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**Civilian Radioactive Waste Management System
Management & Operating Contractor**

Design Alternative Evaluation #3: Post-Closure Ventilation

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EXECUTIVE SUMMARY

This design alternative identifies a series of conceptual designs aimed at utilizing ventilation in the emplacement drifts during the post-closure period. The most promising concepts have been selected for evaluation. The expected benefit provided by post-closure ventilation is improved waste package performance. Improved performance can be achieved by limiting the amount of water contacting the waste packages, which reduces corrosion. Ventilation airflow removes moisture seepage from the rock into the drifts away from the waste packages as water vapor.

A team of engineers met to discuss options for post-closure ventilation. The concepts proposed by this team for investigation in this study fall into three categories:

- **Closed Loop:** The closed-loop concept has the main drifts, shafts, and access ramps to the surface sealed at the termination of preclosure ventilation. (Ventilation fans are shutdown). Heat release from the waste packages, temperature differential in the surrounding rock, moisture influx, and geometric configuration drives natural ventilation in a self-sustaining, recirculation-cycle that cools the waste packages and removes moisture from the immediate area surrounding them.
- **Open Loop:** The open-loop concept has the main drifts, shafts, and access ramps to the surface left open at the termination of preclosure ventilation. (Ventilation fans are shutdown). Heat release from the waste packages, temperature differential in the surrounding rock, moisture influx, and elevation difference between cool air inlet and warm air outlet, drives natural ventilation that cools the waste packages and removes moisture to the surface.
- **Closed/Open Loop:** The closed/open-loop concept combines a closed repository and an open-loop concept. Emplacement drifts are located very close to a system of radiator (or cooling) drifts that are open to the atmosphere through which fresh air circulates. Repository main drifts, shafts, and access ramps to the surface are sealed at the termination of preclosure ventilation. (Ventilation fans are shutdown). The radiator drifts are connected by shafts and ramps to the surface, and provide cooling to the rock surrounding the emplacement drifts. Elevation difference between inlet and exhaust, along with heat release from the waste packages, and temperature differential in the surrounding rock drives natural ventilation that cools the waste packages and removes moisture to the surface.

The following concepts are described in this study and one from each category was selected for waste package performance assessment:

Closed-Loop Concepts:

- **The bow-tie.** This uses inclined emplacement drifts looped to a second pair of access mains to recirculate airflow over the waste packages.
- **The triangle.** This uses an extra main and inclined drift to recirculate airflow over the waste packages.
- **The perimeter loop.** This uses a perimeter loop as a heat sink to remove heat and moisture from the emplacement block.

- Vertical emplacement. This uses twin tunnels with waste placed in vertical boreholes between the tunnels.

Open-Loop Concepts:

- Modified VA design. This is essentially the VA reference design with additional shafts and drifts to promote natural ventilation airflow over the waste packages.
- Bow-tie. The same bow-tie used in the closed loop with open ramps, shafts and drifts to promote natural ventilation airflow.
- Intakes below the horizon. This uses cooling air introduced from underneath the emplacement block to promote airflow up through the mountain.
- Beehive. This multi-layer repository promotes airflow from a perimeter spiral access drift through the centrally located repository.
- Surface fans. This uses the preclosure ventilation fans to provide for post-closure ventilation.
- Wind power. This uses available wind to force air through the intake shafts/ramps for increased cooling airflow.
- Pyramid. This uses exhaust shafts extended above the surface to increase the thermal head available for natural ventilation airflow.
- French drain. This uses graded backfill to promote airflow through the emplacement drifts.
- Perimeter loop. This uses a perimeter drift as a heat sink to promote airflow over the waste packages.
- Individual raises. This uses individual raises at each emplacement drift to promote airflow through the drift.

Closed/Open-Loop Concepts:

- Radiator. This uses a network of naturally ventilated cooling drifts, separate from the repository, to provide for heat and moisture removal from the emplacement drifts.

The bow-tie (closed-loop) and the modified VA design (open-loop) concepts were selected for evaluation and performance assessment simulations. Both the bow-tie and the modified VA design concepts were evaluated using available computer simulations to predict natural ventilation airflow through the emplacement drifts and temperature and humidity conditions at the waste packages. The results from these simulations were then input to the performance assessment simulations for calculation of annual dose rates over time.

The evaluation of the radiator concept was not carried forward. Although the radiator concept appears at first glance to be a simple combination of the closed and open loop designs it is significantly different from both. Placing the cooling drifts parallel to and in-between, the emplacement drifts may improve waste package performance. However, computer simulations for this configuration have not been modeled. Locating the cooling drift midway between the emplacement drifts, in the rock pillar, should provide condensate drainage thus preventing water return to the emplacement drifts. Further study to optimize the layout and to simulate the thermal hydrologic performance of this concept appears to have merit, should the concept of post-closure ventilation be pursued as a portion of the conceptual design selected to be carried forward to the Site Recommendation.

In general, a naturally ventilated repository will be drier than a non-ventilated one for the time the ventilation continues to function. The open-loop modified VA design that continuously removes repository moisture and heat to the atmosphere provides better waste package performance than the bow-tie which removes moisture from the immediate waste package environment. One of the uncertainties is how to predict the long-term impact of rockfall and natural events, such as seismic and climatic changes. The long-term performance of a naturally ventilated repository is totally dependent on the airways remaining open. However, if the natural ventilation stops at some future time, probably well in excess of 10,000 years (see Appendix D for rockfall calculations), the repository would revert to the "closed" conditions similar to the VA Reference Design.

The post-closure performance for this design alternative as compared to the VA Reference Design is as follows:

Table 1. Summary of Peak Dose Rate

Design Alternative	Description	Figure of Merit	Peak Dose within 10,000 years		Peak Dose within 1,000,000 years	
			Peak Annual Dose (mrem/y)	Time to Peak Dose (years)	Peak Annual Dose (mrem/y)	Time to Peak Dose (years)
Base Case	VA Design	25.02	0.0422	10,000	300.9	317,000
Alternative #3 Closed Loop	Bow-Tie	27.63	0.01388	5,600	290.3	317,000
Alternative #3 Open Loop	Modified VA	24.92	0.007906	5,600	268.9	316,000
Alternative #3 Closed/Open Loop	Radiator	Not Evaluated	Not Evaluated	Not Evaluated	Not Evaluated	Not Evaluated

For the 10,000-year cases, dose rates are below the base case results for the first 5,600 years and are driven by the release of radionuclides from the juvenile failure package as shown in Figure 9. The open-loop configuration results are lower than the base case and bow-tie results since there is no advective release from the juvenile failure package. After the juvenile failure, the dose rates for both ventilation cases decrease since no other packages fail during the first 10,000 years.

For the 1,000,000-year result, there is little difference between the base case and the post-closure ventilation cases as shown in Figure 10. The post-closure natural ventilation model lasts for only 10,000 years for the modified VA configuration and 5,000 years for the bow-tie configuration. After this, the model assumes that the natural ventilation stops and the system reverts to closed conditions. The short duration of the ventilation model has little impact on dose rate over the course of 1,000,000 years.

The final task was to evaluate each of the design alternative concepts in terms of the LADS criteria. The results of this evaluation are summarized below:

Bow-Tie Concept (Closed Loop):

1. Post-Closure Performance – Confidence: Design = C, PA = E

The peak dose within 10,000 years is 0.01388 mrem/year and is 290.3 mrem/year between 10,000 to 1,000,000 years. The Figure of Merit (FOM) is 27.63 for this concept.

2. Preclosure Performance – Scale = 3, Confidence = A

This concept accommodates DBEs comparably to the VA Reference Design.

3. Assurance of Safety – Scale = 2, Confidence = C

The assurance of safety for this concept is moderately low relative to the VA Reference Design. The lower rating is because there is more uncertainty in post-closure performance.

4. Engineering Acceptance – Scale = 2.7, Confidence = C+

This concept has a moderately low to moderate potential for acceptance compared to the VA Reference Design. The lower rating is because of design goal violations and uncertainty with the effective lifetime of the alternative. The effective lifetime of the concept is 2,050,000 years, based on the rockfall calculation.

5. Construction, Operations, and Maintenance – Scale = 2.8, Confidence = B

Construction, operations and maintenance issues have moderate disadvantages compared to the VA Reference Design. The slightly lower rating is because there is an increased risk of industrial accident due to additional construction activities.

6. Schedule – Confidence = C

The schedule for the bow-tie for design and licensing is a little longer than the VA Reference Design. A minimally longer design time is anticipated due to the revised bow-tie layout. Additional time to license this layout was also anticipated. This concept would take an estimated 28 years to complete.

7. Cost – Confidence = B

The cost for the bow-tie is \$575 million greater than the VA Reference Design. The greater cost is the capital cost to construct additional mains, ramps and raises.

8. Environmental Considerations – Confidence = Not Rated

Environmental considerations are discussed in Appendix C.

Modified VA Concept (Open Loop):

1. Post-Closure Performance – Confidence: Design = C, PA = E

The peak dose within 10,000 years is 0.007906 mrem/year and is 268.9 mrem/year between 10,000 to 1,000,000 years. The FOM is 24.92 for this concept.

2. Preclosure Performance – Scale = 3, Confidence = A

This concept accommodates DBEs comparably to the VA Reference Design.

3. Assurance of Safety – Scale = 2, Confidence = C

The assurance of safety for these alternatives is moderately low relative to the VA Reference Design. The lower rating is because there is more uncertainty in post-closure performance.

4. Engineering Acceptance – Scale = 2.7, Confidence = A

This concept has a moderately low potential for acceptance compared to the VA Reference Design. The slightly lower rating is because of design goals violations and uncertainty with the effective lifetime. The effective lifetime of the concept is 175,000 years, based on the rockfall calculation.

5. Construction, Operations, and Maintenance – Scale = 2.8, Confidence = B

Construction, operations and maintenance issues have moderate disadvantages compared to the VA Reference Design. The slightly lower rating is because there is an increased risk of industrial accident due to additional construction activities.

6. Schedule – Confidence = C

The schedule for the modified VA concept for licensing is longer than the VA Reference Design. The longer time is because the open loop concept is a major departure from the VA Reference Design and additional licensing time is anticipated. This concept would take an estimated 27 years to complete.

7. Cost – Confidence = B

The cost for the modified VA concept is \$244 million greater than the VA Reference Design. The greater cost is the capital cost to construct two additional shafts and associated connecting drifts.

8. Environmental Considerations – Confidence = Not Rated

Environmental considerations are discussed in Appendix C.

Radiator Concept (Closed/Open Loop):

1. Post-Closure Performance – Confidence: Design = C, PA = E

Neither peak doses nor the FOM were evaluated for this concept.

2. Preclosure Performance – Scale = 3, Confidence = A

This concept is expected to accommodate DBEs comparably to the VA Reference Design.

3. Assurance of Safety – Scale = 2, Confidence = C

The assurance of safety for this concept is moderately low relative to the VA Reference Design. The lower rating is because there is more uncertainty in post-closure performance.

4. Engineering Acceptance – Scale = 2.7, Confidence = C

This concept has a moderately low – moderate potential for acceptance compared to the VA Reference Design. The slightly lower rating is because of design goals violations and uncertainty with the effective lifetime. The effective lifetime of the concept is 175,000 years, based on the rockfall calculation.

5. Construction, Operations, and Maintenance – Scale = 2.8, Confidence = B

Construction, operations and maintenance issues have moderate disadvantages compared to the VA Reference Design. The slightly lower rating is because there is an increased risk of industrial accident due to additional construction activities.

6. Schedule – Confidence = C

The schedule for the radiator concept for site characterization, design and construction is longer than the VA Reference Design. The longer site characterization schedule is anticipated due to possible change to repository footprint. The longer design schedule is anticipated due to the time needed to optimize this design. The longer construction schedule is anticipated due to the significant increase in construction activities. This concept would take an estimated 40 years to complete.

