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Civilian Radioactive Waste Management System
Management & Operating Contractor

Richards Barrier LA Reference Design Feature Evaluation

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Executive Summary

The Richards Barrier is one of the design features being considered for inclusion in the License Application for the repository. The Richards Barrier is a special type of backfill that uses the difference in permeability and capillary properties between two backfill materials to divert groundwater. A coarse layer surrounds the waste package and a fine layer, overlaying the coarse, transports the water around the coarse layer. The Richards Barrier will therefore divert groundwater dripping into an emplacement drift around waste packages stored there. Groundwater is one of the primary reasons that waste packages could corrode causing radionuclides to be release to the environment.

The Richards Barrier does not prevent water from contacting the waste packages, but ensures that the amount of water that does contact the waste package is small. As shown by the dose-rate curves in Attachment I, the Richards Barrier is an effective method of reducing the amount of radioactive material that may be released into the environment. In developing these curves, certain assumptions have been made about the amount of rainfall expected at the repository. If these assumptions are incorrect and the climate is wetter than expected, the Richards Barrier will be able to compensate and ensure that little water contacts the waste packages. Thus the potential for corrosion of the waste packages will be reduced from that of not using a Richards Barrier

The Richards Barrier should be able to function as long as the difference or contrast in properties and the geometry of the interface between the two types of backfill material can be maintained. Over time, this contrast could be destroyed by seismic activity or by the precipitation of minerals contained in the groundwater. There is currently little directly applicable data to indicate to how long this type of barrier will survive.

The Richards Barrier will cost about $600 million (in 1999 dollars). The barrier could be installed with the technology currently available today; it should not be difficult to install, but installation will require specialized equipment. The barrier will cause a spike in temperature around the waste package because of its insulating effects. For this reason, installation of the Richards Barrier should not occur until at least 150 years after emplacement of the waste packages in order to ensure the integrity of the cladding. However, this feature could be combined with pre-closure ventilation, backfill with a higher thermal conductivity, aging, or other features to reduce the closure period.

This feature was evaluated relative to the VA reference design using the eight criteria from Section 4.2.6 as shown in Attachment V. The Richards Barrier should perform well during post-closure as shown by the dose-rate curves in Attachment I. The feature does not have any impact on pre-closure performance. The construction, operations, and maintenance aspects of the feature are rated the same as the VA reference design because Richards Barrier installation will occur at closure. The engineering acceptance rating of the feature is better than the VA reference design. The schedule and cost ratings of the barrier are below the VA reference design because the feature costs money to construct and will add to the overall schedule. The environmental considerations were developed for review by the environmental impacts statement contractor, and were not subject to numerical markup by the License Application Design Selection Team.

A confidence assessment was performed on this feature as shown in Section 7.5.3 and Attachment V.

CONTENTS

FIGURES

TABLES

Contributors to this evaluation:

Jamie Park wrote most of Section 7.7 and part of Attachment V (Section 8)
Doug Orvis (SE&I) supplied information for the summary in Section 2 of Attachment V
Mal Taylor performed the calculations in Attachment II
Dan Hong performed the cost analysis in Section 7.6

1. OBJECTIVE AND SCOPE

The Richards Barrier is one of the design features of the repository to be considered for the License Application (LA). Richards was a soil scientist who first described the diversion of moisture between two materials with different hydrologic properties. In this report, a Richards Barrier is a special type of backfill with a fine-grained material (such as sand) overlaying a coarse-grained material (such as gravel). Water that enters an emplacement drift will first encounter the fine-grained material and be transported around the coarse-grained material covering the waste package, thus protecting the waste package from contact with most of the groundwater. The objective of this report is to discuss the benefits and liabilities to the repository by the inclusion of a Richards Barrier type backfill in emplacement drifts.

The Richards Barrier can act as a barrier to water flow, can reduce the waste package material dissolution rate, limit mobilization of the radionuclides, and can provide structural protection for the waste package. The scope of this report is to:

- Analyze the behavior of barrier materials following the intrusion of groundwater for influxes of 1 to 300 mm per year. The report will demonstrate diversion of groundwater intrusions into the barrier over an extended time period when seismic activity and consolidation may cause the potential for liquefaction and settlement of the Richards Barrier.
- Review the thermal effects of the Richards Barrier on material behavior.
- Analyze the effect of rockfall on the performance of the Richards Barrier and the depth of the barrier required to protect waste packages under the barrier.
- Review radiological and heating conditions on placement of multiple layers of the barrier. Subsurface Nuclear Safety personnel will perform calculations to determine the radiation reduction-time relationship and shielding capacity of the barrier.
- Evaluate the effects of ventilation on cooling of emplacement drifts and dusting potential.
- Evaluate drift conditions and configurations to determine the suitability of Richards Barrier installation methodology.
- Perform cost assessment of barrier material placement.
- Evaluate the feature with criteria that will be supplied by the License Application Design Selection (LADS) Team.
- Comment on the use of depleted uranium as a Richards Barrier material.

This report will not discuss backfill or sealing of ramps, shafts and mains but will limit itself to installing a Richards Barrier in emplacement drifts.

2. QUALITY ASSURANCE

This report evaluates the installation of the Richards Barrier in the repository. The report was prepared under QAP-3-5, *Development of Technical Documents* in accordance with the approved *Technical Document Preparation Plan (TDPP) for LA Reference Design Feature Evaluation #15: Richards Barrier* (CRWMS M&O 1999a). The Richards Barrier feature study was evaluated in the *Activity Evaluation for Design Features for LA Design Selection- Subsurface Repository* (CRWMS M&O 1998a) in accordance with Quality Administrative Procedure QAP-2-0, *Conduct of Activities*, and it was determined that the feature affects items on the *Q-List* (DOE 1998a) and is subject to the *Quality Assurance Requirements and Description* (QARD) (DOE 1998b).

The formal TBV and TBD tracking system described in Nevada Line Procedure NLP-3-15 *To Be Verified (TBV) and To Be Determined (TBD) Monitoring System* are not applicable to this report. However, TBV and TBDs are noted as applicable. The Richards Barrier feature is subject to Quality Assurance (QA) controls.

A formal classification of permanent items has been performed in accordance with QAP-2-3, *Classification of Permanent Items*. Backfill and backfill systems are listed in the *Classification of the Preliminary MGDS Repository Design* (CRWMS M&O 1998c, SS02 & SS18). Backfill is listed as Important to Waste Isolation (QA-2) and the backfill system is listed as Important to Potential Interaction (QA-5). Therefore, an emplacement drift Richards Barrier is inferred to have a similar classification.

3. METHOD

The Richards Barrier design feature is analyzed in accordance with the eight criteria (Section 4.2.6) used for evaluating all design features contained in the *Design Input Request for the Repository Design Selection Process* (CRWMS M&O 1998o) and the revised *Design Input Request for License Application Design Selection (LADS) Phase I Confidence Assessments* (CRWMS M&O 1999f). Conclusions are drawn about the impact of the Richards Barrier on repository performance, based on analyses with respect to the criteria. These criteria are included in the next section of this report. A confidence assessment has been made by the LADS Team and is included in Section 7.5.3.

4. INPUTS

4.1 Parameters

4.1.1 Thermal Conductivity of Crushed Tuff and Sand

The thermal conductivity of crushed tuff is 0.54 W/m-K (Ryder et al, 1996, pg 5-16) and sand is 0.33 W/m-K (Lide 1995, pg 12-180).

4.1.2 Density of Depleted Uranium Aggregate

The density of depleted uranium aggregate depends upon the way it is made. This report will use a value of $8 gm/cm^3$. This value is approximate and is in the lower part of the range of values reported in (Lessing 1995, pg v).

4.2 Criteria

4.2.1 The system (Backfill System) shall be capable of placing backfill in the emplacement drifts. *Backfill Emplacement System Description Document* (CRWMS M&O, 1998d, Item 1.2.1.1).

4.2.2 The system (Backfill System) shall be capable of placing the total repository backfill within a period of 34 years. *Backfill Emplacement System Description Document* (CRWMS M&O, 1998d, Item 1.2.1.2).

4.2.3 The system (Ex-Container System) shall limit the emplacement drift wall temperature to less than 200°C (TBV) to limit the thermal and thermomechanical response of the host rock and surrounding strata and groundwater system. *Ex-Container System Description Document* (CRWMS M&O, 1998i, Item 1.2.1.7).

4.2.4 The system (Ex-Container System) shall have a mass loading of 80-100 metric tons of uranium (MTU) per acre, primarily in the TSw2 geologic unit within the primary area. *Ex-Container System Description Document* (CRWMS M&O, 1998i, Item 1.2.1.10).

4.2.5 The subsystems, which contact the waste packages following emplacement, shall use materials which do not degrade the performance of the waste packages. *Ex-Container System Description Document* (CRWMS M&O, 1998i, Item 1.2.1.15).

4.2.6 The following evaluation criteria will be used in assessing backfill from *Design Input Request for the Repository Design Selection Process* (CRWMS M&O 1998o):

1. Post-Closure Performance
2. Pre-Closure Performance
3. Assurance of Safety
4. Engineering Acceptance
5. Construction, Operations, and Maintenance
6. Schedule
7. Cost
8. Environmental Considerations

These criteria are addressed specifically in more detail in Attachment V.

The evaluation criteria will include a confidence assessment from the *Design Input Request for License Application Design Selection (LADS) Phase I Confidence Assessments* (CRWMS M&O 1999f).

4.2.7 The system (ventilation system) shall maintain the underground air temperatures during the repository remote access (remote equipment) modes as follows:

maximum temperature for emplacement drifts: 50°C.

Subsurface Ventilation System Description Document (CRWMS M&O 1998l, Item 1.2.1.4).

4.2.8 The disposal container shall maintain SNF zircalloy and stainless steel cladding temperature below 350°C (662°F) (TBV). *Canistered Spent Nuclear Fuel Disposal Container System Description Document* (CRWMS M&O 1998b, Item 1.2.1.7)

4.3 Assumptions

4.3.1 Emplacement Drift Wall Temperatures Over Time

Emplacement drift wall temperature (without the barrier) will increase to over 100°C within 4 years of emplacement of waste packages as shown in *Multiple WP Emplacement Thermal Response- Suite 1* (CRWMS M&O, 1998j, pg 24). The emplacement drift wall temperature (without the barrier) will stay above 100°C for thousands of years (CRWMS M&O, 1998j, Tables 6-1 to 6-4). This assumption is based on existing data and does not have to be confirmed in this evaluation. The assumption is used to give an indication of drift wall temperature but not to quantify the value. [Used in Section 7.2]

4.3.2 Maximum Size of Rockfall

The maximum size of a single rock in a rockfall event is assumed to be 25 metric tons as discussed in *Waste Package Design Basis Events* (CRWMS M&O, 1997e, pg 33). This assumption is based on existing data and does not need to be confirmed in this evaluation. This assumption is used in Attachment II to calculate the reduction in impact force expected by the cushioning effects of backfill. [Used in Attachment II]

4.3.3 Effect of Richards Barrier on Long-Term Repository Dose Rate

The long-term repository dose rate will be affected by the Richards Barrier as shown in Attachment I *Design Input Transmittal for WAPDEG and RIP Output and Analysis for DF3 (Backfill Quartz Sand)* (CRWMS M&O, 1999d). This assumption is based on existing data and does not have to be confirmed in this evaluation. The assumption is used to give an indication of the dose-rate over time but not to quantify the value. [Used in Attachment I and Section 7.1.1]

4.3.4 Seepage Rate into Emplacement Drifts with Backfill

The seepage rate into emplacement drifts with a single backfill is approximately 1 mm/year assuming that the potential field theory is correct. The theory assumes that water will travel around an emplacement drift versus dripping into the drift. The mathematical basis for this assumption is more fully explained in *Design Input Transmittal for Scoping Calculations for Engineered Barrier System Modeling and Analysis Support for the License Application Design Selection*

(LADS) for Single Backfill, the Richards Barrier, the Diffusive Barrier, and the Getter Barrier Features (CRWMS M&O 1999b, Item 2). A similar seepage rate is assumed for emplacement drifts with a Richards Barrier. This assumption is based on existing data and does not have to be confirmed in this evaluation. The assumption is used to give an indication of the expected seepage rate, under certain conditions, but not to quantify the value. [Used in Section 7.1]

4.3.5 Average Infiltration Flux

The average infiltration flux over the repository is 5-10 mm/yr as shown in the *Near-Field/Altered-Zone Models Report* (Hardin et al., pg 1-5). This range of flux values is existing data and does not require confirmation. It is conservative to equate the average seepage flux into an emplacement drift to the average infiltration flux at the surface. A range of values is provided because there is variability in the measurement of infiltration flux over an area the size of the repository. [Used in Section 7.1]

4.3.6 Average Density of TSw2 Rock

The average density of TSw2 rock is 2274 kg/m^3 as shown in the *Controlled Design Assumptions Document* (CRWMS M&O, 1998e, TDSS 004). This value is existing data and does not require confirmation. The TSw2 density is needed to determine the mass of a rock that could drop on a waste package. The value is used to determine the reduction in impact force from a rockfall provided by the barrier, but not to design the waste package. The justification for this value is included in the reference. [Used in Attachment II]

