inferior design in comparison to one in which the radionuclide comtaminated groundwater is caused to flow through a much larger volume of engineered backfill in the repository excavations, such as the concept of vertical borehole emplacement in the floor of the repository.

The adequacy of the horizontal emplacement ~~made~~ mode, or of any other candidate, must be closely and defensibly examined to ensure that the entire engineered system performs to the regulatory standards.

4.3 Design Analysis

The design analysis of the engineered system is based on the quantification of the radionuclide mass transfer from the waste package, through the engineered backfills and into the host rock. Mathematical analysis of this mass transfer requires a comprehensive understanding of each system variable and each transport phenomenon, which results in the predicted behavior of each major system component. Mathematical models have been developed which consider most of the important effects and variables.

4.3.1 Release Rate Model Methodology

4.3.1.1 Groundwater Models

A good understanding of site/geological/hydrological conditions is of primary importance, and this must be presented in the form of a conceptual model. Computer codes used to numerically simulate the model must be able to duplicate site conditions (observed from measured data) and changes that will be imposed by repository construction, natural events or human interference.

The goal of groundwater modeling is to predict the flow field past the waste package, through the underground facility and through the geologic setting. The rate of flow past the waste package will control the solubility limited release rate after package failure, and the flow velocity through the engineered system will determine the dominating waste transport mechanism.

4.3.1.2 Mass Transport Models

Calculation of mass transfer from the waste form through the engineered system may involve several interlinked computer codes, which calculate:

- o Inventory of radionculides in the waste.
- o Leaching of waste matrix.
- o Solubility of radioactive elements in groundwater.
- o Transport of waste by groundwater.

The mass transfer model must be able to consider all changes in conditions with time. In order to solve the mass transfer mathematics, boundary conditions must be specified.

For the case of an engineered barrier, the boundaries are the waste form and the host rock. The boundary at the waste form is usually described by a nuclide solubility limit or a leach rate (flux) from the waste. At the host rock the boundary is usually specified by a zero concentration, a flux rate, or a combination of concentration and water flow rate. Each of these specifications, either at the waste-form or host-rock boundary must be assumed, and the use of each yields a different release rate prediction.

The release rate of a radionuclide through an engineered backfill can be driven by a concentration gradient (diffusion, low flow conditions) a hydraulic gradient (advection, high flow conditions) or a thermal gradient (Soret effect).

Mass transfer occurs down the gradient at a rate determined by the resistance to mass transfer and the capacitance effects of the medium through which the mass transfer occurs.

There can be three distinct time frames for the occurrence of nuclide release. These are an initial transient steady state release, followed by inventory depletion when the release from the engineered backfill tails to time equal infinity. The nuclide inventory and thickness of backfill determines if all three time frames can occur because in order for steady state release to occur there must be sufficient mass available from inventory to saturate the backfill. For many nuclides the inventory is not large enough and there will be a transient rise in the release rate followed by a fall to infinity, with no steady state release. The capacitance of a backfill affects the transient release rate, but has little or no effect on the steady state release rate for the dimensions of interest and species half-lives.

Analyses of mass transfer through the engineered system suggest that radionculides with the highest release rates will be characterized, on a relative scale, by high solubility, or low adsorption potential, or high diffusivity, or any combination of these extreme attributes. These three attributes can be controlled or modified to some extent by the engineered backfill.

4.3.2 Data Base

The data base to support the complex design analyses is currently quite limited. A stronger data base must be developed which reflects the large number of system variables and their interdependencies, and which can support the definition of parametric values and distributions for use in design analysis.

The quantities of significance which directly affect the release rate from the engineered system include the species diffusivity through the medium, the capacitance (retardation), and the maximum species concentration in the water at the waste. All these quantities are chemical-species dependent which means that the chemical form of the nuclide must be known. The chemical form of the nuclide is determined by the oxidation state, hydrogen ion activity, and composition of the groundwater. Hence, in calculating release rates, a knowledge of the site geochemistry is essential.

Geological and hydrological parameters used to define the hydrological conceptual model are also important. In particular, the distribution of hydraulic pressure heads (hydraulic gradients) throughout the geologic setting in which the repository is constructed must be known with confidence.

Requirements for an adequate data base include:

- o Key parameters must be measured.
- o Confirmation that the test or analysis measures or determines the requires parameter under conditions relevant to those expected in the repository must be obtained.
- o Interdependency of parameters must be recognized and determined.
- o Parameter uncertainties mut be defined and reduced as much as economically and temporally possible.

4.3.3 Model Verification

The inaccessibility of the engineered system for experimentation leads to uncertainties in the data base and model boundary conditions. Many of the physical properties and parameters that appear in release rate predicton models are generally not well known and variations of values must be considered to determine their relative importance on the results.

This can be done by using ranges of values (sensitivity analyses) or parameter probability distributions (uncertainty analyses), based on either analytic solutions to mass transfer or on numerical methods.