7. Cost – Confidence = B

The cost for the radiator concept has not been determined.

8. Environmental Considerations – Confidence = Not Rated.

Environmental considerations are discussed in Appendix C.

The potential disadvantage to be overcome with all the post-closure ventilation concepts is whether they could be licensed. Some concepts may violate the 10 CFR 60 or the *Mined Geologic Repository Requirements Document* (MGRRD) requirements for permanent closure. For all concepts to be viable, such a disadvantage remains to be overcome.

Post-closure natural ventilation, operating in either closed or open loop provides improved waste package performance. The modified VA concept has performance and capital cost benefits compared to the bow-tie concept, but licensability remains an issue. However, the full benefits of the bow-tie concept may only become apparent when coupled with other design features.

The radiator concept appears to have merit but requires further study.

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1. INTRODUCTION

1.1 OBJECTIVE

The objective of this study is to provide input to the Enhanced Design Alternatives (EDA) for License Application Design Selection (LADS). Its purpose is to develop and evaluate conceptual designs for post-closure ventilation alternatives that enhance repository performance. Post-closure ventilation is expected to enhance repository performance by limiting the amount of water contacting the waste packages. Limiting the amount of water contacting the waste packages will reduce corrosion.

This alternative was originally described as one of the alternative design concepts (CRWMS M&O 1998g, Enclosure 3, Section 8.3.3).

1.2 SCOPE

The scope of this study includes:

- Description of alternative post-closure ventilation conceptual designs
- Develop differential cost (against VA reference design) for each conceptual design
- Estimation of impacts to waste package performance
- Evaluation of selected designs against the LADS criteria.

The effect of the various concepts on the thermal goals is out of the scope of this report.

2. QUALITY ASSURANCE

This activity has been evaluated (CRWMS M&O 1998e) in accordance with QAP-2-0, *Conduct of Activities*, and has been determined to be quality affecting and subject to the requirements of the *Quality Assurance Requirements and Description* (QARD) (DOE 1998a). The quality assurance controls for this document are documented in accordance with NLP-3-18, *Documentation of QA Controls on Drawings, Specifications, Design Analyses, and Technical Documents*.

Any applicable permanent items will be classified in accordance with the *Classification of the Preliminary MGDS Repository Design* analysis (CRWMS M&O 1999h) which was completed in accordance with QAP-2-3, *Classification of Permanent Items*.

The activity is not a site-characterization field activity; therefore, NLP-2-0, *Determination of Importance Evaluations*, is not applicable.

This document was prepared in accordance with QAP-3-5, *Development of Technical Documents* and the Technical Document Preparation Plan (CRWMS M&O 1999i).

3. BACKGROUND

Because the repository is located above the water table in the unsaturated zone, the most important process controlling waste package lifetime is whether or not water drips on the package. Water movement or flux in the unsaturated, fractured tuffs occurs in the matrix and the fractures of the rock. Water generally moves downward in the rock matrix and fractures. Where water drips onto the waste packages, the packages corrode and eventually breach.

The ventilation of the repository affects water seepage from the rock into the drifts. Ventilation takes moisture from the drifts and rock in the form of water vapor. Following waste emplacement, the heat generated by radionuclide decay drives moisture away from the heat source, that is, away from the waste packages. This water re-condenses in the lower temperature areas above, below, and between the hotter drifts. The distribution of water and humid air within and around the repository drifts is variable in space and time. Heterogeneity in the rock properties and variation in the ambient percolation flux cause this variability. There are also differences in the thermal output of different waste packages causing a range of thermal-hydrologic conditions (cooler regions are expected along the edges of the repository). The thermal output of the waste decreases with time; eventually, the rock mass returns to its original temperature, and water flows back toward the repository. Post-closure ventilation will remove heat and water from the emplacement area and is expected to delay the arrival of aqueous moisture in the emplacement drifts. This would enhance waste package performance.

The post-closure ventilation concept team meeting of October 5, 1998 (CRWMS M&O 1999f) developed ventilation concepts (Figure 1) for potential use as a post-closure ventilation alternative. The conceptual designs considered herein fall into three categories:

- "Closed-loop," a system where the primary airways (ramps, mains and shafts) are sealed but have open cells that allow ventilation across the block through the emplacement drifts and in which repository air recirculates underground.
- "Open-loop," a system where the primary airways stay open and in which the repository drifts are open to exchange air with the atmosphere.
- "Closed/open-loop," a system where the primary airways (ramps, mains and shafts) are sealed but whose emplacement drifts are located very close to a system of tunnels open to the atmosphere through which fresh air circulates.

Continuous post-closure ventilation has been discussed in previous studies. One in particular, (CRWMS M&O 1996, p. 5-24) discussed the closed-loop concept and presented some coupled ventilation and hydrothermal evaluations (CRWMS M&O 1996, Appendix D). The study discusses various alternative thermal management techniques, including looped ventilation between two drifts which is similar to the bow-tie concept in Section 5.1.1. However, there is insufficient data available to use in this report.

Figure 1. Technical Approach Diagram

4. INPUTS

The design alternatives are being considered as conceptual and preliminary designs, which will not be used to support construction, fabrication, or procurement. They will not be used as part of a verified design package to be released to another organization for use in design work. Therefore, existing data and inputs requiring confirmation will be identified as TBV, but the provisions of NLP-3-15, *To Be Verified (TBV) and To Be Determined (TBD) Monitoring System*, requiring an identifier to track the status of TBV/TBD information are not required. However, TBVs that already carry a tracking number will be shown for completeness but not tracked.

4.1 PARAMETERS

The design parameters used in this study are described in this section.

4.1.1 Cost Estimates

Conceptual cost estimates (± 50 percent) were developed for the closed-loop and open-loop concepts. These were transmitted in a design input transmittal (CRWMS M&O 1999d, Item 1). The non-Q results are contained in Sections 5.6 and 6.6, and Table E-1 summarizes the estimates. [TBV]

4.1.2 Performance Assessment Simulations

4.1.2.1 Closed-Loop (Bow-Tie) Concept

The performance assessment simulation was performed as a response to a Design Input Request (CRWMS M&O 1999a). The non-qualified results of this simulation were received as a Design Input Transmittal (CRWMS M&O 1999c, Item 3) and include peak dose rates and Figure of Merit value. These are summarized in Section 5.5. [TBV]

4.1.2.2 Open-Loop Alternative (Modified VA Design) Concept

The performance assessment simulation was performed as a response to a Design Input Request (CRWMS M&O 1999b). The non-qualified results of this simulation were received as a Design Input Transmittal (CRWMS M&O 1999c, Item 3) and include peak dose rates and Figure of Merit value. These are summarized in Section 6.5. [TBV]

4.1.3 VA Reference Design Layout

The VA Reference Design layout, as shown in Figure 2, is described in the Viability Assessment (DOE 1998b, Section 7.1.2 and Figure 7-1).

Figure 2. VA Reference Design Layout

4.1.4 Modified VA Design Layout

The drift layout presented in Figure 3 is similar to the VA reference design but includes the addition of two shafts, connecting drifts, and second exhaust main to let natural ventilation perform at high airflow and minimum resistance. The layout is similar to the Preclosure Ventilation layout (1.0 m³/s case) without fans (CRWMS M&O 1999g, Figure 6). Figure 3 is used as the modified VA design layout in Section 6.1.1. [TBV]

4.1.5 Length of the emplacement shaft = 422 m, including the 5.0 m deep sump (CRWMS M&O 1997a, p. 84). For the calculation performed the worst case (longest) shaft length is used. Used in Appendix D.

4.1.6 Mean Saturated Bulk Density = 2.34 g/cc (= 2.34 tonnes/m³) for the Tsw2 (CRWMS M&O 1998d, Table 2). This value is the mean density value for all holes reported. It is considered representative for the level of calculation performed. Used in Appendix D.

4.1.7 Emplacement shaft diameter = 6.7 m (CRWMS M&O 1997a, p. 84). The calculation uses the excavated diameter of the shaft without lining. Used in Appendix D.

4.1.8 Not used.

4.1.9 Access drift height = 7.0 m (CRWMS M&O 1997a, p. 92). The calculation uses the excavated diameter of the shaft without lining. Used in Appendix D.

4.1.10 East and West Main diameter = 7.62 m (CRWMS M&O 1997a, Table 7-2). Used in Appendix D.

4.1.11 Shaft/Raise rockfall frequency estimates (per unit length per year) use the values established for drifts (CRWMS M&O 1998a, p. 8). For conservatism, the high estimate values are used in the rockfall calculations and are listed on pages D-2 and D-4. Used in Appendix D.

4.1.12 Block size distribution (CRWMS M&O 1998a, Table 23) and cumulative percent (CRWMS M&O 1998a, Table III-2) for the Topopah Springs Middle Nonlithophysal (Tptpmn) Unit are used to estimate total rockfall and are listed on pages D-2 and D-4. Used in Appendix D.

4.2 CRITERIA

The design criteria that specifically apply to this study are described in this section.

4.2.1 The system provides access main, ramp, emplacement drift, and turnout grades of 3% or less (CRWMS M&O 1998h, Section 1.2.4.2). Used in Section 5.1.1.

Figure 3. Modified VA Design Conceptual Layout (Open-Loop Concept)

- 4.2.2 The MGR design shall retain the option of using emplacement drift backfill until the license amendment to close the repository has been approved by the NRC (DOE 1999, Section 3.3.I). Used in Section 5.8.

4.3 CODES AND STANDARDS

The codes and standards that specifically apply to this study are described in this section.

Code of Federal Regulations (10 CFR 60 1999):

10 CFR Part 60.102(d): "Stages in the licensing process. There are several stages in the licensing process. The site characterization stage, ... and permanent closure, which includes sealing of shafts. Permanent closure represents the end of active human intervention with respect to the engineered barrier system." This code is used in Sections 5.8, 6.8 & 7.8.

4.4 ASSUMPTIONS

The assumptions and justifications for the assumptions used in this study are described in this section.