4.3.7 Maximum Infiltration Flux

The maximum infiltration flux is 300 mm/year as shown in the *Controlled Design Assumption Document* (CRWMS M&O 1998e, TDSS 026). This value is existing data and does not require confirmation as it will not be used in output products to support construction, fabrication, or procurement of an item. The justification for this value is provided in the reference. [Used in Section 7.1]

4.3.8 Groundwater Table Elevation

The groundwater table is at 730m elevation from *Cross Drift Geotechnical Predictive Reports: Geotechnical Baseline Report* (CRWMS M&O, 1998g, pg 4-1). The average elevation of the repository is approximately 1075m as shown in the *Repository Subsurface Layout Configuration Analysis* (CRWMS M&O, 1997d, pg 33). These elevations are existing data and do not require confirmation in this evaluation. The elevations are needed to show that the repository is located above the water table. Therefore, the exact value for the elevation is not important. [Used in Section 7.1]

4.3.9 Not Used.

4.3.10 Expected Size and Frequency of Earthquakes

An earthquake with a ground acceleration of 0.1g is probable every 150 years and an earthquake with an acceleration of 0.2g is probable every 500 years from the *Engineered Barrier System Performance Systems Study Report* (CRWMS M&O 1997c, pg 5-43). These values are existing data and do not require confirmation as the information is being used to obtain an idea of the size and frequency of earthquakes but not to provide information to support construction, fabrication, or procurement of an item. [Used in Section 7.3]

4.3.11 Groundwater Percolation Rate with Richards Barrier

There is at least an order of magnitude difference in percolation rate between the coarse and fine layers of a Richards Barrier as shown in the *Design Input Transmittal for Scoping Calculations for Engineered Barrier System Modeling and Analysis Support for the License Application Design Selection (LADS) for Single Backfill, the Richards Barrier, the Diffusive Barrier, and the Getter Barrier Features* (CRWMS M&O 1999b, Item 1). The fine layer conducts groundwater much better than the coarse layer at a given value for water potential. This information is existing data and does not require confirmation as it will not be used to support construction, fabrication, or procurement of an item. [Used in Section 7.1]

4.3.12 Thermal Effect of Backfill on Cladding Temperature

The thermal effect of backfill on cladding temperature is shown in Figures 1 and 2. These figures are from *Thermal Calculation of the Waste Package with Backfill* (CRWMS M&O 1999e, pgs 40 and 43). The information is being used to show when the addition of backfill will not cause the cladding temperature to exceed 350°C (4.2.8) but not to determine an exact value of the temperature. [Used in Section 7.2]

4.3.13 Richards Barrier Shielding Estimate

The estimated shielding effects of the Richards Barrier are shown in Attachment III and are from *Emplacement Drift Backfill Shielding Calculation* (CRWMS M&O 1998h, pg 51). This information is existing data and does not require confirmation, as it will not be used to support construction, fabrication, or procurement of an item. [Used in Attachment III]

4.3.14 Richards Barrier Quantity

The Richards Barrier will require a total quantity of 1.7 million m^3 of material from *Emplaced Volumes of Single and Multiple Component Backfill* (CRWMS M&O 1998n, pg 38). This figure is used to provide information for the cost estimate performed as part of this report and does not require confirmation in this evaluation. The value will not be used to support construction, fabrication, or procurement of an item. [Used in Section 7.6]

4.3.15 Depth of Richards Barrier or Backfill

A depth of material over the waste package of approximately 1.0m has been assumed for the Richards Barrier and a depth of approximately 0.6m has been assumed for a single-layer backfill. These values are from *Emplaced Volumes of Single and Multiple Component Backfill* (CRWMS M&O 1998n, pgs 14 and 15). These assumptions are based on existing data and do not need to be confirmed. The assumptions are used in Attachment II to calculate the reduction in impact force expected by the cushioning effects of backfill. [Used in Attachment II]

4.3.16 Cost Information

Richards Barrier installation costs are detailed in Attachment VI and are summarized in Table 4. The Simplified Richards Barrier is estimated to take 5.61 years and 3,599,724 total manhours to construct. The Horseshoe Richards Barrier is estimated to take 6.54 years and 4,198,527 total manhours to construct. These assumptions are based on existing data and do not require confirmation as they will not be use to support construction, fabrication, or procurement of an item. [Used in Section 7.6 and Attachments V & VI]

4.3.17 Material Stockpile

A two month supply of material will be stockpiled for Richards Barrier installation. The stockpile will help balance variations in the rate of Richards Barrier installation and allow for equipment shutdowns. This assumption is based on existing data and does not need to be confirmed as it will not be used to support construction, fabrication, or procurement of an item. [Used in Attachment V]

4.4 Codes and Standards

None

5. REFERENCES

5.1 Documents Cited

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CRWMS M&O 1998k. Not Used.

CRWMS M&O 1998l. *Subsurface Ventilation System Description Document*. BCA000000-01717-1705-00016 REV 00. ICN 1. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980515.0170 and MOL.19980604.0151.

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6. USE OF COMPUTER SOFTWARE

Only word processing software is used to produce this report. Software used to produce some of the Attachments and Figures is contained in the references for the Attachments and Figures.

7. RICHARDS BARRIER EVALUATION

The term "Richards Barrier" is used in this report to describe a special type of backfill. Specifically, the backfilling of emplacement drifts with two materials with different permeability and capillary properties. The interface between the two materials forms a barrier to the flow of water. This barrier forms a preferential path that diverts water along the interface between the two materials. This report describes the effects on the repository system of the barrier and draws conclusions about these effects. This report does not make a blanket recommendation for or against the installation of a Richards Barrier but will instead bring forth a number of points for consideration that will aid decision-makers in deciding whether to install the barrier.

Backfill, and thus the Richards Barrier, has been identified as a means of extending the waste package lifetime *Engineered Barrier System Performance Requirements Systems Study Report* (CRWMS M&O, 1997c, pgs 4-1 to 4-6). This report assesses how sensitive predictions of the Richards Barrier are to performance assumption and to changing conditions.

7.1 Groundwater Effects on Post-Closure Richards Barrier Installation

Before addressing groundwater effects on the barrier, this section describes the repository groundwater environment. Currently, the climate at the repository site is warm and dry, most of the time, with little precipitation during the year. The *Near-Field/Altered-Zone Models Report* (Hardin et al., pg 1-5) indicates that the average water infiltration over the repository has a range of 5 to 10 mm/yr (4.3.5), *under current conditions* (italics added for emphasis). However, flow along cracks or joints may exceed the average. The *Controlled Design Assumptions* document (CRWMS M&O 1998e, pg 10-21) uses an upper bound of 300 mm/yr for water infiltration (4.3.7)

The elevation of the repository waste emplacement level is above the water table (4.3.8) and therefore the rock is in an unsaturated condition. The following quote from the *Near-Field/Altered-Zone Models Report* (Hardin et al., pg 3-47) describes the groundwater flow expected under unsaturated conditions:

> Flow in an unsaturated porous medium is governed by three forces: viscous, gravitational, and matric (capillary + osmotic). As long as the total fluid pressure in fracture or matrix pore water is maintained below atmospheric pressure by matric forces, seepage cannot flow into the drift. Matric forces are caused by the sum of capillary pressure and surface forces at or near the pore walls. At high saturation, or for large pore sizes, such as in fractures, gravitational forces predominate. If flow is sufficiently high, a combination of gravitational and viscous forces will eventually overcome matric forces, and fluid pressure will increase to atmospheric pressure; at that point, seepage into the drift can occur.

This means that groundwater will tend to flow around an emplacement drift except when high flow rates force water into the drift. Groundwater flowing around an emplacement drift may permit about 1 mm/year (4.3.4) of this water into the emplacement drift. However, a crack or fault could provide a pathway for water to enter the emplacement drift. The Richards Barrier will transfer this water around the waste package and allow it to seep into the rock at the sides or bottom of the drift. The Richards Barrier will provide at least an order of magnitude reduction in the amount of water that could contact a waste package (4.3.11). This means that, for example, if 20 mm/year dripped onto the fine layer, the coarse layer would allow a maximum of 2 mm/year to contact the waste package. The Richards Barrier thus provides a significant reduction in the amount of water that can contact the waste package. On-going Engineered Barrier System (EBS) testing should verify assumptions concerning water infiltration and diversion. This testing is in addition to the information already available for Richards Barrier performance from environmental projects as shown in *Control of Water Infiltration into Near Surface LLW Disposal Units – Volume 10* (NRC 1997).

Transportation of water into a drift can also be caused by evaporative pressure from relatively dry ventilation air drawing moisture from the drift wall. In this instance, the moisture is removed from the rock by evaporation, and from the drift by the movement of ventilation air.

The Richards Barrier could be composed of gravel and sand sized material. The Richards Barrier will limit the amount of water that contacts the waste package and therefore may limit the amount of radioactive material that can be carried away from the emplacement drift. Certain types of material can absorb radioactive material; this is the subject of another feature report.

7.1.1 Long-Term Repository Dose-Rate with the Richards Barrier

The effect of groundwater on the waste package and Richards Barrier is important as groundwater can carry radionuclides to the accessible environment. The standard used for evaluation is the projected dose at 20 km from the repository (4.2.6). Attachment I provides the projected dose-rate over 1,000,000 years for the repository with and without a Richards Barrier. The peak dose-rate for less than 10,000 years is 0.012 mrem per year or less *Design Input Transmittal for WAPDEG and RIP Output and Analysis for DF3 (Backfill Quartz Sand)* (CRWMS M&O 1999d, pg 19). The peak dose-rate between 10,000 and 1,000,000 years is over 500 mrem per year and occurs at about the 317,000 year mark (Attachment I). The Figure of Merit (FOM) ranges from 24.11 to 32.31 as determined in the *Design Input Transmittal for WAPDEG and RIP Output and Analysis for DF3 (Backfill Quartz Sand)* (CRWMS M&O 1999d, pg 19). The FOM for the VA reference design is 25.02 mrem per year (CRWMS M&O 1999d, pg 19).

The assumptions used to generate the "base case" curve in Attachment I are included in the *Total System Performance Assessment- Viability Assessment Base Case: Text, Engineering Calculation* (CRWMS M&O 1998m). Discussion of these base case assumptions is outside the scope of this report. However, the specific assumptions used to generate the Richards Barrier curve are germane to this report and are discussed below.

Eight assumptions are made to generate the Richards Barrier curves in Attachment I from *Design Input Transmittal for WAPDEG and RIP Output and Analysis for DF3 (Backfill Quartz Sand)* (CRWMS M&O 1999d, pgs 7-8):

- The Richards Barrier prevents seepage from contacting the waste package until a prescribed failure time. Six failure times were simulated: 2,000; 20,000; 40,000; 60,000; 80,000; and 100,000 years.

- At failure, the base case seepage model is invoked and remains operational until the end of the simulation period. Seepage is assumed to contact 100% of the waste package surface area.

- Backfill (Richards Barrier) alters the thermal environment of the waste packages.

- Backfill (Richards Barrier) is emplaced at 100 years after emplacement of waste.

- The increased package temperature associated with backfill causes cladding degradation from increased creep strain.

- The presence of backfill (Richards Barrier) prevents mechanical failure of cladding through rockfall.

- Waste packages corrode in humid-air conditions while the Richards Barrier is operative.

- Packages with juvenile failures do not experience increased cladding degradation.

The first assumption listed above is not entirely correct but is still conservative. The Richards Barrier will prevent most, but not all, of the groundwater from contacting the waste package as shown in *Design Input Transmittal for Scoping Calculation for Engineered Barrier System Modeling and Analysis Support for the License Application Design Selection (LADS) for Single Backfill, the Richards Barrier, the Diffusive Barrier, and the Getter Barrier Features* (CRWMS M&O 1999b, Item 1, pg 5). It is conservative to assumption that the Richards Barrier fails at some point and that after failure the base case seepage model will be invoked. Another reasonable assumption could be that after failure, the Richards Barrier acts as a single layer of backfill. This assumption would produce smaller dose predictions than are shown in Attachment I.

The assumption is made that the Richards Barrier will fail at some point over its life. This assumption is more conservative than assuming that the barrier lasts until most of the radioactive material in the waste packages completely decays. There is no information on how long the Richards Barrier will last under conditions found in the emplacement drift. On-going Engineered Barrier System (EBS) testing may provide longevity information for this feature.

The assumption that the Richards Barrier will alter the thermal environment is confirmed by the calculation in the *Thermal Calculation of the Waste Package with Backfill* (CRWMS M&O 1999e).

The assumption should be made that barrier installation will only occur after temperatures have decreased to the point that installation of backfill will not cause the cladding temperature to exceed 350°C (4.2.8). Specifying a time period of 100 years is somewhat arbitrary.

To allow for some cladding degradation even at cladding temperatures less than 350°C (4.2.8) is more conservative than to assume that no degradation occurs.

The presence of Richards Barrier backfill may not prevent mechanical failure of waste packages through rockfall. However, as shown in Attachment II, the force experienced by the waste package is greatly reduced. The Richards Barrier will therefore reduce the consequences of this type of event.

The model assumes that the waste package can undergo humid-air corrosion while the Richards Barrier is functional. The waste package will be surrounded by gravel if the Richards Barrier is installed. Since gravel has many air spaces between the particles, moisture will be able to attack the waste package surface. The Richards Barrier will not be able to prevent moisture from contacting the waste package, but can reduce it considerably.