The uncertainties in understanding of all waste transport phenomena, as well as the variability in the models, also suggests the potential for a high degree of uncertainty in the engineered system performance assessment. Modeling uncertainties can be reduced by:

- o Simulating problems with known analytical solutions.
- o Benchmarking - comparing solutions to complex problems obtained using similar computer codes (e.g., BARIER/WAPPA, SWIFT/MAGNUM, NUTRAN/CHAINT).
- o Verifying the conceptual models and computer codes by simulating a monitored event in the real system.

Uncertainties in data and assumptions used in numerical approximations also assures implicit uncertainties in predicted performance of the engineered system. The uncertainties in the waste transport process through the geologic setting are presently considered to be greater. Thus, the data and models which
6 predict engineered system performance must continue to be comprehensively developed. In their absence, it will be difficult, if not impossible, to defensibly predict the engineered system's performance.

than what

5 IDENTIFICATION OF AREAS OF CONCERN

The BWIP SCR describes the state of knowledge concerning disposal of HLW in a repository at the Hanford Site and provides a detailed plan for acquiring additional information to resolve site related issues. The current information base for evaulating release rates from the engineered system as provided in the SCR is sparse. Extensive work will be required, as indicated in Vol. 3 of the SCR, to allow evaluation of the engined barrier system for the basalt repository. This chapter identifies several areas of current concern to NRC with respect to release rates from the engineered barrier system. It focuses on the relative necessity and importance of design and performance attributes of the engineered components of the barrier system. The concerns voiced here are based on the existing information base and studies by NRC and its subcontractors. It is recognized that present concerns over aspects of the BWIP SCR and its treatment of the engineered barrier system will change as new data and information develop.

5.1 Capability of the Site to Meet Draft EPA Criteria

The BWIP SCR emphasizes the important role of natural barriers to minimize release and allow EPA criteria to be met. Chief among the natural barriers is the travel time to the accessible environment which exceeded 10,000 years in the studies reported in the SCR. However, it is by no means demonstrated that travel times will in fact exceed 10,000 years and recent work (Golder Associates, 1982) suggests that a travel time of roughly 1000 years is plausible. Therefore, groundwater travel time, while very long at the BWIP site, may not, by itself, be sufficient to reduce release rates within the first 10,000 years to EPA levels. A careful analysis of the groundwater travel time at the BWIP site is essential.

Two other important natural barriers emphasized in the SCR are retardation in the host rock and solubility constraints on radioactive concentrations. These properties in conjunction with the long groundwater flow times may be shown to limit the release of most nuclides to acceptable levels. However, there are several important radionuclides which may be retarded little in the basalt and may have high solubilities (e.g., I-129, Se-79, and C-14). Evaluation of the role of solubility and retardation is difficult at the present time, since the data base on these phenomena under in situ conditions is so extremely limited. Furthermore, the uncertainties in the extrapolation of measured distribution coefficients and solubilities to calculations of transport of waste over 10 km of geologic media must be considered large. Uncertainties of several orders of magnitude in applying laboratory estimates of distribution coefficients to transport have been reported.

Therefore, it is strongly felt that there is a need at the Hanford site for engineered barriers that can increase confidence in containment of the wastes, and provide an important additional margin of safety.

5.2 Adequacy of Models

Models for assessing release rates from the engineered system are at an early stage of development. Two of the principal very-near-field predictive models, BARIER and WAPPA, are listed in the SCR as "codes currently under development." A list of features in WAPPA that may require modification for basalt are also listed. Other models, such as those used to predict geochemical conditions, also will require modifications to be applicable to the basalt environment. Even when modified, current models do not account for a number of processes that could be of potential importance. It is necessary that the sophistication of present models will develop hand-in-hand with laboratory and field testing and research.

A few examples of the kinds of important near-field processes that need assessment are:

- The Soret effect. The Soret effect is a well known phenomena involving mass transport driven by a thermal rather than a concentration gradient. It is likely to be important in determining chemical conditions round the waste package at early times if backfill is present.

- Corrosion under very low flow conditions. Groundwater flow at BWIP is anticipated to be very low, perhaps only a few liters per year flowing by a single waste package. How the nearly stagnant conditions will affect corrosion processes needs to be addressed.

- Sealing fracture zones. One of the key features of bentonite listed in the SCR is its ability to swell and seal fracture zones. What this means quantitatively in terms of reducing release rates from the engineered system has not been evaluated.

The above examples illustrate that considerable further work is required. This fact appears to be recognized in the SCR.

5.3 Package Backfill as an Engineered Barrier

Backfill around waste canisters is identified in the SCR as a potentially important engineered barrier. The backfill is intended to fulfill two functions: enhance canister lifetime and restrict radionuclide releases when canister failure occurs. Important issues with respect to package backfill are hydraulic conductivity characteristics, nature of additives, buffering capability, retardation potential and reliability.