4.4.1 Closed-Loop Concepts

- 4.4.1.1 Ventilation drifts, shafts, and access tunnels to the surface are sealed at the end of preclosure ventilation. This assumption is fundamental to the definition of repository "closure" and is used throughout the evaluation. [TBV]
- 4.4.1.2 Drift layout per Figure 4. This figure shows approximate dimensions for a typical bow-tie cell, based on using a maximum grade of three percent (Criteria 4.2.1). Actual repository dimensions using this concept could vary from this layout but would have minimal impact on the computer calculations. The basis for the layout is discussed in Section 5.1.1. [TBV]
- 4.4.1.3 Waste package spacing for the bow-tie closed-loop concept equals 1.0 m (Generally the closest waste package spacing that would allow handling with a gantry) (TBV-380) (CRWMS M&O 1998b, p. 21). Used in Section 5.1.1. [TBV]
- 4.4.1.4 Not used.
- 4.4.1.5 The bulking factor used in the rockfall calculation is 1.5. There is no available published number for this factor for random rockfall. Published data is for bulking (swelling) factors for mined and well-blasted rock. This number is considered reasonable for the rockfall calculation. Used in Appendix D. [TBV]

Figure 4. Bow-Tie Layout (Closed-Loop Concept)

- 4.4.1.6 The length of the raises between the upper mains and lower mains is 19.4 m (27 m centerline to centerline minus drift diameter of 7.62 m). This is based on using a maximum emplacement drift slope of 3 percent as shown in Figure 4. Used in Appendix D. [TBV]
- 4.4.1.7 The excavated diameter of the raises required to provide the vertical component of the bow-tie loop is 5.5 m. These are made equal to the emplacement drift diameter (CRWMS M&O 1997c, p. 73) to present minimum airflow resistance. Used in Appendix D. [TBV]
- 4.4.1.8 A height of 10.0 m up the raise is added to the rock volume blockage calculation. The added height is to add volume to compensate for not calculating angles of repose. This is considered conservative and reasonable for the approximate calculation performed. Used in Appendix D. [TBV]

4.4.2 Open-Loop Concepts

- 4.4.2.1 Ventilation drifts, shafts, and access tunnels to the surface are left open at the end of preclosure ventilation. This assumption is fundamental to the definition of open-loop ventilation and is used throughout the evaluation. [TBV]
- 4.4.2.2 The bulking factor used in the rockfall calculation is 1.5. There is no available published number for this factor for random rockfall. Published data is for bulking (swelling) factors for mined and well-blasted rock. This number is considered reasonable for the rockfall calculation. Used in Appendix D. [TBV]
- 4.4.2.3 A height of 10.0 m up the shaft is added to the rock volume blockage calculation. The added height is to add volume to compensate for not calculating angles of repose. This is considered conservative and reasonable for the approximate calculation performed. Used in Appendix D. [TBV]

4.4.3 Closed/Open-Loop Concepts

- 4.4.3.1 Repository ventilation drifts, shafts, and access tunnels to the surface are sealed at the end of preclosure ventilation. This assumption is fundamental to the definition of repository "closure" and is used throughout the evaluation. [TBV]
- 4.4.3.2 The best cooling performance is obtainable from a network of cooling drifts located in the same plane as the emplacement drifts and interlaced between them. In other words, a cooling drift is located between every emplacement drift. The spacing of drifts is the same as the VA Reference Design. For preliminary discussion purposes this spaces the emplacement drifts at 56 m apart, on centers, and cooling drifts are the same. This assumption is considered reasonable for the level of analysis performed for this concept and is used in Section 7.3. [TBV]

5. CLOSED-LOOP CONCEPTS DESCRIPTIONS

5.1 CLOSED-LOOP CONCEPTS

Closed-loop concepts are those that have their main drift/shaft access to the surface sealed at the termination of preclosure ventilation. These then rely on heat release from the waste packages, temperature differential in the surrounding rock, moisture influx, and geometric configuration to drive natural ventilation in a self-sustaining, recirculation cycle that continues to cool the waste packages and remove moisture from the immediate area surrounding them.

5.1.1 Bow-Tie Concept

This concept is a closed-loop system with the emplacement drifts shaped like a bow-tie (or a figure-of-eight) (Figure 5) when observed from the horizontal plane. The total drift area occupies the same area as in the VA, but waste packages are concentrated into the center 50 percent of the emplacement block so that the outer edges serve as heat and moisture sinks. To achieve this, the waste packages will be pushed together such that the waste package spacing is equal to 1.0 m (Assumption 4.4.1.3). Drift spacing is kept equal to the VA Reference Design.

The major modifications to the VA configuration (Assumption 4.4.1.2) include the addition of two (2) lower main drifts located vertically under the West and East mains, access ramps to the lower mains, and multiple vertical raises connecting each upper and lower main. The actual configuration of these openings is not in the scope of this report. The emplacement drifts are inclined at approximately three percent (3%) slope to provide an elevation difference across the emplacement block and remain within the construction and operation design parameters. In the bow-tie configuration adjacent drifts' inclination alternates from upper main to lower main and lower main to upper main along the emplacement block. The outer edges of each drift are inclined down toward each upper main at approximately one-half percent slope (0.5%) to provide for condensate drainage away from the emplacement block. A typical "cell" consists of two adjacent drifts, inclined in opposing directions, with upper and lower mains at each end and raises connecting the mains to complete the ventilation circulation loop.

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Figure 5. Sketch of Bow-Tie Concept

5.1.2 Triangle Concept

The “triangle” concept is a closed-loop system shaped like a triangle when observed from the horizontal plane (Figure 6). As in the bow-tie concept, total drift area occupies the same area as in the VA, and waste packages are concentrated into the center 50 percent of the emplacement block so that the outer edges serve as heat and moisture sinks.

The modification to the VA configuration requires the addition of one (1) lower main drift vertically under an existing main along with its access ramp. Each cell also has a cross-drift, for cooling, over the emplacement drift and a raise at one end connecting upper and lower drifts. (Figure 6) The emplacement drifts are inclined at approximately three percent (3%) slope to provide an elevation difference across the emplacement block and remain within the construction and operation design parameters. In the triangle configuration, adjacent drifts are identical and parallel along the emplacement block. The upper cooling drifts are inclined down toward the upper main at approximately one-half percent slope (0.5%) to provide for condensate drainage

away from the emplacement block. A typical "cell" consists of one emplacement and one cooling drift, and vertical raise, to complete the ventilation circulation loop.

Figure 6. Sketch of Triangle Concept

5.1.3 Perimeter Loop Concept

The perimeter loop concept is one that has a perimeter radiator (cooling) drift located close to the surface, outside the repository block, and above its horizon (Figure 7). Primary airways are connected to this perimeter drift not to the surface. Hot air from the waste packages moves continuously from the emplacement block towards the cooler areas around the perimeter because of air density differential. The drift serves as a heat/moisture sink. Moisture and heat are removed from the waste packages and moisture is condensed and deposited in the perimeter drifts away from the emplacement block. The potential for moisture migration back to the emplacement block is minimal.

The modification to the VA configuration is the addition of the perimeter drift and its drifts connecting to primary airways.

Figure 7. Perimeter Loop (Closed-Loop Concept)

5.1.4 Vertical Emplacement Concept

The vertical emplacement concept is a closed-loop concept based on Colenco Power Engineering's conceptual design (Danko 1997, pp. 36 and 37). This concept places the waste package in a vertical borehole (raise) (Figure 8). A tunnel at their lower and upper ends connects a series of boreholes. In the emplacement block, a series of twin tunnels form the storage area. Alternating boreholes are left open to provide passage for cooling air for heat removal. The horizontal tunnels serve several purposes:

- The lower tunnel is the ventilation supply tunnel, which feeds every borehole from below with cool air. This cool air passes through an annulus between the waste package canister wall and the borehole wall, driven by natural convection caused by the heat generated by radionuclide decay.
- The upper tunnel serves both for loading the waste package into the borehole and for collecting the warm air.
- During preclosure the cooling air is fed into the storage area via a vertical access shaft, the exhaust air is released via a vertical exhaust shaft.

This concept is a major deviation from the VA configuration. The twin tunnel system with multiple vertical boreholes requires significantly more excavation than proposed in the VA configuration and a potentially much larger area footprint.

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Figure 8. Sketch of Vertical Emplacement Concept

5.2 CLOSED-LOOP CONCEPT SELECTION

Since the number of design concepts suggested by the ventilation concept team and considered in this study is large, the matrix in Table 2 is used to highlight the similarities and/or differences between systems.

Table 2 clearly shows that there are more similarities than dissimilarities between the four closed-loop design concepts. This suggests that any one of these designs has some potential to function in a closed-loop natural-ventilation mode. All four rely on the same drivers to remove heat and moisture. These include:

- Heat released by the waste package.
- Heat sink for heat/moisture removal is the rock mass at the extremities of the emplacement block or, as in the vertical emplacement concept, in the adjacent rockmass around the open borehole.
- Drifts/raises are provided to allow recirculation of the airflow back through the emplacement block.

The mechanism used in the vertical emplacement concept is a little different from the other three concepts. It recirculates ventilation airflow around the waste package in a mini-loop. Heat and moisture are removed in the cooler borehole adjacent to the emplacement borehole rather than removed to the outer extremities of the emplacement block.

The bow-tie concept was selected for evaluation for these reasons:

- Existing computer models are capable of performing calculations that demonstrate the viability of the closed-loop concept.
- The bow-tie was taken as the bounding case. If the bow-tie demonstrates that the closed-loop concept works, it is reasonable to assume that the other three concepts will also maintain some degree of self-sustaining natural ventilation airflow.

Table 2. Closed-Loop Concepts

CONCEPT	Bow-Tie	Triangle	Perimeter Loop	Vertical Emplacement
Single level repository (1)	Yes	Yes	Yes	Yes
Compatible with VA layout (2)	Yes	Yes	Yes	No
Main drifts, ramps, shafts sealed	Yes	Yes	Yes	Yes
Emplacement drifts dried and cooled by airflow (3)	Yes	Yes	Yes	Yes
Airflow relies on buoyancy of air warmed by waste package heat (4)	Yes	Yes	Yes	Yes
Water taken from emplacement drifts carried to surface atmosphere (5)	No	No	No	No
Water taken from emplacement drifts deposited in subsurface area outside the emplacement block (6)	Yes	Yes	Yes	No
Computer model – available (7)	Yes	No	No	No

1. Yes means the waste is emplaced in a single repository level. No means a multiple level repository.
2. Yes means that the concept will work based on the VA concept of storing waste packages horizontally in emplacement drifts. No means that other storage methods such as emplacement in boreholes are required.
3. Yes means that ventilation is the primary means.
4. Yes means that natural buoyancy is the primary means.
5. Yes means that the majority of moisture is carried to the surface.
6. Yes means that the majority of moisture is deposited in the subsurface, outside of the emplacement block, remote from the waste packages.
7. Yes means that an existing computer model is available for immediate use, with minimal customization required.

5.3 ENGINEERING DESIGN

The purpose of the conceptual design described herein was to provide sufficient information to permit the Performance Assessment simulation of waste package performance.

The closed-loop concept selected for simulation was the Bow-Tie concept described in Section 5.1.1. Figures 5 and 4 are presented to show a typical cross-section and approximate dimensions for one bow-tie loop (or cell). Details, such as the intake shafts, performance confirmation drifts, enhanced characteristics repository block (ECRB) drift, and access ramps required to access the lower mains are not shown. These are not required for, nor affect, the results of the performance assessment of this concept.

The waste packages were placed close together in the center 50 percent of the emplacement drift to concentrate the available waste package thermal energy. The emplacement drifts are also inclined at approximately three percent to provide as much elevation difference between the upper main at one end and the lower main at the other end of each drift. This emplacement strategy is intended to maximize the natural ventilation pressure difference from end to end, without jeopardizing waste package emplacement. Waste package emplacement in the inclined drifts is not evaluated in this study and will be addressed in future studies, as necessary.

5.4 POTENTIAL SYSTEM FAILURES

A fundamental requirement for successful long-term operability for any of the design concepts considered in this study is that primary airways retain the ability to maintain ventilation airflow.

5.4.1 Airway Degradation

Over the lifetime of the repository, rockfalls are expected to occur. Initiating events could be natural events such as seismic and climatic changes. One postulated scenario has the potential to stop the closed-loop natural-ventilation airflow. This is a rockfall(s) occurring in one or more of the vertical raises or in an emplacement drift. Such a rockfall could block the connecting emplacement drift at the bottom of the raise. Rockfalls that occur in inclined emplacement drifts will pose some obstruction to airflow, but are unlikely to totally block-off the drift. Rock blocks that fall from the roof of a drift will leave an equivalent "hole" in the roof that will allow air to continue to flow around the obstruction. Flow resistance may increase, but it is expected that ventilation airflow would continue.

An estimate of the number of rockfalls, the tonnage and volume that could occur in one of the closed-loop raises is made, using the data available in the *Preliminary Block Size Calculation* (CRWMS M&O 1998a). The high estimate data is used as the most conservative bounding case, along with the "worst case" block size distribution, to calculate the rockfall tonnage and time for blockage to occur (Appendix D, pp. D-4 & D-5).