Assuming that a waste package undergoing juvenile failure will not experience increased cladding degradation is a fair simplifying assumption

The Attachment I Richards Barrier curves show an improvement of a maximum of 2 to 3 orders of magnitude in dose-rate over 100,000 years if the barrier does not fail. Without the Richards Barrier the base case dose-rate is about 10 mrem/year after about 100,000 years.

7.2 Thermal Effects of Post-Closure Richards Barrier Installation

Thermal energy will be produced by the waste packages. This energy will cause the emplacement drift and surrounding rock to become heated to more than 100°C (4.3.1) at the thermal loading of 85 MTU/acre (4.2.4). The emplacement drift temperature will increase until a peak is reached and then a slow decline in temperature will occur. The peak will be less than 200°C (4.2.3). The decline in temperature will take place over thousands of years (4.3.1).

A recently published document *Thermal Calculation of the Waste Package with Backfill* (CRWMS M&O 1999e) has calculated the effect of the Richards Barrier on waste

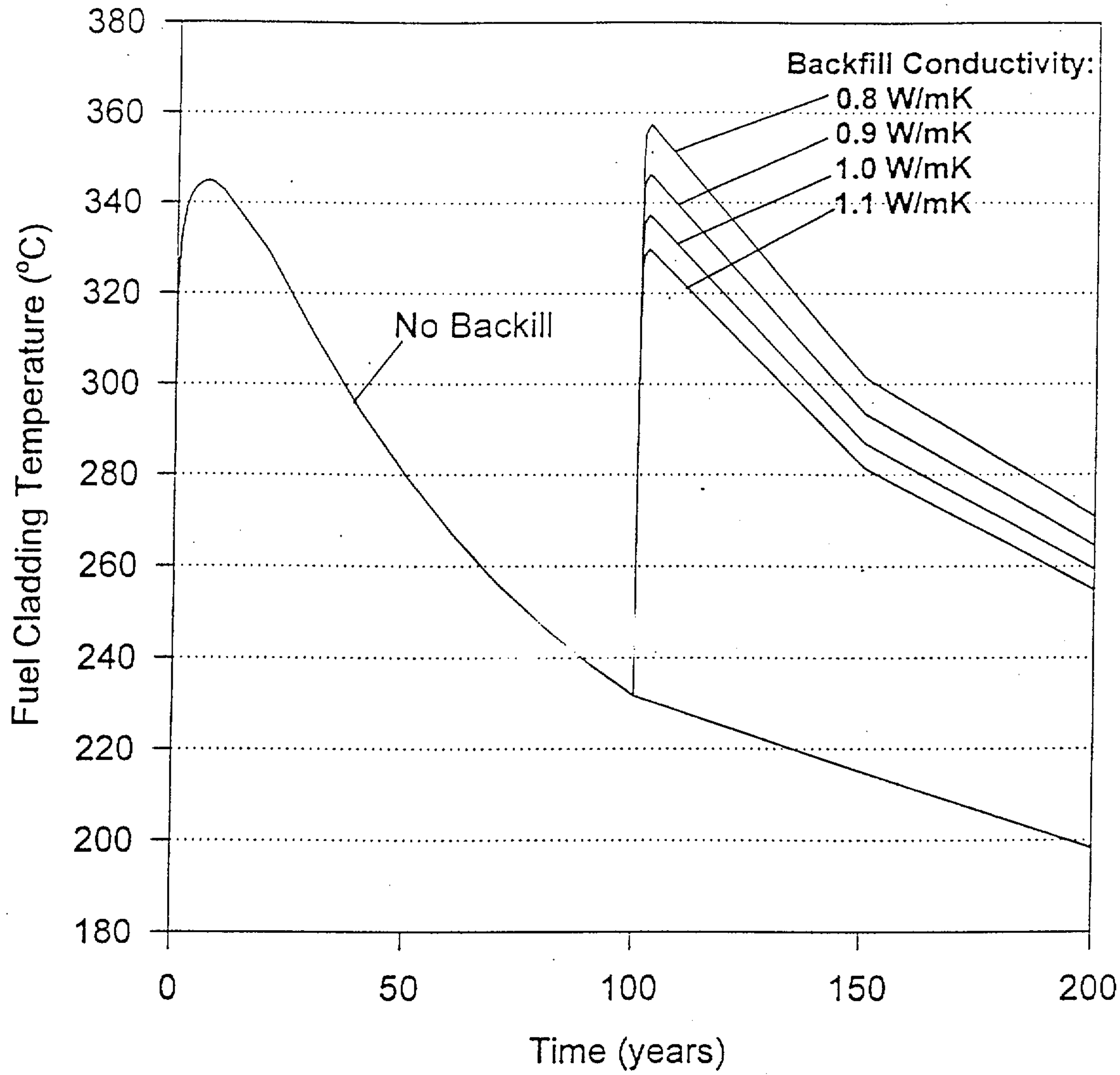

Figure 1. Effect of Richards Barrier on Waste Package Fuel Cladding Temperature (Backfill at 100 years) from *Thermal Calculation of the Waste Package with Backfill* (CRWMS M&O 1999e, pg 40). The calculation used a 3-Dimensional ANSYS model.

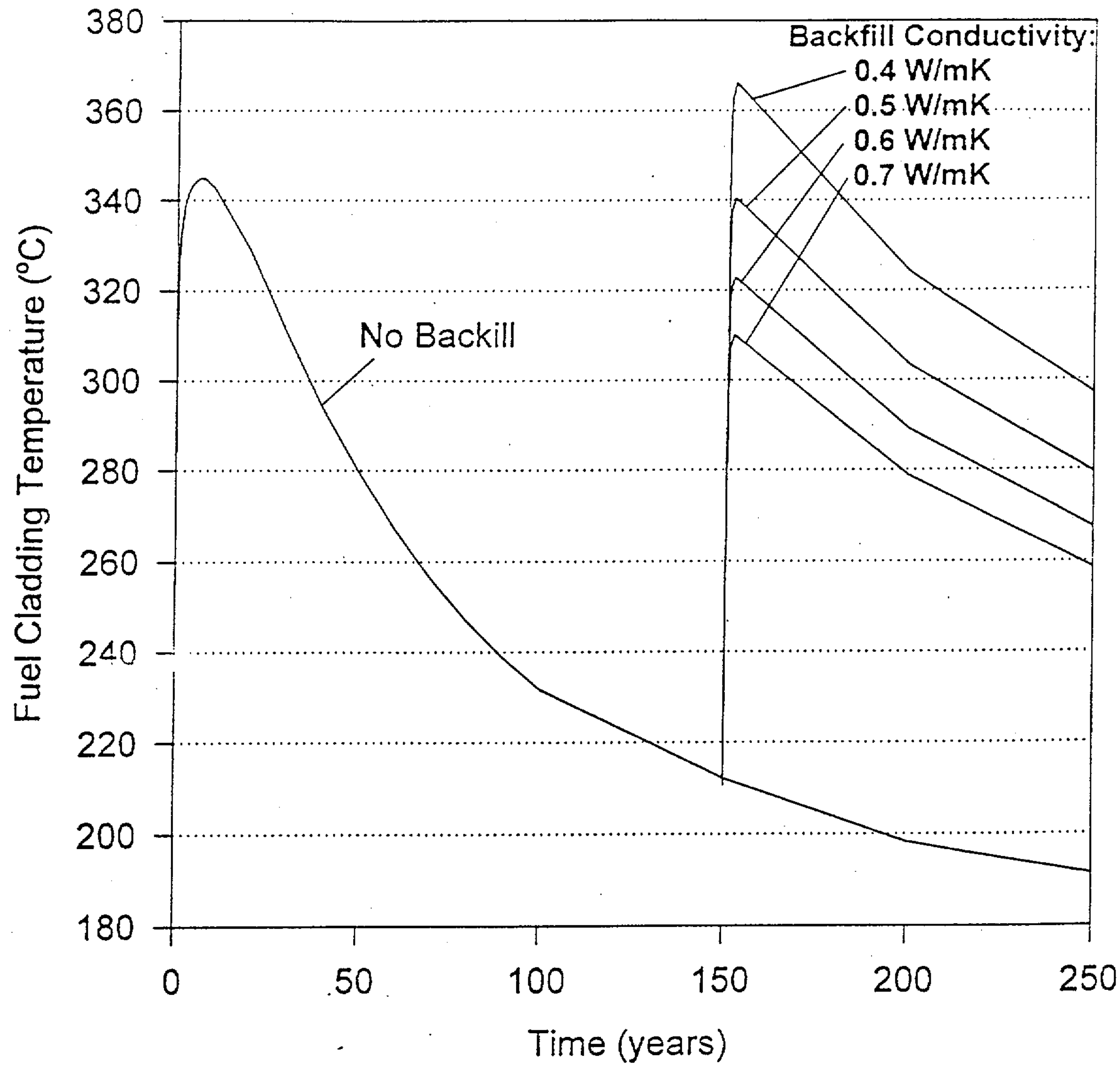

Figure 2. Effect of Richards Barrier on Waste Package Fuel Cladding Temperature (Backfill at 150 years) from *Thermal Calculation of the Waste Package with Backfill* (CRWMS M&O 1999e, pg 43). The calculation used a 3-Dimensional ANSYS model.

package temperature. A calculation was performed using different material thermal conductivities. Waste package fuel cladding temperatures are shown in Figures 1 and 2. These temperature are for a 21 Pressurized Water Reactor (PWR) waste package (this is the hottest waste package type based on average heat output) (CRWMS M&O 1999e, pg 7).

The maximum allowable cladding temperature is 350°C (4.2.8) to avoid creep rupture. The figures show that the cladding temperature stays below this value for the "no backfill" case. Figure 1 shows the cladding temperature for installation operations performed at 100 years and shows that a material with a thermal conductivity of greater than about 0.9 W/m-K will be required at 100 years to produce a cladding temperature below 350°C (4.2.8). Figure 2 shows the cladding temperature for installation operations performed at 150 years. Figure 2 shows that a material with a thermal conductivity of greater than about 0.5 W/m-K will be required at 150 years to produce a cladding temperature below 350°C (4.2.8).

Crushed tuff has an average thermal conductivity of 0.54 W/m-K (4.1.1) and sand has a conductivity of 0.33 W/m-K (4.1.1). These values imply that installation of a Richards Barrier should not occur prior to at least 150 years after emplacement, using materials that are commonly available. The conductivity of the Richards Barrier is not calculated but would be based on the relative thicknesses and conductivities of its component materials. If barrier installation occurred prior to 150 years, the cladding temperature would exceed 350°C (4.2.8), as the materials used do not conduct heat quickly enough, and thus would not be acceptable. However, the Richards Barrier could be combined with pre-closure ventilation, backfill with a high thermal conductivities, aging, or other features to reduce the closure period.

7.3 Seismic and Subsidence Effects on Post-Closure Richards Barrier Installation

As discussed below, seismic events could cause compaction of the Richards Barrier, cause it to change its shape, or disturb the interface between the two sizes of material. Subsidence of the Richards Barrier could be caused by the corrosion of the waste package that allows barrier material to enter voids within the waste package.

As discussed in Section 7.4 of this report, the Richards Barrier will be placed in the emplacement drifts with little or no compaction. However, a sand or gravel material compacts very little, even with compactive effort, so its ability to compact under seismic loading is limited. In addition, the barrier will be placed in an emplacement drift with a finite diameter, and therefore the total height of material that could compact is limited. The emplacement drift also confines the barrier, forcing it to keep its general shape and position. Sand or gravel with few fines is freely draining, and therefore is not subject to liquefaction. Liquefaction is caused by excess pore pressure (groundwater subjected to seismic events can cause this pressure to develop). Therefore, seismic events should have little or no effect on compaction of the Richards Barrier.