5.3.1 Hydraulic Conductivity

The SCR emphasizes the advantages of choosing a low conductivity backfill. A low conductivity backfill limits water contact with the waste canister and allows only diffusional transport of released radionuclides through the backfill. However, restricting backfill choices to only low conductivity backfills may be premature. A low conductivity backfill may be able to exclude water from the canister for only about a hundred years (Golder Associates, 1982). Also, low groundwater flow conditions at BWIP may well ensure diffusion dominated transport for even a high conductivity backfill. Therefore, the advantage of a low conductivity material should be carefully evaluated.

5.3.2 Additives

The SCR states that additives to sorb or precipitate some nuclides may have to be added to backfill to ensure compliance with the NRC release criterion, and compliance may not be possible without such additives. However, little support for the feasiblity of this approach is provided. There is concern therefore that additives may not prove to be either a feasible or reliable approach. The SCR recognizes that additional work in this area is required.

5.3.3 Buffers

The SCR states that buffers could be added to backfill material to maintain reducing conditions at early times (a few hundred years) and hence limit canister corrosion rates. There appears to be recognition that buffers have little value at later times when the basalt reducing environment dominates and defines E~~H~~h conditions. However, the SCR presents little quantitative evidence that buffers will perform their objective or that they will significantly improve repository performance.

Although buffers, like additives, seem like a good idea, there is concern that there might be too much optimism on "fixes" to the basic backfill material. The difficulties of reliably tailoring backfill materials to specific functions needs to be emphasized.

5.3.4 Retardation Potential

The SCR emphasizes the importance of package backfill as a diffusional barrier to radionuclide release. However, a typical diffusion time for an unsorbed nuclide through such backfill is about one year (Golder Associates, 1982). Hence, significant retardation is required if the backfill is to appreciably delay release. there are a number of highly sorbed nuclides (Cm, Am, Pu and Th) which may be expected to be contained for long times by the backfill. However, there are also a number of non-solubility limited nuclides such as Se-79, C-14, I-129, and Ra-226 for which the backfill may be insufficient as an engineered barrier. Reliance on the package backfill as a diffusion barrier for all nuclides is considered to be premature and unsupported.

5.3.5 Reliability

The waste package emplacement scheme includes delayed backfilling around the horizontally placed waste packages, with a 75:25 mixture of crushed basalt and bentonite pellets. The system includes a backfill placement pipe, along the length of the hole, which can be withdrawn as backfill is blown into place.

Since the engineered barrier system in the reference design relies entirely on the waste package backfill, the reliability of the in-place properties of the backfill is critical. Delayed backfill placement using the proposed scheme will lead to large uncertainties because:

- Spalling of rock from the inside of the hole from thermal stresses may prevent complete backfilling due to blockages.
- Obtaining consistent compaction density, porosity, and hydraulic conductivity values for the backfill around the complete annulus of the hole will be impossible to verify.

No in situ tests of this proposed method have been undertaken to date.

In recognition of these potential problems, an alternative emplacement system using pre-case backfill blocks contained within the waste container is also proposed in the SCR. The relative reliability of these two systems must be evaluated in the performance assessment.

5.4 Adequacy of Repository Design

The basic disposal scheme described in the SCR involves horizontal emplacement of canisters in long boreholes stretching between repository tunnels. This horizontal emplacement scheme was chosen because it minimizes excavation costs. Off-setting this positive result is the fact that horizontal emplacement may make meeting NRC and EPA criteria more difficult than if wastes were vertically emplaced beneath storage rooms.

The advantage of vertical emplacement at BWIP is that room backfill may be used as an engineered barrier. The vertically driven flow must pass through the room backfill if the backfill has a sufficiently high hydraulic conductivity. If the backfill also has a high porosity and good retardation characteristics, it will strongly delay and reduce releases from the engineered system. With room backfill, waste must pass through a significantly greater thickness of material than it would for package backfills. A further advantage is that room backfill is much less affected by the extreme thermal, radiation and geochemical processes occurring in the immediate vicinity of the waste canister. Finally, verification of room backfill transport predictions is likely to be easier than verification of far-field transport predictions.

While horizontal emplacement may prove to be both acceptable and cost-effective, it is considered premature at this stage to eliminate room backfill as an engineered barrier in a basalt repository.

5.5 Repository Backfill Program

Based on NRC project work, there is strong reason to believe that repository sealing can be accomplished with relatively high permeability backfill materials, rather than expensive, highly "impermeable" seals. The porous and sorptive backfill materials could sufficiently delay the anticipated small amount of contaminated water that are anticipated to flow through the tunnel and shaft system under anticipated conditions.

The design and performance objectives for backfills should be developed through a comprehensive analysis program.

A key question to be addressed in evaluating requirements for a repository sealing program is whether horizontal transport pathways exist. Radionuclide transport from a basalt repository is likely to be predominently vertical, driven by the thermal bouyancy force. If this is true, reliance on tunnel seals will be minimized (Golder Associates, 1982). A rapid resolution of this question by 3-dimensional modeling would permit reasonable requirements for repository seals to be proposed and evaluated. This should occur early on in the repository design process.