Since rockfall frequency calculations (Parameter 4.1.11) are based on a per unit length of drift per year (/km/yr), the number of rockfalls per year predicted are proportional to the length of the drift/raise. In the example used for this study, the raise is 19.4 m long (Assumption 4.4.1.6.)

between the upper and lower mains (center to center). Therefore, the calculated time for total blockage of the lower main, at the bottom of the raise, is directly proportional to the raise length.

The calculated time for such a blockage to occur in a closed-loop raise is approximately 2,050,000 years (Appendix D, p. D-5).

5.4.2 System Life Expectancy

The rockfall calculation (Appendix D, p. D-5) provides us with an estimate of life expectancy. The calculation predicts that closed-loop natural-ventilation could function up to approximately 2,050,000 years.

It is important to point out that the level of confidence in this number is low for the following reasons:

- The preliminary block size calculation does not include the short trace length fractures (i.e., fractures less than 1-m length). This has the potential to change the block size distribution, which could increase the total rockfall tonnage. The result would be a decrease in the calculated time for blockage to occur.
- The rockfall frequency (/km/yr) is based on available empirical information, and the uncertainty of this number is high.
- The calculation is based on block size distributions for the Tptpmn unit oriented at N72W (Parameter 4.1.12). For this study, this is considered as the "worst case" size distribution and no consideration is given to true rock unit location. Up to now, the block size work has not considered vertical shafts and raises in their calculations.

5.5 PERFORMANCE ASSESSMENT SIMULATION

A total system performance assessment simulation was conducted for the closed-loop concept (bow-tie). This evaluation was submitted as a Design Input Transmittal (CRWMS M&O 1999c, Item 3) and is identified in Section 4.1.2.1 as an input parameter.

5.5.1 Performance Assessment Simulation Results

The peak dose rates were determined for two periods: less than 10,000 years; and between 10,000 and 1,000,000 years. The results (CRWMS M&O 1999c, Item 3, p. 13) are shown in Figures 9 & 10 and summarized in Table 3. The 10,000-year case shows a very low peak dose rate of 0.01388 mrem/year. This is considerably smaller than the VA Reference Design base case of 0.0422 mrem/year. The 1,000,000-year case shows a small peak dose rate decrease from 300.9 mrem/year for the base case to 290.3 mrem/year. The Figure of Merit (FOM) for the closed-loop concept is 27.63, compared with 25.02 for the base case.

For the 10,000-year case, the dose rate is equal to the base case result for the first 5,600 years and is driven by the release of radionuclides from the juvenile failure package (CRWMS M&O 1999c, Item 3, p. 13). After the juvenile failure, the dose rate decreases since no other packages fail during the first 10,000 years.

For the 1,000,000-year case, there is little difference between the base case and the closed-loop, post-closure ventilation case (CRWMS M&O 1999c, Item 3, pp. 13 & 14). The post-closure natural ventilation model only lasts for 5,000 years for the bow-tie configuration. After this, the model assumes that the natural ventilation stops and the system reverts to closed conditions. The short duration of the ventilation model has little impact over the course of 1,000,000 years.

Table 3. Summary of Results for Performance Assessment Simulation for the Bow-Tie Concept

	Base Case VA Reference Design	Closed Loop (Bow-Tie)	Difference
Figure of Merit (FOM)	25.02	27.63	+10 %
<10,000 years			
Peak Dose (mrem/year)	0.0422	0.01388	-67 %
Peak Dose Time (years)	10,000	5,600	-4,400
10,000 to 1,000,000 years			
Peak Dose (mrem/year)	300.9	290.3	-3.5 %
Peak Dose Time (years)	317,000	317,000	0

Author's Note: The following figure was prepared by the PA group as part of the PA simulation results (CRWMS M&O 1999c, Item 3, Figure 2) and is reproduced herein for reference.

Figure 9. Base Case and Post-Closure Ventilation 10,000-year Dose Rate Results

Author's Note: The following figure was prepared by the PA group as part of the PA simulation results (CRWMS M&O 1999c, Item 3, Figure 3) and is reproduced herein for reference.

Figure 10. Base Case and Post-closure Ventilation 1,000,000-year Dose Rate Results

5.5.2 Performance Assessment Conclusions

The performance assessment simulation shows an improvement over the VA Reference Design in terms of peak dose for the less than 10,000-year case. The peak dose of 0.01388 mrem/year is considerably lower than the base case of 0.0422 mrem/year. For the long-term simulation of 10,000 years to 1,000,000 years, the peak dose decreases slightly. The overall FOM for this concept increases by approximately 10 percent from 25.02 to 27.63.

5.6 COST ESTIMATE

A conceptual cost estimate was developed for this closed-loop design alternative, based on the design described in Section 5.3. This cost estimate is not included in the Activity Evaluation (CRWMS M&O 1998e) and is not subject to QARD requirements (DOE 1998a). The estimate is conceptual (± 50 percent) and is expressed in 1999 dollars. A summary table is presented in Appendix E (CRWMS M&O 1999d, Item 1) and is identified in Section 4.1.1 as an input

parameter. The estimated cost for implementing this alternative is approximately \$575 million. This cost is in addition to the VA Reference Design estimated costs.

5.7 LADS CRITERIA

The analysis of the closed-loop design alternative addresses the eight criteria requested by the LADS group (CRWMS M&O 1998f). The criteria are presented in Appendix A of this study. The responses to the criteria questions are presented in Table B-1 in Appendix B. The confidence assessments for the LADS criteria are included in the Appendix B tables and are detailed in Appendix F.

5.8 LICENSABILITY

The closed-loop concept has the surface accesses sealed. It therefore would not violate the 10 CFR 60 requirement for permanent closure (Section 4.3).

Since the closed-loop concept leaves the emplacement drifts open, this concept could violate the MGRRD requirement (Criteria 4.2.2) to retain the option of using emplacement drift backfill. This is a potential disadvantage to the concept's licensability.

6. OPEN-LOOP CONCEPTS DESCRIPTIONS

6.1 OPEN-LOOP CONCEPTS

Open-loop concepts are those that have their main drift/shaft access to the surface left open at the termination of preclosure ventilation. With one exception considered, ventilation fans are shutdown. Heat release from the waste packages, temperature differential in the surrounding rock, moisture influx, and elevation difference between cool air inlet and warm air outlet drives natural ventilation that continues to cool the waste packages and remove moisture to the surface.

6.1.1 Modified VA Design Concept

This concept uses a modified VA configuration of an open-loop system. Emplacement drifts are essentially horizontal and are connected to the East and West Mains at their extremity, and to two exhaust mains located centrally under the emplacement block. The East, West and Exhaust Mains are primary airways connecting to ramps and ventilation shafts. Two additional shafts and associated connecting drifts are required to provide sufficient airflow for heat and moisture removal (Parameter 4.1.4.).

At the completion of preclosure ventilation, the powered ventilation fans are shutdown and removed. The North and South ramps and one shaft act as cool air intakes and the remaining shafts as warm air outlets (Figure 3). This system relies on natural ventilation pressure difference and heat released by the waste packages to maintain airflow through the emplacement drifts.

Preliminary study data from the *Nye County Waste Repository Project Office Independent Scientific Investigations Program Annual Report, May 1997 – April 1998*, suggests that high natural-ventilation airflows are possible (Nye County 1998, Section 8.0, pp. 86 to 92). Their proposal differs from the VA Reference Design configuration by recommending that the project study placement of the waste packages closer together and reducing the overall footprint of the repository (Nye County 1998, Section 8.6, pp. 91, 92).

6.1.2 Bow-Tie Concept

The bow-tie open-loop concept uses identical cell configuration to that described in Section 5.1.1. The bow-tie connections to the preclosure ventilation ramps, shafts and drifts are left open. See Figure 4 for similar concept.

The major modifications to the VA Reference Design configuration include the addition of two (2) lower mains, access ramps to the lower mains, multiple vertical raises, and more intake and exhaust shafts. Because the emplacement drifts are inclined from lower main to upper main in alternating directions, the warm upper mains connect to exhaust shafts and the cool lower mains connect to intake shafts/ramps. This requires significantly more drift and shaft construction than the VA Reference Design configuration.

6.1.3 Intakes Below The Emplacement Horizon Concept

This concept uses the VA configuration with cold-air intake drifts from the surface connected to the repository block from below (Figure 11). The preclosure ventilation ramps and shafts are sealed. Heat and moisture are removed from the repository block by the natural breathing of the mountain. Hot air and moisture that percolates up through the mountain is replaced by the cool air that is introduced from underneath the repository block.

The major modification to the VA configuration is the addition of the drifts necessary to supply the source of cool airflow into the emplacement drifts from underneath the block horizon.

Figure 11. Intakes below the Emplacement Horizon Concept

6.1.4 Beehive Concept

The beehive concept (Bergman et al. 1987, Sheet 1 of 8) is an open-loop system shaped like a beehive (or vertical cylinder with conical sections top and bottom) (Figure 12). Emplacement drifts are located in the center of the beehive with access drifts vertically through the center and from the outer perimeter. Proposals have been patented by Swedish scientists (Bergman et al. 1987, p. 2), to encase such a central storage area with clay to form a barrier to water influx to the waste materials. In addition, they propose to surround the entire storage area with a cage-like network of interconnected vertical and horizontal drifts to provide a path for water influx removal to a sump and pump at the bottom of the cage.

6.1.5 Fans On The Surface Concept

This concept uses the VA configuration with continued operation of the surface ventilation fans during post-closure. In effect, this is really an extension of the preclosure operation.

6.1.6 Wind-Powered Ventilation Concept

This concept is essentially the same as the VA configuration with the addition of wind scoops (traps) at the cooling air intakes to capture available wind. The wind is used to push/pump air through the repository block, after the waste heat level drops and natural ventilation pressure is low. The wind scoop would need to be capable of rotating with changes in wind direction to keep the opening facing into the wind. Such a design would be maintenance intensive.

6.1.7 Pyramid Concept

This concept uses the modified VA configuration with the open-loop natural ventilation proposed in Section 6.1.1 and the addition of shaft collars/extensions around each exhaust shaft. The shaft extension is supported by building a rock pyramid around the shaft. Increasing the height of the hot-air column increases the natural ventilation airflow.

6.1.8 French Drain Concept

This concept uses the VA configuration with the addition of fill in the ramps, shafts, and drifts at closure. A graded permeable fill material is used. This allows some airflow to permeate through the emplacement drifts to move heat and moisture away from the waste packages. Careful location of surface openings is necessary to assure no water infiltration reaches the waste packages.

FIG 1

Figure 12. Beehive Concept

Author's Note: This sketch is shown for reference only. The tag numbers shown refer to descriptions included with Fig 1 of the Patent Application (Bergman et al. 1987, Sheet 1 of 8).

6.1.9 Perimeter Loop Concept

The perimeter loop concept is one that has a perimeter radiator (cooling) drift located close to the surface, outside the repository block, and above its horizon (Figure 13). Primary airways are connected to this perimeter drift which is also connected to the surface. The drift serves as a heat/moisture sink and exchanges air with the atmosphere. Hot air from the waste packages moves continuously from the emplacement block towards the cooler areas around the perimeter by natural ventilation. Moisture and heat are removed from the waste packages by the natural ventilation airflow to atmosphere.

The modification to the VA configuration is the addition of the perimeter drift, shafts from the drift to the surface and drifts connecting it to primary airways.

6.1.10 Individual Raises Concept

This concept has the modified VA configuration with the open-loop natural ventilation proposed in Section 6.1.1 and the addition of an individual raise to the surface at each emplacement drift (Figure 14). The raises are connected to the drifts outside the emplacement block so that moisture does not return toward the waste packages.

The modification to the VA configuration is the addition of a raise at every emplacement drift.

Figure 13. Perimeter Loop (Open-Loop Concept)

Figure 14. Individual Raises Concept

6.2 OPEN-LOOP CONCEPTS SELECTION

Since the number of design concepts suggested by the ventilation concept team and considered in this study is large, the matrix in Table 4 is used to highlight the similarities and/or differences between systems.