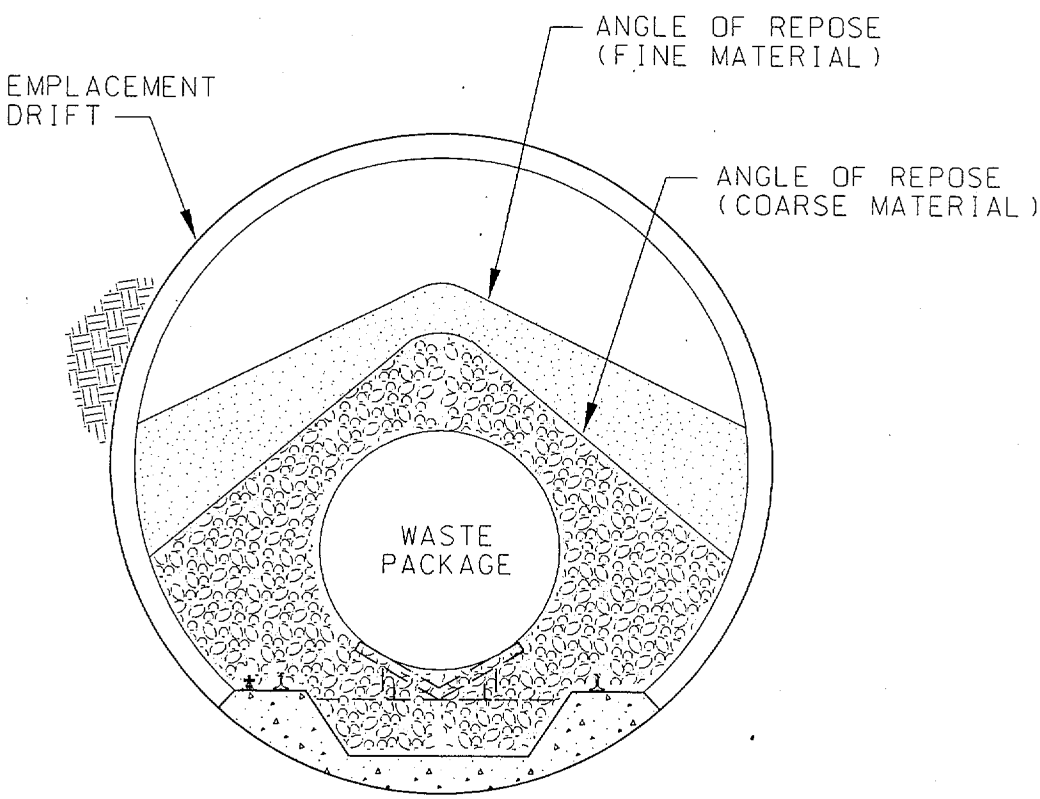

FIGURE 3
RICHARDS BARRIER
SIMPLIFIED GEOMETRY

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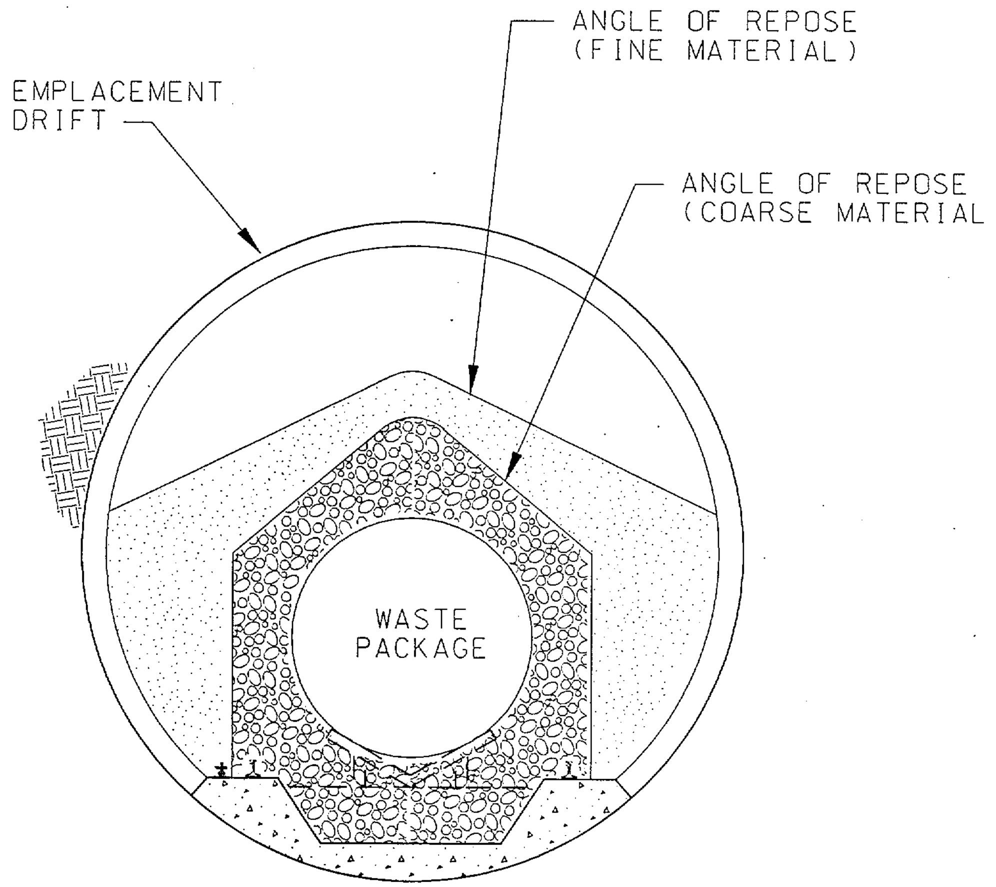

FIGURE 4
RICHARDS BARRIER
"HORSESHOE" GEOMETRY

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Seismic events can cause the Richards Barrier to change its shape. Figures 3 and 4 depict typical cross sections. The Richards Barrier will be placed loose, in a series of piles. These piles may flatten over time as discussed in the *Engineered Barrier System Performance Requirements Systems Study Report* (CRWMS M&O 1997c, pgs 5-35 to 5-45). The piles should be sized to provide some cover over the waste package even after flattening of the pile. An earthquake with a 0.1g acceleration is probable every 150 years and, with a 0.2g acceleration every 500 years (4.3.10), although larger earthquakes can occur at longer time periods.

The waste package will eventually corrode and collapse, causing the Richards Barrier to subside as it fills the voids in the waste package. In this instance the waste package has failed, but the Richards Barrier can still reduce the wicking of groundwater (which could carry dissolved radioactive material).

A seismic event could destroy the interface between the two sizes of material. That is, the two materials could mix thus blurring the interface. The fine-grained portion of the Richards Barrier would therefore no longer divert water around the coarse-grained. If the interface between the two materials is destroyed then the Richards Barrier should perform as a single layer of backfill. However, there is historical information from Japanese burial vaults that blurring of the interface should not occur as discussed in the *Analysis and Confirmation of Robust Performance for the Flow-Diversion Barrier System within the Yucca Mountain Site* (EPRI 1996, pgs vi to vii). The Japanese burial vaults have a similar construction to the barrier proposed for the repository.

7.4 Richards Barrier Installation Methodology

Two recent analyses discussed the installation of backfill and this discussion is applicable to the Richards Barrier. The *Constructability Analysis of Backfill and Dripshield Configurations* (CRWMS M&O 1998f) assessed different backfill design configurations from a constructability standpoint. The *Backfill Strategy and Preliminary Design Analysis* (CRWMS M&O 1997a) went into detail about the methods and procedures for placing backfill. These analyses provide more detail than will be presented in this report. Figure 5 provides a conceptual design for the Richards Barrier installation operation. A brief summary of the Richards Barrier installation method is provided below:

- Richards Barrier materials will be obtained. This material could be crushed tuff and quartz sand (CRWMS M&O 1997a, pg 61). The material could also be imported from an offsite source. The material will be selected so as not to adversely react with the waste package (4.2.5).

- The barrier material will be crushed, screened and washed to produce a specific gradation (CRWMS M&O 1997a, pg 61). Preliminary design information is provided in Attachment IV.

- The emplacement drift temperature will be cooled to 50°C or below (4.2.7) by the ventilation system and kept at this level throughout backfill operations.

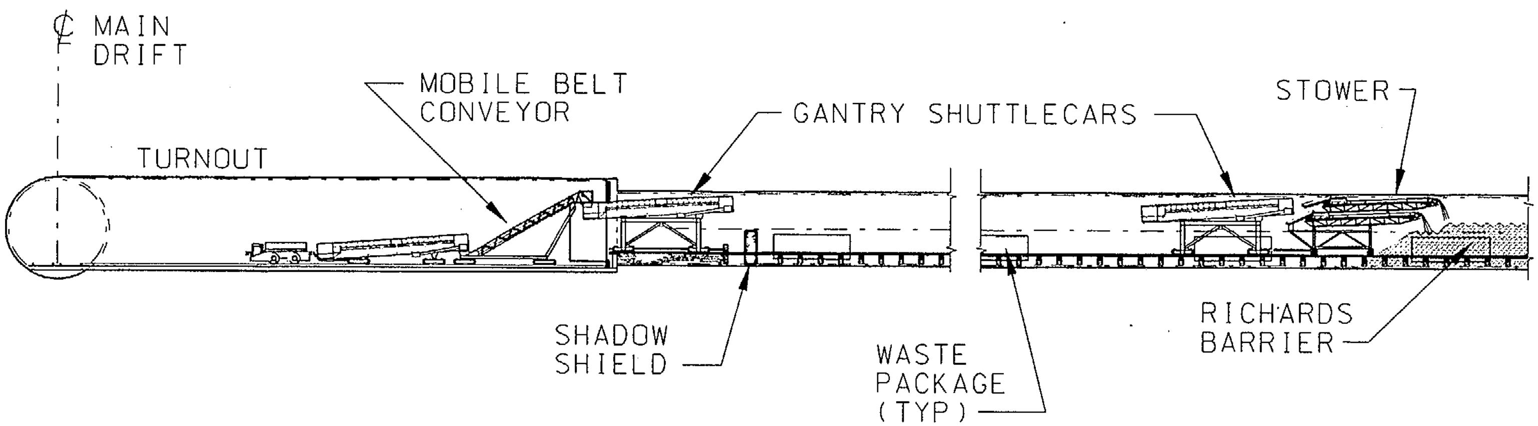

FIGURE 5
EMPLACEMENT DRIFT CONCEPTUAL DESIGN
FOR RICHARDS BARRIER INSTALLATION

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- The materials will be transported to the emplacement drift by railcar or conveyor (CRWMS M&O 1997a, pg 62).

- Specially constructed equipment will place the Richards Barrier materials in the drift. A mobile belt conveyor will move the material from the turnout and load a shuttle car. The shuttle car will move the material from the emplacement drift door, over the shadow shield and waste packages, down the emplacement drift, and empty into the stower conveyor hopper (CRWMS M&O 1997a, pg 37). The stower conveyor will place the Richards Barrier over the waste package. The equipment will be designed to operate remotely in the hot environment of the emplacement drift. Some compaction of the material could be achieved by installing vibrators on the front portion of the stower conveyor. These vibrators could stick into the material and vibrate it for compaction.

- There are two concepts for placing a Richards Barrier: 1) Place a layer of fine-grained material over a coarse-grained material as shown in Figure 3. The material is placed via a conveyor belt and the material piles up at its angle of repose under the discharge for the belt. There are two conveyors and their discharge points are offset so that the two types of material do not mix. When sufficient cover is obtained, the conveyor is advanced and the process repeated. 2) Utilize a vertical form to construct the barrier shown in Figure 4. The form holds the coarse and fine-grained materials separate until the form is advanced.

- Backfill placement for both concepts is estimated to take about six years to accomplish (Section 7.6) (4.2.2).

A system will need to be developed to monitor installation operations while they are occurring in the emplacement drift. A laser/stereo-vision system could be employed to provide feedback to the operator of the backfill equipment. Stereo-vision units located on either side of the stower conveyor could provide vision and depth perception for the operator. The laser portion of the unit could provide feedback on backfill height and uniformity.

Electrical power for installation operations could be provided by the gantry power conductor located in the emplacement drifts. The emplacement drifts should be inspected, periodically, up to the time installation occurs and thus electrical power should be available in the emplacement drifts.

This placement method is proposed far in advance of when the Richards Barrier will actually occur and thus it is subject to change due to technological advances. Installation operations could take place during the present time period using existing technology and methods (4.2.1). Therefore, the risk of not being able to perform installation operations is low. However, a Richards Barrier installation will make recovery of the waste packages more difficult as the barrier would have to be removed to recover the waste packages. Therefore, installation of a Richards Barrier should not occur while recovery of the waste packages is still desired.

7.5 Emplacement Drift Conditions Affecting Richards Barrier Installation

There are several emplacement drift conditions that could affect the Richards Barrier or installation operations. When the barrier is emplaced, heat and dust will be the main problems. After the installation operations are complete; heat, groundwater, relative humidity, and rockfalls in the emplacement drifts could affect the barrier. Each of these items is discussed below.

Prior to installation operations, the emplacement drifts will need to be cooled to at least 50°C (4.2.7) so that equipment can operate very specialized electronic control and power systems. The placement of the barrier will create dust and the dust will need to be controlled for health and safety reasons.

The ventilation system will be used to keep the emplacement drifts at or below 50°C (4.2.7). This temperature moderation will be accomplished by blowing air through the drifts. During Richards Barrier installation the cross sectional area of the drift will decrease and consequently the velocity of the air will increase across the top of the barrier. If the material size is small (i.e., sand) it could be moved out of position by the ventilation air. Ventilation air can mobilize any dust that is generated during installation operations. This dust will be blown down the drift and could pose a health and safety problem to workers down the air stream from the installation operation.

Using a washed material for the barrier could reduce these problems. The washing process removes the fine material that could become airborne and generate dust. A gravel-sized material could remove the possibility of ventilation air moving the material out of position. Dust that is generated as a result of the installation operation could be diverted into a separate return air stream for removal from the repository.

After placement of the barrier and reduction of airflow, the waste package temperature will increase. The increase in temperature will be due to the insulating effects of the barrier. Moisture within the barrier will be boiled out of the material because of the high temperatures within the drift. This moisture will increase the relative humidity within the emplacement drift unless ventilation air is used to remove the moisture from the drift.

The temperature will slowly decline over thousands of years until ambient rock temperatures are reached (4.3.1). When the average drift temperature goes below approximately 100°C, groundwater will be able to percolate through the emplacement drifts. Groundwater can corrode the waste packages and carry dissolved minerals. Precipitation of the minerals could damage or destroy the interface between the coarse and fine materials of the Richards Barrier.

The Richards Barrier can protect the waste package by providing a cushion. A barrier depth of 1.0m could attenuate the force felt by a waste package from a rock fall by 75% (Attachment II).
The Richards Barrier provides radiation protection for workers as shown in Attachment III. This attachment shows the depth of backfill that will produce certain radiation

exposures, over time. The 1.0m depth of backfill proposed in this evaluation would produce less than 10 mrem per hour after 100 years at the backfill surface. This information is provided in the event workers need to enter the emplacement drift after backfill but prior to final closure. Steps should be taken to avoid disturbance of the backfill to prevent higher radiation exposures than those estimated in Attachment IV.

7.5.1 Evaluation of the Feature Relative to the VA Reference Design

A numerical evaluation of the different aspects of the feature is contained in Attachment V. The averages of the numerical evaluations are summarized in Section 7.5.2.

The Richards Barrier is a post-closure feature and does not affect the pre-closure VA reference design environment, including throughput capacity, reliability, maintainability, and inspectability of manufactured and constructed items. However, during closure there is the possibility of an accident between a piece of backfill equipment and a waste package, but it is unlikely to breach the waste package. No new design basis events (DBEs) are introduced by this design feature (DF).

The Richards Barrier feature is simple in concept and therefore its design elements should be clearly communicated and its post-closure function easy to demonstrate. The feature supports two of the four elements of the repository safety strategy (limited water contacting waste packages and low rate of release of radionuclides from breached waste packages).

There are acceptable engineering methods to analyze the feature, such as computer modeling and full-scale testing. There is both engineering and regulatory precedence for the feature. There are no specific mining or nuclear industry regulations for the use of Richards Barrier and there is no regulatory precedence for placing a Richards Barrier in a nuclear waste repository. However, Richards Barriers have been used on environmental projects. Environmental projects are generally approved by a state or federal agency. There is engineering precedence in the design of dams for the construction of the Richards Barrier as shown in Attachment IV.

The design and construction of the feature uses proven methods. The construction and material handling problems are, for the most part, not unique. There will be unique equipment associated with the construction, its ability to perform under the conditions likely to be present in the emplacement drifts will need to be demonstrated. On-going tests for EBS performance should supply qualified data for the design of this feature.

No high-level design goals for the Mined Geologic Repository (MGR) are violated if backfilling occurs after 150 years. If backfilling occurs prior to 150 years, then thermal goals could be violated. Continuous pre-closure ventilation, post-closure ventilation, backfill with a high thermal conductivity, and aging of the waste are ways to reduce the drift temperature. These methods of temperature reduction are the subject of other features reports and are thus outside the scope of this evaluation. The placement of a Richards Barrier will restrict the ability to remove waste packages at some future time.

The filling of the emplacement drifts will also restrict the collection of certain types of performance confirmation data prior to closure. No performance confirmation activities are planned to occur after closure.

The effective lifetime of the feature is not available. However, a Richards Barrier will be difficult to disturb once it is placed, and if disturbed should still be able to perform most of its function.

The material placed over the waste package should decrease the amount of radiation workers are expected to receive, as shown in Attachment III. Installation of backfill will increase the exposure of workers to industrial accidents. These two safety aspects should counterbalance each other.

The feature will affect the environment. These affects are discussed in Attachment V but not discussed in the body of this report as there are no criteria for their evaluation.

7.5.2 Summary of Criteria for Backfill Feature

The evaluation criteria from Section 4.2.6 are summarized in this section. A more complete discussion is provided in Attachment V.

The Richards Barrier Design Feature (DF) should perform as well as the VA reference design following post-closure. The feature does not have any impact on pre-closure performance as backfill is a post-closure activity, but it may have effects during closure. During closure there is the possibility of an accident between a piece of equipment and a waste package, but it is unlikely to breach the waste package. No new Design Basis Events (DBEs) are introduced by this DF. The following tables summarize the Assurance of Safety (Table 1), Engineering Acceptance (Table 2), and Construction, Operations, and Maintenance (Table 3)

Table 1. Summary of Assurance of Safety Evaluation

Criteria	Rating (1-5)
Does your DF have uncertainties in post-closure performance?	4
What is the potential to reduce the uncertainties by the time of construction and of closure?	4
Overall assessment	4

Table 2. Summary of Engineering Acceptance Evaluation

Criteria	Rating (1-5)
Can the function of each element in the design be clearly communicated?	4
Which of the four elements of the repository safety strategy does it support?	4
Does the engineering analysis follow accepted methods?	3
Is the post-closure function simple to demonstrate?	4
Is there regulatory and/or engineering precedence for your design?	4
What is the availability of qualified data to support your design likely to be in the LA time frame?	4
Is the design constructable with proven methods?	4
Are any high-level design goals for the MGR (such as the Controlled Design Assumptions (CDA)) violated by the use of this design?	5
What is the effective lifetime of the feature or major component of the alternative in supporting the particular element of the repository safety strategy?	4
Overall assessment	4

Table 3. Summary of Construction, Operations, and Maintenance Evaluation

Criteria	Rating (1-5)
Would your DF increase or decrease worker radiation safety and/or industrial safety?	3
Would this DF increase or decrease reliability, availability, maintainability, and inspectability of manufactured and constructed items?	N/A
Would this DF increase or decrease throughput capability?	N/A
Would this DF improve or decrease the ability to perform performance confirmation activities?	3
Overall assessment	3

The schedule and cost criteria are judged to be below that of the VA reference design, because cost and time are added to the VA reference design to accomplish backfill.

The environmental considerations were developed for review by the environmental impacts statement contractor, and were not subject to numerical markup by LADS. However, environmental considerations are discussed further in Attachment V.

7.5.3 Confidence Assessment

The following assessment has been made for this design feature. The same information can be found in Attachment V.

7.5.3.1 Post-Closure Performance (LDE)

Moderately low (D) level of confidence. There is uncertainty in the effective lifetime of the barrier, thus pre-selected failure times (e.g., 2K, 8K, etc.) are used in Performance Assessment (PA) models. These times are essentially just assumptions without much basis.

7.5.3.2 Post-Closure Performance (PA Analyst)

Low (E) level of confidence. No model is available for the lifetime of the barrier, however a sensitivity case has been run. It is not known how effective seepage diversion would be and how long diversion would last.

7.5.3.3 Pre-Closure Performance

Not applicable to this design feature.

7.5.3.4 Assurance of Safety

Moderate (C) level of confidence. Tests and studies currently planned and underway will provide information valuable for defining uncertainties.

7.5.3.5 Engineering Acceptance

Moderately high (B) level of confidence. There are engineering analogs that, while not quite analogous, provide useful data. Laboratory data are also available, although the scale-up will be difficult. The lifetime of the system is also uncertain.

7.5.3.6 Construction, Operation, and Maintenance

Moderately high (B) level of confidence. This feature can be designed to be safe. It is likely that prototypes and additional testing will be needed.

7.5.3.7 Schedule

Moderately (C) level of confidence. There are uncertainties in the machinery to be used and construction efficiency.

7.5.3.8 Cost

Moderately (C) level of confidence. There are uncertainties in design and construction.

7.6 Cost Assessment

The estimated cost (Attachment VI) of the Richards Barrier depends upon the configuration of the barrier. An inverted "Vee" configuration similar to Figure 3 will cost about $560 million (in 1999 dollars) and a "Horseshoe" configuration similar to Figure 4 will cost about $640 million (in 1999 dollars). These costs are both total and lifecycle costs as the repository will be closed soon after the Richards Barrier is installed. Therefore, no additional lifecycle costs will be incurred beyond the initial cost to install the barrier. A summary of these costs is presented in Table 4. The costs are predicated on filling 115 emplacement drifts with 1.7 million m^3 of material (4.3.14). The total number of repository emplacement areas could be 120 drifts. Allowing 5 drifts for observation or spares leaves 115 drifts. The installation of a barrier like Figure 3 will take about 5.6 years, and like Figure 4 will take about 6.5 years (4.3.16)

Table 4. Richards Barrier Emplacement Costs

	Millions (1999 $)	
Cost Item	**Inverted Vee**	**Horseshoe**
Labor	150.7	175.8
Supplies	77.7	91.1
Material	63.3	65.3
Capital (Equipment)	31.6	39.4
Subcontracts	1.9	2.0
Subtotal Direct Cost	325.2	373.6
General Expenses	53.3	60.8
Arch/ Engineer	36.5	41.8
Construction Management	36.5	41.8
Fee	33.7	38.7
Contingency	74.1	84.9
Subtotal Indirect Cost	234.1	268.0
Total Cost	559.3	641.6

7.7 Depleted Uranium as a Richards Barrier Material

Depleted uranium (DU) aggregate is being considered as one of the possible materials used in this feature due to the large quantity of DU held by the DOE. Using this material, as backfill, would be a way to aid the disposal of excess depleted uranium.

Depleted uranium is a radioactive material that emits alpha radiation. It can exist at ambient conditions in various chemical compounds that have the form of a solid, liquid, or gas. If DU is in a solid form, it may be a metal or an oxide. In a liquid form, it would be in an aqueous solution. As a gas, it may be uranium hexafluoride (UF6). In order to be a viable material for this feature, depleted uranium will need to be converted to a solid state, preferably as a uranium oxide. Once it is in the form of a solid powder, it will most likely be bound together to form depleted uranium aggregate (DUAGG) pellets. The transformation of depleted uranium to DUAGG will occur at the site from where the material originates. Originating sites include Oak Ridge, Tennessee, Paducah, Kentucky, Portsmouth, Ohio, and Savannah River, South Carolina. It could be transported by truck or rail in 55-gallon drums.

If depleted uranium aggregate is used for a material in the Richards Barrier, it will most likely be the coarse sized bottom layer. In order to incorporate depleted uranium aggregate with the Richards Barrier feature, there may need to be some changes. These changes may include changing the placement method and the DUAGG material size. The density of DUAGG is 8gm/cm^3 (4.1.2), which is about four or five times the density of sand or gravel. The waste packages may be damaged upon the placement of DUAGG due to the difference in density. This may encourage an alteration in the method of placement. Another change in the design may include a modification of the material size. In order for the Richards Barrier to work, the proper material sizes are necessary. The DUAGG may be too large to use as the fine material. It may not create the necessary capillary barrier to protect the waste package from water. Therefore, a different size DUAGG may need to be produced.

There are benefits and drawbacks for using depleted uranium in the repository as the backfill material. Using depleted uranium as the backfill material has one large advantage; it partially eliminates the problem with disposal of depleted uranium. This is a national problem and a problem for the Department of Energy.

There are three possible disadvantages for using depleted uranium as backfill material. One is that the uranium will be soluble. Uranium may then travel with the groundwater to the accessible environment. Another possible disadvantage is that depleted uranium will increase the amount of radon gas underground and that the radon will escape into the atmosphere through ventilation discharge shafts and/or ramps. A third disadvantage is that depleted uranium is a carcinogenic material. Workers will be required to wear personal protective equipment when placing the material to avoid body contact and inhalation from dust. Cost could also be a disadvantage, but it has not bee determined who will pay for the conversion of depleted uranium to DUAGG and transportation to Yucca Mountain.

8. CONCLUSIONS

A Richards Barrier could be installed in the repository as part of the enhancements to the VA reference design. This feature would reduce the amount of water that could contact the waste packages stored in the repository. Water is one of the primary factors in waste package corrosion as discussed in Section 7.1.

Precipitation at the ground surface will travel downward past the emplacement drifts at the repository level to the groundwater table. As shown in the *Near-Field/Altered-Zone Models Report* (Hardin et al., pg 3-47), if the flux is small the groundwater will be diverted through the rock around the emplacement drifts. During higher flux conditions, water could seep into the drifts and drip onto the waste packages in the emplacement drifts. A Richards Barrier could divert the seepage around the waste packages, whereupon the flow would continue towards the groundwater table.

The Richards Barrier will not prevent water from contacting the waste package, but will limit the amount of water to a small flow. The waste package will eventually corrode and possibly release radionuclides into the environment. As shown in Attachment I, the expected dose-rate with the Richards Barrier at 20km from the repository is initially much less than the VA reference design. However, at some point the barrier will fail. After this failure, the dose-rate will increase and eventually approach the VA reference design dose-rate.

The Richards Barrier could fail if the difference in capillary properties, or the interface between the coarse and fine barrier materials, is disturbed. Degradation could be caused by seismic events or by precipitation of minerals from groundwater. Currently there is little or no available information on how long the Richards Barrier would last in a Yucca Mountain repository.

If the Richards Barrier is installed it will act as a thermal insulator and thus increase the temperature of the waste package. Based on calculations used in this report, the barrier should not be installed prior than 150 years after emplacement, in order to keep the waste package cladding temperature below 350°C (4.2.8). However, the Richards Barrier feature could be combined with other design features, such as pre-closure ventilation, backfill with a high thermal conductivity, or aging to reduce the pre-closure period.

The Richards Barrier could be installed with technology available today. However, a Richards Barrier should not be installed if recovery of the waste packages is contemplated. Two possible designs for the Richards Barrier are proposed in this report. Both designs should work but testing will be required to determine the better of the two designs.