Table 4 clearly shows that there are more similarities than dissimilarities between the ten open-loop design concepts. With the exception of the surface fan concept, this also suggests that any one of these designs have some potential to function in an open-loop natural-ventilation mode. The surface fan concept is preclosure ventilation extended through post-closure. Open loop is used here to describe a concept that includes one or more of the following:

- Open primary airways (ramps, shafts, drifts, and raises) for airflow.
- Primary airways filled with a graded permeable material to let the emplacement drifts “breathe” to the surface.
- Natural breathing of the mountain, in conjunction with open cool-air intakes and sealed primary airways, to ventilate the emplacement block.

One concept stands out as being significantly different from the rest. This is the beehive. The beehive (Section 6.1.4) is a multiple-level repository concept. This concept could violate certain bounding parameters, such as maintaining required overburden and clearance to the water table, and maximum rock temperature. These parameters are outside the scope of this study and thus this concept is not evaluated further here.

The Intakes below the Horizon (Section 6.1.3) and the French Drain (Section 6.1.8) are similar in concept. Each relies on airflow through a permeable rockmass to remove both moisture and heat. The permeability is different in each of the concepts but airflow would be small in either case. Computer modeling of these concepts would require considerable effort to predict flows through either the mountain or the permeable fill. These are not evaluated further here.

The Surface Fans (Section 6.1.5) and the Wind Power (Section 6.1.6) concepts use the VA configuration with electric-powered or wind-powered assistance to the inherent natural ventilation provided by the elevation difference between intakes and exhausts. Both require long-term maintainability and offer limited benefits over the natural ventilation modified VA configuration. A computer software model is available for the fan concept. However, since it is expected that the natural ventilation modified VA system will be able to provide adequate airflow and moisture removal to protect the waste packages these are not evaluated further here.

Table 4. Open-Loop Concepts

CONCEPT	Modified VA Design	Bow-Tie	Intakes Below Horizon	Beehive	Surface Fans
Single level repository (1)	Yes	Yes	Yes	No	Yes
Compatible with VA layout (2)	Yes	Yes	Yes	No	Yes
Main drifts, ramps, shafts sealed	No	No	Yes	No	No
Emplacement drifts dried and cooled by airflow (3)	Yes	Yes	Yes	Yes	Yes
Airflow relies on buoyancy of air warmed by waste package heat (4)	Yes	Yes	Yes	Yes	No
Airflow relies on buoyancy caused by difference in elevation between intake and exhaust openings (5)	No	No	No	No	No
Water taken from emplacement drifts carried to surface atmosphere (6)	Yes	Yes	No	Yes	Yes
Computer model – available (7)	Yes	No	No	No	Yes

1. Yes means the waste is emplaced in a single repository level. No means a multiple level repository.
2. Yes means that the concept will work based on the VA concept of storing waste packages horizontally in emplacement drifts. No means that other storage methods such as emplacement in boreholes are required.
3. Yes means that ventilation is the primary means.
4. Yes means that natural buoyancy is the primary means.
5. Yes means that natural ventilation flow driven by the difference in elevation is the primary means.
6. Yes means that the majority of moisture is carried to the surface by the natural ventilation airflow.
7. Yes means that an existing computer model is available for immediate use, with minimal customization required.

Table 4. Open-Loop Concepts (Continued)

CONCEPT	Wind Power	Pyramid	French Drain	Perimeter Loop	Individual Raises
Single level repository (1)	Yes	Yes	Yes	Yes	Yes
Compatible with VA layout (2)	Yes	Yes	Yes	Yes	Yes
Main drifts, ramps, shafts sealed	No	No	No	No	No
Emplacement drifts dried and cooled by airflow (3)	Yes	Yes	Yes	Yes	Yes
Airflow relies on buoyancy of air warmed by waste package heat (4)	No	No	Yes	Yes	Yes
Airflow relies on buoyancy due to difference in elevation between intake and exhaust openings (5)	Yes	Yes	No	No	No
Water taken from emplacement drifts carried to surface atmosphere (6)	Yes	Yes	No	Yes	Yes
Computer model – available (7)	No	No	No	No	No

1. Yes means the waste is emplaced in a single repository level. No means a multiple level repository.
2. Yes means that the concept will work based on the VA concept of storing waste packages horizontally in emplacement drifts. No means that other storage methods such as emplacement in boreholes are required.
3. Yes means that ventilation is the primary means.
4. Yes means that natural buoyancy is the primary means.
5. Yes means that difference in elevation is the primary means.
6. Yes means that the majority of moisture is carried to the surface by the natural ventilation airflow.
7. Yes means that an existing computer model is available for immediate use, with minimal customization required.

The modified VA design concept was selected for evaluation for these reasons:

- Existing computer models are available and capable of demonstrating the viability of this concept.
- The modified VA design presents the lower bounding case. If the modified VA design configuration demonstrates that an open-loop natural-ventilation concept works, it is reasonable to assume that the following concepts will also function in an open-loop configuration:
 - The Bow-Tie (Section 6.1.2): This configuration has little benefit over the modified VA. The higher “local” areal mass loading may drive higher airflow than the VA configuration, but only if significantly more drifting and shafts are provided.
 - The Pyramid (Section 6.1.7): The engineered exhaust stacks will drive a higher airflow than the modified VA, but with significant additional construction costs.
 - The Perimeter Loop (Section 6.1.9): The perimeter loop would be most beneficial, but multiple intake and exhaust shafts are required.
 - The Individual Raises (Section 6.1.10): Individual raises, one for each emplacement drift, would have less flow resistance, resulting in higher airflow than the modified VA configuration, but with significant additional construction costs.

6.3 ENGINEERING DESIGN

The purpose of the conceptual design described herein was to provide sufficient information to permit the Performance Assessment simulation of waste package performance.

The open-loop concept selected for simulation was the Modified VA Design concept described in Section 6.1.1. Figure 3 is presented to show a three-dimensional view of the modified repository. Details, such as the performance confirmation drifts, enhanced characteristics repository block (ECRB) drift are not shown. These are not required for, nor affect, the results of the performance assessment of this concept.

The emplacement drift layout and the waste package spacing are the same as the VA Reference Design (Parameter 4.1.3).

6.4 POTENTIAL SYSTEM FAILURES

As previously stated in Section 5.4, the fundamental requirement for successful long-term operability for any of the design concepts considered in this study is that primary airways retain the ability to maintain ventilation airflow.

6.4.1 Airway Degradation

The postulated scenario that has the potential to stop the open-loop natural-ventilation airflow is a rockfall(s) occurring in a shaft. Such a rockfall could block the connecting access drift at the bottom of the shaft. The same initiating events discussed in Section 5.4.1 also apply here. As previously stated in Section 5.4.1, rockfalls that occur in inclined emplacement drifts will pose some obstruction to airflow, but are unlikely to totally block-off the drift.

An estimate of the number of rockfalls, the tonnage and volume that could occur in one of the open-loop shafts is made, using the data available in the *Preliminary Block Size Calculation* (CRWMS M&O 1998a). The high estimate data is used as the most conservative bounding case, along with the "worst case" block size distribution, to calculate the rockfall tonnage and time for blockage to occur (Appendix D, pp. D-2 & D-3).

Since rockfall frequency calculations (Parameter 4.1.11) are based on a per unit length of drift per year (/km/yr), the number of rockfalls per year predicted are proportional to the length of the drift/shaft. In the example used for this study, the emplacement shaft is 422 m long (Parameter 4.1.5.). Therefore, the calculated time for total blockage of the access drift, at the bottom of the shaft, is directly proportional to the shaft length.

The calculated time for such a blockage to occur in the emplacement shaft is approximately 175,000 years (Appendix D, p. D-3).

6.4.2 System Life Expectancy

The rockfall calculation (Appendix D, p. D-3) provides us with an estimate of life expectancy. The calculation predicts that open-loop natural-ventilation could function up to approximately 175,000 years.

It is important to point out that the level of confidence in this number is low. The concerns expressed in Section 5.4.2 also apply here.

6.5 PERFORMANCE ASSESSMENT SIMULATION

A total system performance assessment simulation was conducted for the open-loop concept (modified VA design). This evaluation was submitted as a Design Input Transmittal (CRWMS M&O 1999c, Item 3) and is identified in Section 4.1.2.2 as an input parameter.

6.5.1 Performance Assessment Simulation Results

The peak dose rates were determined for two periods: less than 10,000 years; and between 10,000 and 1,000,000 years. The results (CRWMS M&O 1999c, Item 3, p. 13) are shown in Figures 9 & 10 and summarized in Table 5. The 10,000-year case shows a very low peak dose rate of 0.007906 mrem/year. This is significantly smaller than the VA Reference Design base case of 0.0422 mrem/year. The 1,000,000-year case shows a small peak dose rate decrease from 300.9 mrem/year for the base case to 268.9 mrem/year. The Figure of Merit (FOM) for the closed-loop concept is 24.92, compared with 25.02 for the base case.

Table 5. Summary of Results for Performance Assessment Simulation for the Modified VA Concept

	Base Case VA Reference Design	Open Loop (Modified VA Design)	Difference
Figure of Merit (FOM)	25.02	24.92	<1 %
<10,000 years			
Peak Dose (mrem/year)	0.0422	0.007906	-81 %
Peak Dose Time (years)	10,000	5,600	-4,400
10,000 to 1,000,000 years			
Peak Dose (mrem/year)	300.9	268.9	-11 %
Peak Dose Time (years)	317,000	316,000	-1,000

The relative humidity within the repository drifts remains below 30 percent for the lifetime of the open-loop ventilation. With the low relative humidity, it is assumed that no dripping will occur onto the waste packages, therefore there will be no dripping flux through the juvenile failure package for 10,000 years (CRWMS M&O 1999c, Item 3, p. 12). For the 10,000-year case, the dose rate is below the base case result for the first 5,600 years and is driven by the release of radionuclides from the juvenile failure package (CRWMS M&O 1999c, Item 3, p. 13). The open-loop (modified VA design) results are lower than the base case and the bow-tie results since there is no advective release from the juvenile failure package. After the juvenile failure, the dose rate decreases since no other packages fail during the first 10,000 years.

For the 1,000,000-year case, there is little difference between the base case and the open-loop, post-closure ventilation case (CRWMS M&O 1999c, Item 3, pp. 13 & 14). The post-closure natural ventilation model only lasts for 10,000 years for the modified VA configuration. After this, the model assumes that the natural ventilation stops and the system reverts to closed conditions. The short duration of the ventilation model has little impact over the course of 1,000,000 years.

6.5.2 Performance Assessment Conclusions

The performance assessment simulation shows a significant improvement over the VA Reference Design in terms of peak dose for the less than 10,000-year case. The peak dose of 0.007906 mrem/year is considerably lower than the base case of 0.0422 mrem/year. For the long-term simulation of 10,000 years to 1,000,000 years, the peak dose decreases very slightly. The overall FOM for this concept of 24.92 is essentially the same as the base case value of 25.02.

6.6 COST ESTIMATE

A conceptual cost estimate was developed for this open-loop design alternative, based on the design described in Section 7.3. This cost estimate is not included in the Activity Evaluation (CRWMS M&O 1998e) and is not subject to QARD requirements (DOE 1998a). The estimate is conceptual (± 50 percent) and is expressed in 1999 dollars. A summary table is presented in

Appendix E (CRWMS M&O 1999d, Item 1) and is identified in Section 4.1.1 as an input parameter. The estimated cost for implementing this alternative is approximately \$244 million. This cost is in addition to the VA Reference Design estimated costs.

6.7 LADS CRITERIA

The analysis of the open-loop design alternative addresses the eight criteria requested by the LADS group (CRWMS M&O 1998f). The criteria are presented in Appendix A of this study. The responses to the criteria questions are presented in Table B-2 in Appendix B. The confidence assessments for the LADS criteria are included in the Appendix B tables and are detailed in Appendix F.

6.8 LICENSABILITY

The open-loop concept leaves the surface accesses open. It therefore violates the 10 CFR 60 requirement for permanent closure (Section 4.3).

Since the open-loop concept leaves the emplacement drifts open, this concept could violate the MGRRD (Criteria 4.2.2) requirement to retain the option of using emplacement drift backfill.

These are potential disadvantages to the concept's licensability.

7. CLOSED/OPEN-LOOP CONCEPT DESCRIPTION

7.1 CLOSED/OPEN-LOOP CONCEPT

The radiator closed/open-loop concept is one that combines a closed repository and an open-loop concept. Emplacement drifts are located very close to a system of radiator (or cooling) drifts that are open to the atmosphere through which fresh air circulates (Figure 15). The spacing of drifts is the same as the VA Reference Design (Assumption 4.4.3.2). With the total drift area occupying the same area as in the VA, the waste packages would have to be concentrated into the emplacement drifts. To achieve this, the waste packages would be pushed together such that the waste package spacing would be equal to 1.0 m (Assumption 4.4.1.3). Repository main drift/shaft access to the surface is sealed at the termination of preclosure ventilation. Ventilation fans are shutdown. The radiator drifts are connected by shafts/ramps to the surface, and provide cooling to the rock surrounding the emplacement drifts. Elevation difference between inlet and exhaust, along with heat release from the waste packages, and temperature differential in the surrounding rock drives natural ventilation that continues to cool the waste packages by conduction from the hot rock and remove moisture to the surface.

Figure 15. Sketch of Radiator Concept

7.2 CLOSED/OPEN-LOOP CONCEPTS DESIGN SELECTION

The concept described below postulates that optimum cooling benefits may be achieved by placing the “radiator” (cooling) drifts in the plane of the repository and interlacing with the repository emplacement drifts. However, further study of alternative locations for the cooling drifts may demonstrate that this postulation is incorrect.

7.3 ENGINEERING DESIGN

No design layouts are available for this concept. However, the best cooling performance is assumed (Assumption 4.4.3.2) to be obtainable from a grid of cooling drifts located in the same

plane as the emplacement drifts and interlaced between them (the emplacement drifts alternate with the cooling drifts). The final size of the repository, with this design concept, or other alternatives, depends on the thermal loading used, and the drift centerline spacing selected. Interlacing the cooling drifts parallel to and alternating between the emplacement drifts may improve waste package performance. This location for the cooling drifts has the potential to act as a drain point for water influx that channels down in the pillar between the emplacement drifts. Water influx that might otherwise infiltrate the emplacement drifts would be diverted around the heat pipe, which forms over the emplacement drift, into the cooling drift and be removed from the mountain by evaporation in the cooling airflow.

7.4 POTENTIAL SYSTEM FAILURES

Regardless of the final layout configuration used for this concept, the same fundamental requirements and concerns discussed previously in Sections 5.4 and 6.4 apply.

7.4.1 Airway Degradation

The same conservative estimates of numbers of rockfalls and the time for blockages to occur calculated for the bow-tie (Section 5.4.1) and the modified VA design (Section 6.4.1), can be used here. This concept is essentially a combination of these two concepts. The "worst case" time for blockage to occur, in a vertical shaft, is 175,000 years (Appendix D, p. D-3).

7.4.2 System Life Expectancy

The same rockfall calculation (Appendix D, p. D-3) provides us with a reasonable estimate of life expectancy. The open-loop portion of the radiator concept could function up to approximately 175,000 years.

7.5 PERFORMANCE ASSESSMENT SIMULATION

The single concept evaluated in this study consists of the "closed" VA reference design repository and an "open" network of ventilation drifts, totally separate from the repository, with its own shafts and access ramps to the surface. The combination of the two concepts, closed loop and open loop, and the thermal hydrologic interaction between them, is a complex problem to computer model. None of the project's available thermal hydrologic simulations fit the modeling needs. Considerable time and manpower would need to be committed to developing a suitable model and running the ventilation and layout options just to analyze this concept to an equivalent degree as the bow-tie and the open loop. Consequently, no input data was available to run a total system performance assessment simulation.

7.6 COST ESTIMATE

It was not possible to do a cost estimate based on current knowledge. However, since the cooling drifts require their own network of access ramps, perimeter drifts and shafts, the construction effort could approach that of the repository itself.

7.7 LADS CRITERIA

The analysis of the closed/open-loop design alternative addresses the eight criteria requested by the LADS group (CRWMS M&O 1998f). The criteria are presented in Appendix A of this study. The responses to the criteria questions are presented in Table B-3 in Appendix B. The confidence assessments for the LADS criteria are included in the Appendix B tables and are detailed in Appendix F.

7.8 LICENSABILITY

The closed-loop portion of this concept (i.e., the repository) has the surface accesses sealed. It therefore would not violate the 10 CFR 60 requirement for permanent closure (Section 4.3). However, the open-loop portion of this concept (i.e., the cooling section) leaves its surface accesses open and therefore could violate the 10 CFR 60 requirement for permanent closure.

Since the repository may or may not backfill the emplacement drifts, this concept could violate the MGRRD requirement (Criteria 4.2.2) to retain the option of using emplacement drift backfill.

These are potential disadvantages to the concept's licensability.

8. COMPUTER SOFTWARE

This study includes a commercial spreadsheet application, used to perform the rockfall calculations (Appendix D). The formulas used are given and the calculations are verifiable by visual inspection and hand calculation. Inputs and assumptions are referenced in the calculations and listed in Sections 4.1 and 4.4.

Software Title: Microsoft Excel
Software Version: 97 SR-2

9. CONCLUSIONS

Post-closure natural ventilation, operating in either closed or open loop provides improved waste package performance. The modified VA concept has performance and capital cost benefits compared to the bow-tie concept, but licensability remains an issue. However, the full benefits of the bow-tie concept may only become apparent when coupled with other design features. The radiator concept appears to have merit but requires further study.

The following conclusions are considered preliminary, based on non-qualified inputs.

9.1 CLOSED-LOOP (BOW-TIE) CONCEPT

Compared to the VA reference base-case design, the bow-tie concept shows some improvement in waste package performance in the short term (Figures 9 and 10). Long-term performance is essentially identical to the VA design.

The performance assessment simulation shows an improvement over the VA Reference Design in terms of peak dose for the less than 10,000-year case. The peak dose of 0.01388 mrem/year is considerably lower than the base case of 0.0422 mrem/year. For the long-term simulation of 10,000 years to 1,000,000 years, the peak dose decreases slightly. The overall FOM for this concept increases by approximately 10 percent from 25.02 to 27.63.

The long-term performance of a naturally ventilated repository is totally dependent on the airways remaining open. The rockfall calculation presented in Appendix D (p. D-5) suggests that the bow-tie configuration could remain open in excess of 2,050,000 years. However, if the natural ventilation stops at some future time, the repository would revert to the "closed" conditions considered acceptable for the VA design. The full benefits of the bow-tie concept may only become apparent when coupled with other design features/alternatives.

The potential disadvantage to be overcome with the closed-loop concept is whether it could be licensed. The closed-loop concept could violate the MGRRD requirement to retain the option of using emplacement drift backfill.

The closed-loop (bow-tie) concept was evaluated against the LADS criteria (Table B-1) and is summarized below:

1. Post-Closure Performance – Confidence: Design = C, PA = E

The peak dose within 10,000 years is 0.01388 mrem/year and is 290.3 mrem/year between 10,000 to 1,000,000 years. The Figure of Merit (FOM) is 27.63 for this concept.

2. Preclosure Performance – Scale = 3, Confidence = A

This concept accommodates DBEs comparably to the VA Reference Design.

3. Assurance of Safety – Scale = 2, Confidence = C

The assurance of safety for this concept is moderately low relative to the VA Reference Design. The lower rating is because there is more uncertainty in post-closure performance.

4. Engineering Acceptance – Scale = 2.7, Confidence = C+

This concept has a moderately low to moderate potential for acceptance compared to the VA Reference Design. The lower rating is because of design goal violations and

uncertainty with the effective lifetime of the alternative. The effective lifetime of the concept is calculated to be 2,050,000 years.

5. Construction, Operations, and Maintenance – Scale = 2.8, Confidence = B

Construction, operations and maintenance issues have moderate disadvantages compared to the VA Reference Design. The slightly lower rating is because there is an increased risk of industrial accident due to additional construction activities.

6. Schedule – Confidence = C

The schedule for the closed loop for design and licensing is a little longer than the VA Reference Design. A minimally longer design time is anticipated due to the revised bow-tie layout. Additional time to license this layout was also anticipated. This concept would take an estimated 28 years to complete.

7. Cost – Confidence = B

The cost for the closed loop (bow-tie) is \$575 million greater than the VA Reference Design. The greater cost is the capital cost to construct additional mains, ramps and raises.

8. Environmental Considerations – Confidence = Not Rated

Environmental considerations are discussed in Appendix C.

9.2 OPEN-LOOP (MODIFIED VA DESIGN) CONCEPT

The open-loop concept shows definite waste package performance advantages over both the VA design and the bow-tie. The low relative humidity will prevent water dripping onto the waste packages, improving long-term performance. Overall, the performance will be better than the VA design because of the low relative humidity achieved.

The performance assessment simulation shows a significant improvement over the VA Reference Design, in terms of peak dose for the less than 10,000-year case. The peak dose of 0.007906 mrem/year is considerably lower than the base case of 0.0422 mrem/year. For the long-term simulation of 10,000 years to 1,000,000 years, the peak dose decreases very slightly. The overall Figure of Merit (FOM) for this concept of 24.92 is essentially the same as the base case value of 25.02.

As in the closed-loop concept, the long-term performance of a naturally ventilated open-loop repository is totally dependent on the airways remaining open. The rockfall calculation presented in Appendix D (p. D-3) suggests that the open-loop configuration could remain open for around 175,000 years.

The potential disadvantages to be overcome with the open-loop concept are whether it could be licensed. The open-loop concept violates the 10 CFR 60 requirement for permanent closure and could violate the MGRRD requirement to retain the option of using emplacement drift backfill. Another disadvantage is the effective lifetime of the open repository along with the security barriers that would be required.

The open-loop (modified VA design) concept was evaluated against the LADS criteria (Table B-2) and is summarized below:

1. Post-Closure Performance – Confidence: Design = C, PA = E

The peak dose within 10,000 years is 0.007906 mrem/year and is 268.9 mrem/year between 10,000 to 1,000,000 years. The FOM is 24.92 for this concept.

2. Preclosure Performance – Scale = 3, Confidence = A

This concept accommodates DBEs comparably to the VA Reference Design.

3. Assurance of Safety – Scale = 2, Confidence = C

The assurance of safety for these alternatives is moderately low relative to the VA Reference Design. The lower rating is because there is more uncertainty in post-closure performance.

4. Engineering Acceptance – Scale = 2.7, Confidence = A

This concept has a moderately low potential for acceptance compared to the VA Reference Design. The slightly lower rating is because of design goals violations and uncertainty with the effective lifetime. The effective lifetime of the concept is calculated to be 175,000 years.

5. Construction, Operations, and Maintenance – Scale = 2.8, Confidence = B

Construction, operations and maintenance issues have moderate disadvantages compared to the VA Reference Design. The slightly lower rating is because there is an increased risk of industrial accident due to additional construction activities.

6. Schedule – Confidence = C

The schedule for the open loop for licensing is longer than the VA Reference Design. The longer time is because the open loop concept is a major departure from the VA Reference Design and additional licensing time is anticipated. This concept would take an estimated 27 years to complete.