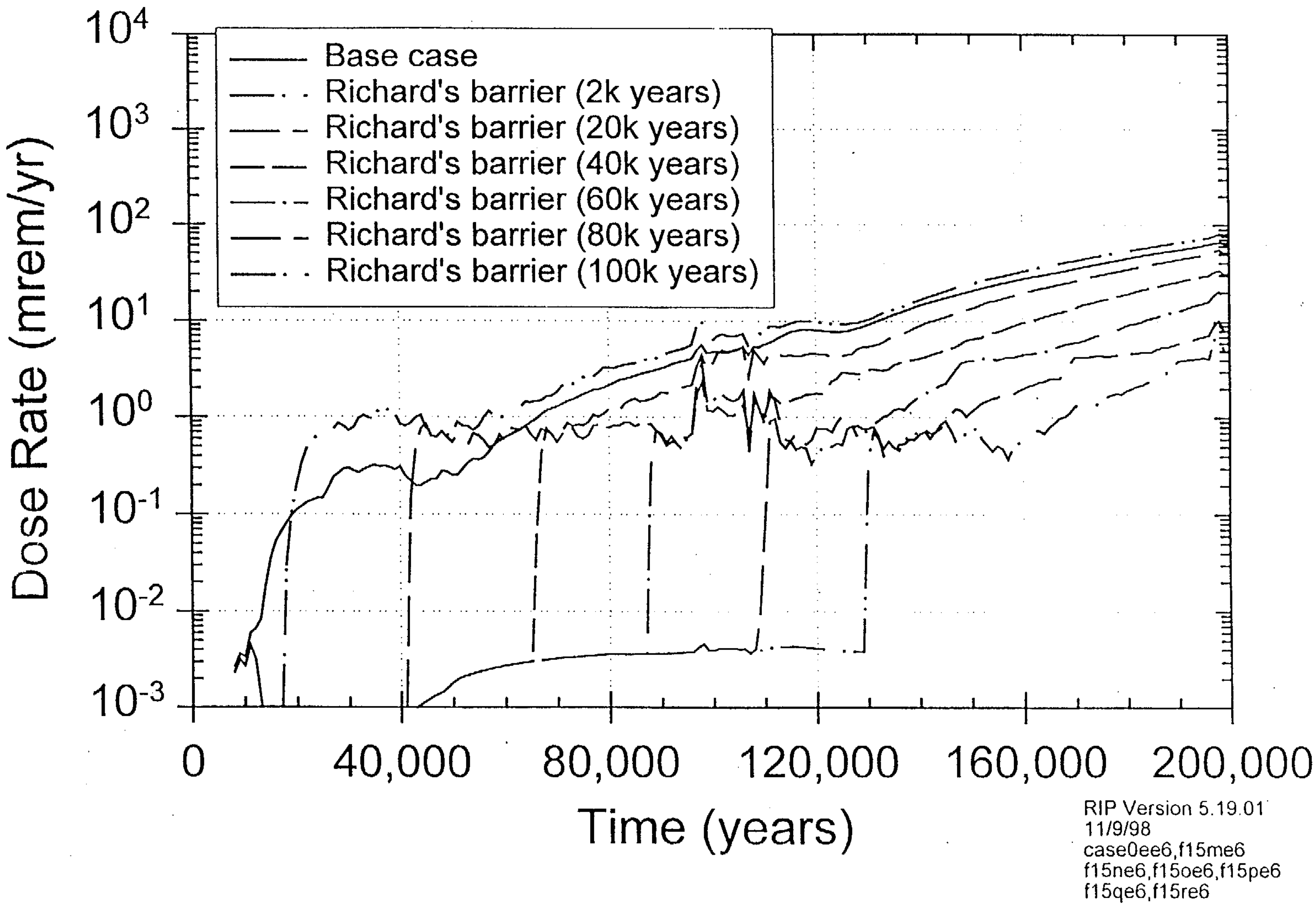
The estimated cost of the Richards Barrier is about $600 million (in 1999 dollars) and will require about 6 years to install. Possible materials to be used for the barrier include sand and gravel. Crushed tuff or depleted uranium could be used for the gravel-sized material.

9. ATTACHMENTS

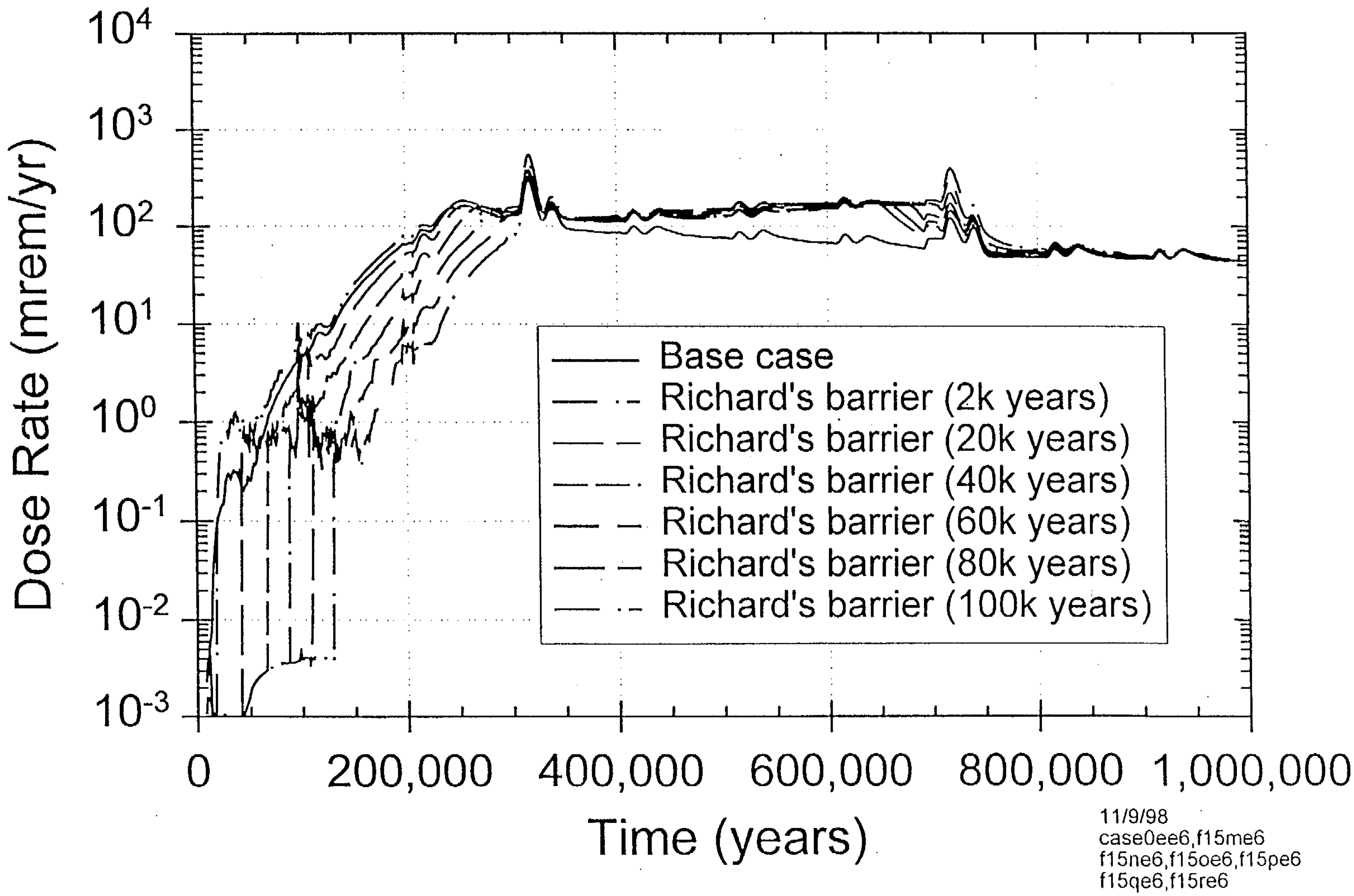
There are six (6) attachments to this document.

Attachment I:	Dose-Rate History Over Time	(2 pages)
Attachment II:	Impact Pressures from Rockfall	(3 pages)
Attachment III:	Estimates of Backfill Shielding Requirements	(1 page)
Attachment IV:	Design Guidelines for Richards Barrier	(1 page)
Attachment V:	Evaluation Criteria for Design Feature #15: Richards Barrier	(13 pages)
Attachment VI:	LADS Cost Estimate	(3 pages)

Feature 15
200,000-yr Total Dose-Rate History
All Pathways, 20 km



Feature 15
1,000,000-yr Total Dose-Rate History
All Pathways, 20 km



Impact Pressures from Rockfall

Purpose of this calculation is to determine the approximate relative difference between impact pressure from a falling rock striking the Waste Package (WP) and a falling rock striking the top of backfill materials placed over the WP to a depth of "h" meters.

Section 4.3.2 shows the rockfall that the WP be designed to withstand is a 25 MT rock within the TSw2 unit.

Average density for TSw2 is 2274 kg/m³, Section ~~4.1.3~~ 4.3.6 NEK 11/19/98

Cubic size of 25 MT rock:

$$\frac{25000\ kg}{2274\ kg/m^3} = 10.99\ m^3 \quad or \quad 2.2\ m/side$$

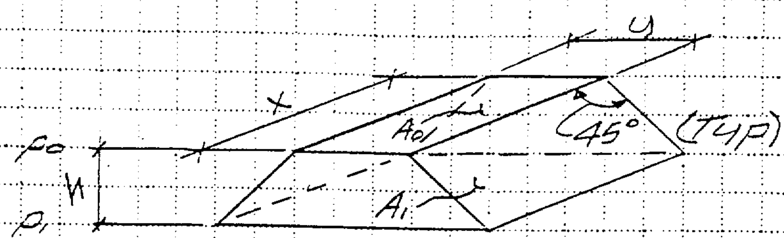
Use impact area of 2m x 2m

For depth of backfill (h) use 1.0m & 0.6m. (4.3.15)

For this purpose the pressure from the rock striking the top of backfill (p_o) will be distributed to a parallel plane above and tangent to the top of the WP at a depth (h) from the top of backfill providing a distributed [illegible] (p_1).

Distribution of pressure p_o through the granular backfill will be at an angle of 45° for this analysis.

Impact Pressures from Rockfall



$A_0 = xy$

$A_1 = (x+2h)(y+2h)$

$p_0 > p_1$ pressure over Area A_0 & A_1

Change in pressure Δ_p is directly related to:

$$\Delta_p = \frac{A_0}{A_1} = \frac{xy}{(x+2h)(y+2h)}$$

For h = 1.0 m:

$$\Delta_p = \frac{xy}{(x+2)(y+2)}$$ & If: x = y = 2 m

$\Delta_{p_1} = 0.25$

For h = 0.6 m:

$$\Delta_p = \frac{xy}{(x+1.2)(y+1.2)}$$ & If: x = y = 2.0 m

$\Delta_{p_3} = 0.39$

Impact Pressures from Rockfall

Summary:

For $h = 1.0\,m$ of backfill above WP, pressure on WP will be:

For a $2.0 \times 2.0\,m$ impact surface on top of backfill - 25% of surface pressure

For $h = 0.6\,m$ (as above)

- 39% of surface pressure

Attachment III

Estimates of Backfill Shielding Requirements (4.3.13)

Assumptions for this table contained in CRWMS M&O 1998h.

Notes: 1) Dose rates are at the backfill surface.

2) LA & VA WP designs are only one of several under consideration. The reference contains more details.

3) Waste Package is 21 PWR size.

Target Dose Rate	Backfill Shielding Thickness above Waste Package[a] (mm)			
	Design Basis Fuel[b]		Average Spent Nuclear Fuel[c]	
	T[d] = 100 yr	T = 300 yr	T = 100 yr	T = 300 yr
VA WP Design[e]				
100 mrem/hr	200	0	150	0
50 mrem/hr	270	40	220	0
10 mrem/hr	460	250	390	190
LA WP Design[f]				
100 mrem/hr	470	120	420	70
50 mrem/hr	540	200	480	140
10 mrem/hr	690	390	630	330

[a] Tsw2 swell factor = 75%

[b] Design basis fuel at time of emplacement: 4.2% enrichment, 48086 MWd/MTU burnup, and 10 years decay after reactor discharge.

[c] Average SNF at time of emplacement: 3.69% enrichment, 39560 MWd/MTU burnup, and 26 years decay after reactor discharge.

[d] T = backfill time (time after waste emplacement), years.

[e] VA WP design: 20 mm C-22 inner barrier and 100 mm A516 outer barrier.

[f] LA WP design:* 20 mm Ti inner barrier and 40 mm C-22 outer barrier.

*Assumed WP design for LA.

Attachment IV
Design Guidelines for Richards Barrier

The work that has been accomplished to date on the Richards Barrier has indicated that the barrier will be composed of sand & gravel. However, no specific requirements have been proposed for the sand and gravel. The relative sizes of these materials are important to ensure that groundwater flow does not carry the finer material into the coarser material. The book Design of Small Dams (Bureau of Reclamation 1974) contains information about design of filters as this is an important aspect of dam construction. On page 235 the following guidelines are presented:

1) $\frac{D_{15} \text{ of the filter}}{D_{15} \text{ of the base material}}$ = 5 to 40, provided that the filter does not contain more than 5% of material finer than 0.074mm (No. 200 sieve).

2) $\frac{D_{15} \text{ of the filter}}{D_{85} \text{ of the base material}}$ = 5 or less

3) The grain-size curve of the filter should be roughly parallel to that of the base material.

Notes:

a) The "filter" will be the gravel material and the sand will be the "base material" for these formulas.
b) The "D" in the formulas above refers to a particular point on the gradation curve for the material. The D_{15} refers to the size on the gradation curve at which 15% of the material passes through the sieves.

Although the Richards Barrier is not a dam, it is somewhat analogous to a sand filter for a dam. The sand filter for the dam is a layer placed between the impervious core and the rock exterior to ensure that fine material from the core does not migrate and plug the voids in the rock exterior. The Richards Barrier will also operate under unsaturated conditions and low flows, as opposed to a sand filter that operates under saturated conditions and high flows. This design may therefore not be appropriate for the Richards Barrier but no other information is available to guide this aspect of the design. Additional testing will need to be conducted to determine the material characteristics of the Richards Barrier.

Attachment V
Evaluation Criteria for Design Feature #15: Richards Barrier

The following questions are intended to solicit information for the design features. This information is a subset of the overall evaluation criteria, which will be used for subsequent evaluation of the Enhanced Design Alternatives (EDA).

1. Post-Closure Performance

- What is the peak dose rate to an average individual of a critical group at a distance of 20 km from the repository site and the time of peak, considering two time periods:
  a) less than 10,000 years;
  b) between 10,000 years and 1,000,000 years?
  c) An evaluation of a figure of merit of the integrated dose should be included in the evaluation. This evaluation is given by the equation:

$$\text{Timing FOM} = 1/(\ln 10^6 - \ln 10^3) \int_{1000}^{1My} \dot{D}(t)\frac{dt}{t}$$

  Note: This information should be based on a single realization (central value) calculation, in most cases.

- If the potential for juvenile failure exists, include the discussion of results using the juvenile failure scenario.

Scale – Quantitative estimates of expected peak dose and FOM in mrem/yr.

Summary – No numerical rating scheme has been developed for this criteria.

Evaluation of Post-Closure Performance:

- Peak dose rate to an average individual of a critical group at a distance of 20 km from the repository site and the time of the peak:

a) less than 10,000 years.

As per Attachment I, the peak dose rate for less than 10,000 years is 0.012 mrem per year or less. This result is also included in Section 7.1.1.

b) between 10,000 and 1,000,000 years.

As per Attachment I, the peak dose between 10,000 years and 1,000,000 years is over 500 mrem/year and occurs at about the 317,000 year mark. This is similar to the base case curve. This result is also included in Section 7.1.1.

c) Evaluation of a figure of merit.

A figure of merit (FOM) has been accomplished by the Performance Assessment organization using the formula mentioned above. The FOM ranges from 32.31 mrem/year for a Richards Barrier failure at 2,000 years to 24.11 mrem/year for a Richards Barrier failure at 100,000 years. These figures are also mentioned in Section 7.1.1 of the evaluation.

- Potential for juvenile failure.

The potential for juvenile failure should be no more than the base case and may even be less. The Richards Barrier will protect waste packages against rockfalls and thus this component of the juvenile failure scenario will be decreased. Section 7.1.1 discussed juvenile failures.

2. Pre-Closure Performance

What is your assessment of the pre-closure performance of your DF on 1 1-5 scale? Please provide a 1-5 assessment of each question using this scale and a brief (one-to-two sentence) written basis for the evaluation. The overall evaluation should be the simple average of the assessments for each question.

- Would your DF increase or decrease the probability of a Design Basis Event (DBE)?
- Would your DF add a DBE? Is the DBE bounded by other DBEs?
- Would your DF increase or decrease the consequences of a DBE?
- Does your DF increase or decrease challenges to the repository safety systems?

Scale – Range from 1 to 5. A "1" would indicate that there are significant disadvantages in accommodating DBEs relative to the VA Reference Design; a "2" would indicate that there are moderate disadvantages in accommodating DBEs relative to the VA Reference Design; a "3" would indicate that the DBEs are accommodated comparably to the VA Reference Design; a "4" would indicate that there are moderate advantages in accommodating DBEs relative to the VA Reference Design; and a "5" would indicate that the DF has significant advantages in accommodating DBEs relative to the VA Reference Design.

- What expected dose to the public at the pre-closure area boundary is calculated?

Scale - Quantitative estimates of expected peak dose in mrem/year.

Summary – The Richards Barrier is a closure/ post-closure feature and thus all pre-closure performance evaluation criteria are not applicable. During closure there is a possibility of an accident between a piece of backfill equipment and a waste package, but it is unlikely to breach the waste package. No new DBEs are introduced by this design feature. This conclusion is also mentioned in Section 7.5.2.

3. Assurance of Safety

What is your assessment of the assurance of safety of your DF on a 1-5 scale. Please provide a 1-5 assessment of each question using this scale and a brief (one-to-two sentence) written basis for the evaluation. The overall evaluation should be the simple average of the assessments for each question.

- Does your DF have uncertainties in post-closure performance.
- What is the potential to reduce the uncertainties by the time of construction and of closure?

Scale – A "1" would indicate that the design provides a low assurance of safety because there are large and significant uncertainties that are unlikely to be reduced, and/or that the design is particularly sensitive to disruptive events; a "2" would provide a moderately low assurance of safety comparable to the VA Reference Design; a "3" would indicate that there is a reasonable assurance of safety relative to uncertainties and disruptive events comparable to the VA Reference Design; a "4" would indicate a moderately high assurance of safety comparable to the VA Reference Design; and "5" would indicate that the design provides very high assurance of safety comparable to the VA Reference Design, because the uncertainties are low or are likely to be significantly reduced, and/or the design is insensitive to disruptive events.

Summary – The following Table summarizes the results of the evaluation for these criteria:

Table V-1. Summary of Assurance of Safety Evaluation

Criteria	Rating
Does your DF have uncertainties in post-closure performance?	4
What is the potential to reduce the uncertainties by the time of construction and of closure?	4
Overall assessment	4

Evaluation of Assurance of Safety:

- Does your DF have uncertainties in post-closure performance?

The performance of this feature is good overall. However, as shown in Attachment I, there is uncertainty as to how long the feature will last. If the feature stays intact, it will continue to make a significant contribution to reducing the dose rate at the 20 km boundary. The feature performance and specific assumptions for the performance are discussed in Section 7.1.1 of the evaluation.

- What is the potential to reduce the uncertainties by the time of construction and of closure?

The potential for reduction in uncertainty is good, but depends upon the effort made to reduce the uncertainties. On-going EBS performance testing may reduce uncertainties as mentioned in Section 7.1.1 of the evaluation.

4. Engineering Acceptance

What is the potential for acceptance of the engineering design of your DF in a regulatory environment? Please provide a 1-5 assessment of each question using this scale and a brief (one-to-two sentence) written basis for the evaluation. The overall evaluation should be the simple average of the assessments for each question.

- Can the function of each element in the design be clearly communicated?
- Which of the four elements of the repository safety strategy does is support (limited water contacting waste packages, long waste package lifetime, low rate of release of radionuclides from breached waste packages, radionuclide concentration reduction during transport from the waste packages)?
- Does the engineering analysis follow accepted methods?
- Is the post-closure function simple to demonstrate?
- Is there regulatory and/or engineering precedence for your design?
- What is the availability of qualified data to support your design likely to be in the LA time-frame?
- Is the design constructable with proven methods?
- Are any high level design goals for the MGR (such as the CDA) violated by the use of this design?

Scale – 1 to 5, a "1" would indicate that the design has a very low potential for acceptance comparable to the VA Reference Design; a "2" would indicate a moderately low potential for acceptance comparable to the VA Reference Design; a "3" would indicate a moderate potential for acceptance comparable to the VA Reference Design; a "4" would indicate a moderately high potential for acceptance comparable to the VA Reference Design; and a "5" would indicate a very high potential for acceptance comparable to the VA Reference Design.

- If applicable, what is the effective lifetime of the feature or major component of the alternative in supporting the particular element of the repository safety strategy?

Scale – Quantitative estimate of the effective lifetime in years, or expected distribution of lifetime, if available.

Summary – The following Table summarizes the results of the evaluation for these criteria:

Table V-2. Summary of Engineering Acceptance Evaluation

Criteria	Rating
Can the function of each element in the design be clearly communicated?	4
Which of the four elements of the repository safety strategy does it support?	4
Does the engineering analysis follow accepted methods?	3
Is the post-closure function simple to demonstrate?	4
Is there regulatory and/or engineering precedence for your design?	4
What is the availability of qualified data to support your design likely to be in the LA time-frame?	4
Is the design constructable with proven methods?	4
Are any high level design goals for the MGR (such as the CDA) violated by the use of this design?	5
What is the effective lifetime of the feature or major component of the alternative in supporting the particular element of the repository safety strategy?	4
Overall assessment	4

Evaluation of Engineering Acceptance:

- Can the function of each element in the design be clearly communicated?

  Since the design is simple, the function of all elements should be able to be clearly communicated. Possible designs are shown in Figures 3 and 4.

- Which of the four elements of the repository safety strategy does it support?

  This feature limits the amount of water that can contact the waste package and should limit the rate of release of radionuclides from breached waste packages as mentioned in Section 7.5.1 of the evaluation. The feature provides some rockfall protection.

- Does the engineering analysis follow accepted methods?

  Acceptable methods are available to analyze the feature and will be followed as mentioned in Section 7.5.1 of the evaluation.

- Is the post-closure function simple to demonstrate?

  Both the design and function of this feature are simple. Therefore, the post-closure should be simple to demonstrate. On-going EBS testing should help to demonstrate the function. A discussion of the EBS testing program is outside the scope of this evaluation, but EBS testing is mentioned in Section 7.5.1 of the evaluation.

- Is there regulatory and/or engineering precedence for your design?

  There is both regulatory and engineering precedence for this feature. The Richards Barrier has been used on environmental projects (landfills). These projects are generally approved by a state for federal agency. There is engineering precedence in the design of dams for the construction of the Richards Barrier (See Attachment IV). Engineering and regulatory approval is mentioned in Section 7.5.1 of the evaluation.

- What is the availability of qualified data to support your design likely to be in the LA time-frame?

  On going tests for EBS performance should supply qualified data for the design of this feature as mentioned in Section 7.5.1 of the evaluation.

- Is the design constructable with proven methods?

  This design should be constructable. The construction and material handling problems are, for the most part, not unique. There will be unique equipment associated with the construction and its ability to perform under the conditions likely to be present in the emplacement drifts will need to be demonstrated. Construction of the feature is discussed in Section 7.4 of the evaluation.

- Are any high level design goals for the MGR (such as the CDA) violated by the use of this design?

  No high level goals are violated. However, the placement of a Richards Barrier will restrict the ability to remove waste packages at some future time. The filling of the emplacement drifts will also restrict the collection of certain type of performance confirmation data. No performance confirmation activities are planned to occur after closure. Goals are discussed in Section 7.5.1.

- What is the effective lifetime in years, or expected distribution of lifetime, if available?

  The effective lifetime in years is not available. However, baring seismic events that disrupt the interface between the two materials or clogging of the sand or gravel by minerals deposited by groundwater, the feature should last hundreds of thousands of years. Possible affects to backfill by seismic and subsidence effects are discussed in Section 7.3.

5. Construction, Operations, and Maintenance

Are there any particular difficulties or advantages that your DF has relative to the VA Reference Design for the following construction, operations, and maintenance characteristics:

- Would your DF increase or decrease worker radiation safety and/or industrial safety?
- Would this DF increase or decrease reliability, availability, maintainability, and inspectability of manufactured and constructed items?

- Would this DF increase or decrease throughput capacity?
- Would this DF improve or decrease the ability to perform performance confirmation activities?

Scale – 1 to 5, a "1" would indicate that the design has significant disadvantages or difficulties in construction, operations, and maintenance issues comparable to the VA Reference Design; a "2" would indicate moderate disadvantage or difficulties in construction, operations, and maintenance issues comparable to the VA Reference Design; a "3" would indicate that the construction, operations, and maintenance issues are comparable to those of the VA reference Design; a "4" would indicate moderate advantages in construction, operations, and maintenance issues relative to the VA Reference Design; and "5" would indicate that there are significant advantages in construction, operations, and maintenance issues relative to the VA Reference Design.

Summary – The following Table summarizes the results of the evaluation for these criteria:

Table V-3. Summary of Construction, Operations, and Maintenance Evaluation

Criteria	Rating
Would your DF increase or decrease worker radiation safety and/or industrial safety?	3
Would this DF increase or decrease reliability, availability, maintainability, and inspectability of manufactured and constructed items?	N/A
Would this DF increase or decrease throughput capability?	N/A
Would this DF improve or decrease the ability to perform performance confirmation activities?	3
Overall assessment	3

Evaluation of Construction, Operations, and Maintenance:

- Would your DF increase or decrease worker radiation safety and/or industrial safety?