7. Cost – Confidence = B

The cost for the open loop is \$244 million greater than the VA Reference Design. The greater cost is the capital cost to construct two additional shafts and associated connecting drifts.

8. Environmental Considerations – Confidence = Not Rated

Environmental considerations are discussed in Appendix C.

9.3 CLOSED/OPEN-LOOP (RADIATOR) CONCEPT

Preliminary indications are that interlacing the cooling drifts parallel to and alternating between the emplacement drifts may improve waste package performance. This location for the cooling drifts has the potential to act as a drain point for water influx that channels down in the pillar between the emplacement drifts. Water influx that might otherwise infiltrate the emplacement drifts would be diverted around the heat pipe, which forms over the emplacement drift, into the cooling drift and be removed from the mountain by evaporation in the cooling airflow. This action can be expected to provide significant benefits to the long-term waste package performance. Due to time constraints, computer simulations for this configuration have not been modeled. Further study to optimize the layout and to simulate the thermal hydrologic performance of this concept appear to have merit, should the concept of post-closure ventilation be pursued as a portion of the conceptual design selected to be carried forward to the Site Recommendation.

The potential disadvantage to be overcome with the closed/open-loop concept is whether it could be licensed. The closed/open-loop concept could violate the 10 CFR 60 requirement for permanent closure and the MGRRD requirement to retain the option of using emplacement drift backfill. Another disadvantage is the effective lifetime of the open radiator drifts and shafts along with the security barriers that would be required.

The closed/open-loop (radiator) concept was evaluated against the LADS criteria (Table B-3) and is summarized below:

1. Post-Closure Performance – Confidence: Design = C, PA = E

Neither peak doses nor the FOM were evaluated for this concept.

2. Preclosure Performance – Scale = 3, Confidence = A

This concept is expected to accommodate DBEs comparably to the VA Reference Design.

3. Assurance of Safety – Scale = 2, Confidence = C

The assurance of safety for this concept is moderately low relative to the VA Reference Design. The lower rating is because there is more uncertainty in post-closure performance.

4. Engineering Acceptance – Scale = 2.7, Confidence = C

This concept has a moderately low – moderate potential for acceptance compared to the VA Reference Design. The slightly lower rating is because of design goals violations and uncertainty with the effective lifetime. The effective lifetime of the concept is calculated to be 175,000 years.

5. Construction, Operations, and Maintenance – Scale = 2.8, Confidence = B

Construction, operations and maintenance issues have moderate disadvantages compared to the VA Reference Design. The slightly lower rating is because there is an increased risk of industrial accident due to additional construction activities.

6. Schedule – Confidence = C

The schedule for the closed/open loop for site characterization, design and construction is longer than the VA Reference Design. The longer site characterization schedule is anticipated due to possible change to repository footprint. The longer design schedule is anticipated due to the time needed to optimize this design. The longer construction schedule is anticipated due to the significant increase in construction activities. This concept would take an estimated 40 years to complete.

7. Cost – Confidence = B

The cost for the closed/open-loop concept has not been determined.

8. Environmental Considerations – Confidence = Not Rated.

Environmental considerations are discussed in Appendix C.

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11. APPENDICES

Appendix A: Pages A-1 to A-5
LADS Evaluation Criteria

Appendix B: Pages B-1 to B-10
LADS Criteria Responses

Appendix C: Pages C-1 to C-4
Environmental Considerations

Appendix D: Pages D-1 to D-5
Rockfall Calculations

Appendix E: Pages E-1 to E-2
Cost Estimate

Appendix F: Pages F-1 to F-3
Confidence Assessments

APPENDIX A
LADS EVALUATION CRITERIA

Author's Note: The following document was prepared by the LADS group for evaluating the design alternatives (CRWMS M&O 1998f). The evaluation criteria have been reproduced herein for reference.

The following questions are intended to solicit information from the leads for the design features (DF) and design alternatives (DA). This information is a subset of the overall evaluation criteria, which will be used for subsequent evaluations of the Enhanced Design Alternatives (EDA). Note that the evaluation criteria that are applicable only to enhanced design alternatives are not included here (e.g., defense in depth).

The responses to the questions below should be addressed in an Appendix to the 3-5 reports being developed for the DA and DFs. The responses should include a short explanation of the basis for the response.

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 the peak, considering two time periods:
 - a) less than 10,000 years and
 - 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:

$$\text{Timing FOM} = 1/(\ln 10^6 - \ln 10^3) \int_0^{1\text{My}} \dot{D}(t) \frac{dt}{t}$$

[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.

2. Pre-Closure Performance

What is your assessment of the pre-closure performance of your DF or DA 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.

- Would your DF or DA increase or decrease the probability of a Design Basis Event (DBE)?
- Would your DF or DA add a DBE? Is this DBE bounded by other DBEs?
- Would your DF or DA increase or decrease the consequences of a DBE?

- Does your DF or DA 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 or DA 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.

3. Assurance of Safety

What is your assessment of the assurance of safety of your DF or DA 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 or DA have uncertainties in post-closure performance.
- What is the potential to reduce the uncertainties by the time of construction and of closure?

Scale: 1 to 5. 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.

4. Engineering Acceptance

What is the potential for acceptance of the engineering design of your DA or 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 it 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.

5. Construction, Operations, and Maintenance

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

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

6. Schedule

For your DF or DA, how does the L.A. 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.

7. Cost

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

Scale: Cost in 1999 dollars. Costs which occur significantly later than the current schedule for the VA reference design should be noted where possible.

8. Environmental Considerations

What are the environmental considerations associated with your DF or DA relative to the VA Reference Design? (Pending completion of the formal evaluation of the environmental impacts by the EIS Contractor.)

APPENDIX B
LADS CRITERIA RESPONSES

Author's Note: The following tables summarize the LADS criteria evaluation of the post-closure ventilation design alternative #3 (DA#3). The LADS criteria are presented in Appendix A for reference. The confidence assessment criteria and detail are presented in Appendix F.

Table B-1. Evaluation of Closed-Loop (Bow-tie) Concept

QUESTION ¹	SCALE ²	CONFIDENCE ³	RESPONSE
1. Post-closure Performance		Design = C PA = E	
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 the peak, considering two time periods: a) less than 10,000 years	0.01388 mrem/yr		(Section 5.5.1)
b) between 10,000 years and 1,000,000 years	290.3 mrem/yr		(Section 5.5.1)
c) an evaluation of a figure of merit of the integrated dose should be included in the evaluation using a specified equation.	27.63 mrem/yr		(Section 5.5.1)
• If the potential for juvenile failures exist, provide this information to PA and include the discussion of results using the juvenile failure scenario.	0.01388 mrem/yr		This has equal potential for juvenile failures as the VA design. After juvenile failure, the dose rate decreases since no other packages fail during the first 10,000 years.
2. Preclosure Performance	3	A	
What is your assessment of the preclosure performance of Design Alternative #3 on a 1-5 scale?			The bow-tie configuration is expected to perform equally to the VA configuration in preclosure performance. The increased grade could produce an effect on the waste package impact energy as the result of a runaway gantry. Runaway gantry events are bounded by runaway transporter events. This design alternative is not expected to result in greater consequences than events previously evaluated.
• Would Design Alternative #3 increase or decrease the probability of a Design Basis Event (DBE)?	3		
• Would Design Alternative #3 add a DBE? Is this DBE bounded by other DBEs?	3		
• Would Design Alternative #3 increase or decrease the consequences of a DBE?	3		
• Does Design Alternative #3 increase or decrease challenges to the repository safety systems?	3		
• What expected dose to the public at the preclosure area boundary is calculated?	Not Available		
3. Assurance of Safety	2	C	
What is your assessment of the assurance of safety of Design Alternative #3 on a 1-5 scale?			The bow-tie configuration has more drifts and raises than the VA design. Therefore there is more potential for the increased exposure to rockfall which could impair the airflow and shutdown the natural ventilation cycle.
• Does Design Alternative #3 have uncertainties in post-closure performance?	2		
• What is the potential to reduce the uncertainties by the time of construction and of closure?	2		It is not likely that the uncertainty will be reduced by the time of construction and of closure because the prediction of tunnel failure, which could cause natural ventilation to stop, is difficult to predict.

QUESTION ¹	SCALE ²	CONFIDENCE ³	RESPONSE
4. Engineering Acceptance	2.7	C+	
<p>What is the potential for acceptance of the engineering design of Design Alternative #3 in a regulatory environment?</p> <ul style="list-style-type: none"> Can the function of each element in the design be clearly communicated? 	3		The bow-tie configuration and natural ventilation is simple and easy to understand. Airflow is driven by the difference in elevation between the inlet and exhaust ends of the emplacement drifts and heat supplied by the waste packages.
<ul style="list-style-type: none"> Which of the four elements of the repository safety strategy does it 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)? 	Not Applicable		This design alternative supports limited water contacting the waste packages. Allowing air to flow in the emplacement drifts after the repository is closed does this. The air keeps the emplacement drifts cooler and drier than the VA case.
<ul style="list-style-type: none"> Does the engineering analysis follow accepted methods? 	3		The ventilation system design used here is no different to those used in mining and tunneling.
<ul style="list-style-type: none"> Is the post-closure function simple to demonstrate? 	3		This alternative is simple to demonstrate. It is the use of natural ventilation, recirculating through the emplacement drifts, to evaporate water.
<ul style="list-style-type: none"> Is there regulatory and/or engineering precedence for your design? 	2		There is no regulatory precedence for this design alternative. There is engineering precedence.
<ul style="list-style-type: none"> What is the availability of qualified data to support your design likely to be in the LA time-frame? 	3		No additional data will be available over that currently available.
<ul style="list-style-type: none"> Is the design constructable with proven methods? 	3		This is the same concept as the VA design.
<ul style="list-style-type: none"> Are any high-level design goals for the MGR (such as the CDA) violated by the use of this design? 	2		This could violate the MGRRD requirement to retain the option of using emplacement drift backfill (Criteria 4.2.2).
<ul style="list-style-type: none"> 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? 	2,050,000 years		Rockfall calculations are provided in Appendix D.
5. Construction, Operations, and Maintenance	2.8	B	
<p>Are there any particular difficulties or advantages that Design Alternative #3 has relative to the VA reference design for the following construction, operations, and maintenance characteristics: Would Design Alternative #3 increase or decrease</p> <ul style="list-style-type: none"> worker radiation safety industrial safety? 	3 2		There is no affect to worker radiation safety. The additional drift development may increase the risk of industrial accidents.
<ul style="list-style-type: none"> Would Design Alternative increase or decrease reliability, availability, maintainability, and inspectability of manufactured and constructed items? 	3		There is no equipment operation required for this alternative and the repository will be sealed. Therefore reliability, availability, maintainability and inspectability of manufactured and constructed items does not apply.

QUESTION ¹	SCALE ²	CONFIDENCE ³	RESPONSE
<ul style="list-style-type: none"> Would Design Alternative increase or decrease throughput capability? 	3		This is a post-closure activity.
<ul style="list-style-type: none"> Would Design Alternative improve or decrease the ability to perform performance confirmation activities? 	3		This is a post-closure activity.
6. Schedule	28 years	C	
For Design Alternative #3, how does the LA schedule compare to that for the VA reference design? <ul style="list-style-type: none"> Site characterization Design Licensing Construction 	0 years 1 year 2 years 25 years		No additional site characterization activities are anticipated. Design is anticipated to take minimal additional time. Additional time is anticipated for licensing because this violates the requirements for backfill included with "permanent closure." Construction of the bow-tie emplacement drifts is expected to be achievable within the VA design schedule by the use of additional equipment and simultaneous excavations.
7. Cost		B	
What is the difference in estimated total cost relative to the VA Reference Design? (Conceptual Design Estimating is applicable-- $\pm 50\%$)	\$575 million		Cost data summary is provided in Appendix E.
8. Environmental Considerations	⁴	Not Rated	
What are the environmental considerations associated with Design Alternative #3 relative to the VA Reference Design? (Pending completion of the formal evaluation of the environmental impacts by the EIS Contractor.)	Not Rated		The environmental considerations are discussed in the questionnaire in Appendix C.