  As shown in Attachment III, material placed over the waste package should decrease the amount of radiation workers are expected to receive. Installation of the Richards Barrier will increase the exposure of workers to industrial accidents. These two safety aspects should counterbalance each other. Radiation protection is mentioned in Section 7.5 and industrial accidents mentioned in Section 7.5.1 of the evaluation.

- Would this DF increase or decrease reliability, availability, maintainability, and inspectability of manufactured and constructed items?

  The Richards Barrier is a closure/post-closure feature and thus does not have operational or maintenance aspects as mentioned in Section 7.5.1 of the evaluation.

- Would this DF increase or decrease throughput capability?

The Richards Barrier is a closure/post-closure feature and thus does not have operational aspects as mentioned in Section 7.5.1 of the evaluation.

- Would this DF improve or decrease the ability to perform performance confirmation activities?

  The ability to conduct performance confirmation activities within the drift would end with the installation of the Richards Barrier. This particular point may be a moot one as the repository will be closed soon after installation of the Richards Barrier. Performance confirmation activities are not scheduled to be performed after closure. A discussion of performance confirmation activities is outside the scope of this evaluation, but performance confirmation is mentioned in Section 7.5.1 of the evaluation.

6. Schedule

For your DF, how does the LA schedule compare to that for the VA reference design?
Scale – Difference in time required for changes to site characterization, design, licensing, and construction relative to the VA Reference Design.

Evaluation of Schedule:

Installation of the Richards Barrier should take about six years to accomplish. This six years should not be added significantly to the schedule, as it is possible to overlap some closure activities with Richards Barrier installation activities. Schedule is discussed in Section 7.6 of the evaluation.

7. Cost

What is the difference in estimated total cost relative to the VA Reference Design? (Conceptual Design Estimating is applicable - ± 50%)

Scale – Cost in 1999 dollars. Costs which occur significantly later than the current schedule for the VA Reference Design should be noted where possible.

Evaluation of Cost:

As per Table 1, the Richards Barrier adds about $600 million to the VA Reference Design. These costs would be incurred at closure. Costs are discussed in Section 7.6 of the evaluation and a cost estimate is provided in Attachment VI. The evaluation of cost is not subject to QARD requirements.

8. Environmental Considerations

What are the environmental considerations associated with your DF relative to the VA Reference Design? (Pending completion of the formal evaluation of the environmental impacts by the EIS Contractor). Details of the environmental considerations are not subject to *QARD* (DOE 1998b) requirements.

Evaluation of Environmental Considerations:

1. Impacts to land use and ownership

Land use - Approximately 1.7 million cubic meters of material will be necessary to include this feature in the repository. Up to 100% of the coarse material could be depleted uranium, if it is chosen as one of the materials. It may be necessary to have four stockpiles and two processing plants, about 2-3 hectares of surface area, for a two months supply of material (4.3.17). No new land will be required because operations for this feature are at the time of closure. Therefore, there will be previously used land that may be vacant at the time of closure and able to be used for construction of this feature.

The stockpile area is calculated as follows:

$1{,}700{,}000\ m^3/\ (6\ \text{yrs*} \times 12\ \text{mo/yr}) \approx 23{,}600\ m^3/\text{mo}$

$23{,}600\ m^3/\text{mo} \times 2\ \text{mo} = 47{,}200\ m^3$

Allowing an average stockpile height of 3m would mean all stockpiles would occupy:

$47{,}200\ m^3\ /\ 3m \approx 15{,}700\ m^2$

Allowing for roads around the stockpiles plus crushing and screening equipment will boost this value to 20,000 to 30,000 m^2 or 2-3 hectares.

Notes: * 6 years is an average value for both types of Richards Barrier.

Land ownership – No impacts.

2. Impacts to air quality

Nonradiological impacts –The ventilation fans underground will be on during the construction phase of Richards Barrier because the drifts will need to be cooler when the Richards Barrier is placed (waste packages are already in the drifts). These fans may cause some of the fine material to be elevated in the drifts causing dusting problems. After the construction of the Richards Barrier is complete and the fans are no longer running, any dusting problems will terminate.

Emissions will only be a concern during the placement phase of the Richards Barrier. Surface emissions will come from the equipment used to transport the material. Some pollution may come from the processing plant but this will be regulated. There will be no underground emissions because the equipment to transport and place the material will be electric.

Radiological impacts – If one of the materials is chosen to be depleted uranium, there will be an increase in the amount of radon. The radon gas may be underground as well as on the surface. The radon may escape through ventilation shafts into the atmosphere and disperse.

3. Impacts to hydrology, including surface water and groundwater

If depleted uranium is used, there may be an increase in the contamination of water because there will be more radioactive material placed underground and this radioactive material may be without the benefit of containerization or other engineering barriers.

4. Impacts to biological resources and soils

This feature will require approximately 2-3 hectares. However, there will be no disturbance in the land because previously used land will now be vacant and employable for the construction phase. There will be no effect on the life patterns of wildlife. The only impact on noise and ground vibration will be for the transportation and implementation of the materials. There will be some impact on subsurface/surface temperatures. There will be a need for outdoor lighting, during the construction phase of the Richards Barrier due to the need to ensure safe transport of the material.

5. Impacts to cultural resources

No additional excavation will be necessary for this feature due to previously used land. The only changes in the noise level are for the construction phase of the Richards Barrier.

6. Socioeconomic impacts

Approximately 320 personnel will be needed for this feature. This figure is calculated as follows (4.3.16):

(3,600,000 mhrs + 4,200,000 mhrs)/ (5.61 yrs + 6.54 yrs) $\approx$ 640,000 mhrs/yr

There are about 2,000 manhours in a year per person:

640,000 mhrs/yr / 2,000 mhrs = 320 people.

7. Impacts to occupational and public health and safety

There will be an increase in the potential for industrial accidents because of the operations needed to implement this feature. Although personnel will not be in the drifts, there still may be some incidental radiation to workers outside the drift doors. Additional shielding may be required for personnel. If depleted uranium is chosen as one of the materials, there may be a need for additional shielding for the workers.

8. Noise impacts

Occupational noise occurs only during the placement of the Richards Barrier at the time of closure.

9. Impacts on aesthetics

Four stockpiles and two processing plants placed on previously used land, about 2-3 hectares of land. Night lighting will be needed for safe transport of the material on the surface.

10. Impacts to utilities, energy, materials, and site services

Approximately 1.7 million cubic meters of Richards Barrier material will be needed. There will be an increase in water use for controlling dust and use in the plant. The electrical power needed for this feature will be approximately 272 million kwh for the high thermal load case. The peak power will be about 7734 kw. The amount of diesel fuel required will be about 2.5 million liters for the high thermal load case. Approximately 3.0 million liters of oil and 100,000 kgs of grease will be necessary to implement this feature. All figures are from the draft of the *Engineering File – Subsurface Repository* CRWMS M&O document BCA000000-01717-5705-00005 Rev 01B pg I-2.

11. Impacts to management of repository generated waste and the use of hazardous materials

Sanitary waste management will be necessary for the implementation of this feature (due to the increase in work force). If depleted uranium is used for this feature, some additional management will be required, such as to control and record dosimeter readings and worker exposure to the radioactive material.

12. Impacts to environmental justice

No impacts.

13. Summary of primary impacts on 3 thermal loads (high, medium, low)

No studies have been done to evaluate this impact. Richards Barrier could be used for all three thermal loads.

14. Summary of primary impacts on packaging options for transportation:

No impacts.

15. Summary of primary short term impacts (including operations, retrieval, and closure)

There are no short-term impacts from the Richards Barrier since it will not be implemented until closure.

16. Summary of primary long term impacts (after closure)

The long-term impacts are that the Richards Barrier may delay the transport of water to the waste packages, therefore delaying the transport of radionuclides and improving waste isolation.

9. Confidence Assessment

The following assessment has been made for this design feature. The information can be found in Section 7.5.3.

The scale of confidence is as follows:

- High level of confidence (A): the assessment is readily supported, defensible, and not subject to uncertainty
- Moderately high (B): the assessment is supportable, reasonably defensible, and only subject to moderate uncertainty
- Moderate (C): the assessment is supportable, reasonably defensible with some possible weaknesses, and subject to moderate levels of uncertainty
- Moderately low (D): the assessment is not well supported, has some weaknesses in terms of defensibility, and subject to uncertainty
- Low (E): the assessment is not well supported, has significant weakness in terms of defensibility, and subject to considerable uncertainty

Note that for each Design Feature (DF), two assessments are made for post-closure performance: one by the lead design engineer (LDE) and another by the performance assessment analyst (PA analyst).

Post-Closure Performance (LDE)

Moderately low (D) level of confidence. There is uncertainty in the effective lifetime of the barrier, thus pre-selected failure times (e.g., 2K, 8K, etc.) are used in PA models. These times are essentially just assumptions without much basis.

Post-Closure Performance (PA Analyst)

Low (E) level of confidence. No model is available for the lifetime of the barrier, however a sensitivity case has been run. It is not known how effective seepage diversion would be and how long diversion would last.

Pre-Closure Performance

Not applicable to this design feature.

Assurance of Safety

Moderate (C) level of confidence. Tests and studies currently planned and underway will provide information valuable for defining uncertainties.

Engineering Acceptance

Moderately high (B) level of confidence. There are engineering analogs that, while not quite analogous, provide useful data. Laboratory data are also available, although the scale-up will be difficult. The lifetime of the system is also uncertain.

Construction, Operation, and Maintenance

Moderately high (B) level of confidence. This feature can be designed to be safe. It is likely that prototypes and additional testing will be needed.

Schedule

Moderately (C) level of confidence. There are uncertainties in the machinery to be used and construction efficiency.

Cost

Moderately (C) level of confidence. There are uncertainties in design and construction.

Attachment VI
LADS Cost Estimate (4.3.16)

Details in this attachment are not subject to Q-requirements (CRWMS M&O 1998a)

RICH/ RD'S BARRIER

Estimate Title: Design Feature 15 - Richard's Barrier
Estimate File Loc: O:\\df15.xls

Date: 11-Feb-99
Estimated By: J. Stieger
Ptoduct Author: Paul Pierce

Line No.	Account Code	Description	Qty	U/M	M/E $/Unit	M/E Total $	Unit Mhrs	Total Mhr	$/Mhr	Total Labor $	Subcontract/ Other $	Grand Total
1												
2		**Richards Barrier Simple Geometry**										
3												
4		Direct Costs										
5		Labor								150,700,000		150,700,000
6		Consumables and Expendables				77,700,000						77,700,000
7		Direct Construction Material				63,300,000						63,300,000
8		Equipment Rental and Purchase				31,600,000						31,600,000
9		* 3% for Surface Equipment and Facilities for backfill material									1,900,000	1,900,000
10												
11		*Subtotal Direct Costs*				172,600,000				150,700,000	1,900,000	325,200,000
12												
13		Indirect Costs										
14												
15		General and Administrative Cost									53,400,000	53,400,000
16		Fee									33,700,000	33,700,000
17												
18		*Subtotal Indirect Costs*									87,100,000	87,100,000
19												
20		**Total Direct and Indirect Costs**				172,600,000				150,700,000	89,000,000	412,300,000
21												
22		Contingency									74,100,000	74,100,000
23												
24		Management and Integration									73,000,000	73,000,000
25												
26		**Total**										559,400,000
27												
28												
29												
30		1999 Escalation Rate										1.023
31		**Grand Total**										572,266,200
32												
33												
34												
35												
36		* Cost Particular to this feature										
37												
38												

df15.xls

RICHARD'S BARRIER

Estimate Title: Design Feature 15 - Richard's Barrier
Estimate File Loc: O:\\df15.xls

Date: 11-Feb-99
Estimated By: J. Stieger
Ptoduct Author Paul Pierce

Line No.	Account Code	Description	Qty	U/M	M/E $/Unit	M/E Total $	Unit Mhrs	Total Mhr	$/Mhr	Total Labor $	Subcontract/ Other $	Grand Total
1												
2	**Richards Barrier Horseshoe Configuration**											
3												
4		<u>Direct Costs</u>										
5		Labor										
6		Consumables and Expendables								175,800,000		175,800,000
7		Direct Construction Material				91,100,000						91,100,000
8		Equipment Rental and Purchase				65,300,000						65,300,000
9		* 3% for Surface Equipment and Facilities for backfill material				39,400,000						39,400,000
10											2,000,000	2,000,000
11		*Subtotal Direct Costs*										
12						195,800,000				175,800,000	2,000,000	373,600,000
13		<u>Indirect Costs</u>										
14												
15		General and Administrative Cost										
16		Fee									60,800,000	60,800,000
17											38,600,000	38,600,000
18		*Subtotal Indirect Costs*										
19											99,400,000	99,400,000
20		**Total Direct and Indirect Costs**										
21						195,800,000				175,800,000	101,400,000	473,000,000
22		Contingency										
23											84,900,000	84,900,000
24		Management and Integration										
25											83,700,000	83,700,000
26		**Total**										
27												641,600,000
28												
29												
30		19[illegible]9 Escalation Rate										
31		**Grand Total**										1.023
32												656,356,800
33												
34												
35												
36		* Cost Particular to this feature										
37												
38												

df15.xls