¹ LADS Criteria Questions are detailed in LADS Evaluation Criteria, Appendix A.

² Scale ratings are detailed in LADS Evaluation Criteria, Appendix A.

³ Confidence ratings are detailed in Confidence Assessments, Appendix F. All assessments of confidence were made by the lead design engineer (LDE) except for post-closure performance, which had one assessment made by the LDE and another by the performance assessment (PA) analyst.

⁴ Environmental Considerations were not rated.

Table B-2. Evaluation of Open-Loop (Modified VA Design) Concept

QUESTION ¹	SCALE ²	CONFIDENCE ³	RESPONSE
1. Post-closure Performance		Design = C PA = E	
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 the peak, considering two time periods: a) less than 10,000 years	0.007906 mrem/yr		(Section 6.5.1)
b) between 10,000 years and 1,000,000 years	268.9 mrem/yr		(Section 6.5.1)
c) an evaluation of a figure of merit of the integrated dose should be included in the evaluation using a specified equation.	24.92 mrem/yr		(Section 6.5.1)
• If the potential for juvenile failures exist, provide this information to PA and include the discussion of results using the juvenile failure scenario.	0.007906 mrem/yr		This has equal potential for juvenile failures as the VA design. After juvenile failure, the dose rate decreases since no other packages fail during the first 10,000 years.
2. Preclosure Performance	3	A	
What is your assessment of the preclosure performance of Design Alternative #3 on a 1-5 scale?			The open-loop configuration is expected to perform equally to the VA configuration in preclosure performance.
• Would Design Alternative #3 increase or decrease the probability of a Design Basis Event (DBE)?	3		
• Would Design Alternative #3 add a DBE? Is this DBE bounded by other DBEs?	3		
• Would Design Alternative #3 increase or decrease the consequences of a DBE?	3		
• Does Design Alternative #3 increase or decrease challenges to the repository safety systems?	3		
• What expected dose to the public at the preclosure area boundary is calculated?	Not Applicable		
3. Assurance of Safety	2	C	
What is your assessment of the assurance of safety of Design Alternative #3 on a 1-5 scale?			The open-loop configuration is the same concept as the VA design. However, for natural ventilation to provide long-term cooling and moisture removal, airflow must be maintained in the drifts. There is potential for rockfall to impair the airflow and shutdown the natural ventilation cycle.
• Does Design Alternative #3 have uncertainties in post-closure performance?	2		
• What is the potential to reduce the uncertainties by the time of construction and of closure?	2		It is not likely that the uncertainty will be reduced by the time of construction and of closure.

QUESTION ¹	SCALE ²	CONFIDENCE ³	RESPONSE
4. Engineering Acceptance	2.7	A	
<p>What is the potential for acceptance of the engineering design of Design Alternative #3 in a regulatory environment?</p> <ul style="list-style-type: none"> Can the function of each element in the design be clearly communicated? 	3		The open-loop configuration is simple and easy to understand. The difference in elevation between the shaft collars and ramp portals, along with the heat generated by the waste packages, cause air to flow by natural ventilation through the repository.
<ul style="list-style-type: none"> Which of the four elements of the repository safety strategy does it 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)? 	Not Applicable		This design alternative's objective is to extend the waste package lifetime by reducing drift air temperature and moisture which limits the amount of water contacting the waste packages. Allowing air to continue flowing in the emplacement drifts does this. The air keeps the drifts cooler and drier than the VA case.
<ul style="list-style-type: none"> Does the engineering analysis follow accepted methods? 	3		The ventilation calculations use the same software and method as in the VA design.
<ul style="list-style-type: none"> Is the post-closure function simple to demonstrate? 	3		This alternative is simple to demonstrate. It is the use of natural ventilation, circulating through the emplacement drifts, to remove heat and evaporate water to the surface.
<ul style="list-style-type: none"> Is there regulatory and/or engineering precedence for your design? 	2		There is no regulatory precedence for this design alternative. There is engineering precedence. The design is a slightly modified VA design.
<ul style="list-style-type: none"> What is the availability of qualified data to support your design likely to be in the LA time-frame? 	3		The data is currently available.
<ul style="list-style-type: none"> Is the design constructable with proven methods? 	3		This is the same concept as the VA design.
<ul style="list-style-type: none"> Are any high-level design goals for the MGR (such as the CDA) violated by the use of this design? 	2		This is the same concept as the VA design. However, it is an open-loop design operating after "closure." This violates 10 CFR 60's requirement for permanent closure (Section 4.3).
<ul style="list-style-type: none"> 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? 	175,000 years		Rockfall calculations are provided in Appendix D.
5. Construction, Operations, and Maintenance	2.8	B	
<p>Are there any particular difficulties or advantages that Design Alternative #3 has relative to the VA reference design for the following construction, operations, and maintenance characteristics: Would Design Alternative #3 increase or decrease</p> <ul style="list-style-type: none"> worker radiation safety industrial safety? 	3 2		There is no affect to worker radiation safety. The additional shaft development may increase the risk of industrial accidents.
<ul style="list-style-type: none"> Would Design Alternative increase or decrease reliability, availability, maintainability, and inspectability of manufactured and constructed items? 	3		Since there is no equipment operation required for this alternative. Reliability, availability, maintainability and inspectability of manufactured and constructed items does not apply.

QUESTION ¹	SCALE ²	CONFIDENCE ³	RESPONSE
<ul style="list-style-type: none"> Would Design Alternative increase or decrease throughput capability? 	3		This is a post-closure activity.
<ul style="list-style-type: none"> Would Design Alternative improve or decrease the ability to perform performance confirmation activities? 	3		This is a post-closure activity.
6. Schedule	27 years	C	
<p>For Design Alternative #3, how does the LA schedule compare to that for the VA reference design?</p> <ul style="list-style-type: none"> Site characterization Design Licensing Construction 	<p>0 years</p> <p>0 years</p> <p>2 years</p> <p>25 years</p>		<p>No additional site characterization activities are anticipated.</p> <p>No additional design is anticipated.</p> <p>Because this is a major departure from the VA design (by violating "permanent closure"), significant additional time may be required for licensing.</p> <p>Construction of the open-loop configuration is the same as the VA design. The VA design schedule can be maintained.</p>
7. Cost		B	
What is the difference in estimated total cost relative to the VA Reference Design? (Conceptual Design Estimating is applicable--±50%)	\$244 million		Cost data summary is provided in Appendix E.
8. Environmental Considerations	⁴	Not Rated	
What are the environmental considerations associated with Design Alternative #3 relative to the VA Reference Design? (Pending completion of the formal evaluation of the environmental impacts by the EIS Contractor.)	Not Rated		The environmental considerations are discussed in the questionnaire in Appendix C.

¹ LADS Criteria Questions are detailed in LADS Evaluation Criteria, Appendix A.

² Scale ratings are detailed in LADS Evaluation Criteria, Appendix A.

³ Confidence ratings are detailed in Confidence Assessments, Appendix F. All assessments of confidence were made by the lead design engineer (LDE) except for post-closure performance, which had one assessment made by the LDE and another by the performance assessment (PA) analyst.

⁴ Environmental Considerations were not rated.

Table B-3. Evaluation of Closed/Open-Loop Concept

QUESTION ¹	SCALE ²	CONFIDENCE ³	RESPONSE
1. Post-closure Performance		Design = C PA = E	
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 the 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 using a specified equation.	Not Evaluated Not Evaluated Not Evaluated		
• If the potential for juvenile failures exist, provide this information to PA and include the discussion of results using the juvenile failure scenario.	Not Evaluated		This has equal potential for juvenile failures as the VA design.
2. Preclosure Performance	3	A	
What is your assessment of the preclosure performance of Design Alternative #3 on a 1-5 scale? • Would Design Alternative #3 increase or decrease the probability of a Design Basis Event (DBE)?	3		The closed/open-loop configuration is expected to perform equally to the VA configuration in preclosure performance.
• Would Design Alternative #3 add a DBE? Is this DBE bounded by other DBEs?	3		
• Would Design Alternative #3 increase or decrease the consequences of a DBE?	3		
• Does Design Alternative #3 increase or decrease challenges to the repository safety systems?	3		
• What expected dose to the public at the preclosure area boundary is calculated?	Not Available		
3. Assurance of Safety	2	C	
What is your assessment of the assurance of safety of Design Alternative #3 on a 1-5 scale? • Does Design Alternative #3 have uncertainties in post-closure performance?	2		The closed/open-loop configuration has significantly more drifts and raises than the VA design. There is some potential for the increased exposure to rockfall to impair the airflow and shutdown the natural ventilation cycle both within the "closed" emplacement drifts and the "open" cooling drifts.
• What is the potential to reduce the uncertainties by the time of construction and of closure?	2		It is not likely that the uncertainty will be reduced by the time of construction and of closure.

QUESTION ¹	SCALE ²	CONFIDENCE ³	RESPONSE
4. Engineering Acceptance	2.7	C	
<p>What is the potential for acceptance of the engineering design of Design Alternative #3 in a regulatory environment?</p> <ul style="list-style-type: none"> Can the function of each element in the design be clearly communicated? 	3		<p>The closed/open-loop configuration is simple and easy to understand. The repository is sealed and airflow and moisture removal within the emplacement drifts is driven by the adjacent open-loop cooling-drifts. The difference in elevation between the shaft collars and ramp portals, along with heat conducted through the rock, cause air to flow by natural ventilation through the cooling drifts.</p>
<ul style="list-style-type: none"> Which of the four elements of the repository safety strategy does it 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)? 	Not Applicable		<p>This design alternative supports limited water contacting the waste packages. This design alternative's objective is to extend the waste package lifetime using natural ventilation to reduce drift air temperature and relative humidity while still meeting permanent closure requirements.</p>
<ul style="list-style-type: none"> Does the engineering analysis follow accepted methods? 	3		<p>A very simple engineering judgement approach was used for this design concept.</p>
<ul style="list-style-type: none"> Is the post-closure function simple to demonstrate? 	3		<p>This alternative is simple to demonstrate. It is the use of thermal conductivity through the rockmass, surrounding the emplacement drifts, to remove heat and evaporate water to the adjacent cooling drifts.</p>
<ul style="list-style-type: none"> Is there regulatory and/or engineering precedence for your design? 	2		<p>There is no regulatory precedence for this design alternative. There is engineering precedence.</p>
<ul style="list-style-type: none"> What is the availability of qualified data to support your design likely to be in the LA time-frame? 	3		<p>No additional data will be available over that currently available.</p>
<ul style="list-style-type: none"> Is the design constructable with proven methods? 	3		<p>This is the same concept as the VA design.</p>
<ul style="list-style-type: none"> Are any high-level design goals for the MGR (such as the CDA) violated by the use of this design? 	2		<p>The cooling section could violate 10 CFR 60's requirement for permanent closure (Section 4.3).</p>
<ul style="list-style-type: none"> 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? 	175,000 years		<p>Rockfall calculations are provided in Appendix D. No calculation is performed for this concept, but the radiator drifts may be expected to have a similar lifetime to the open-loop concept.</p>
5. Construction, Operations, and Maintenance	2.8	B	
<p>Are there any particular difficulties or advantages that Design Alternative #3 has relative to the VA reference design for the following construction, operations, and maintenance characteristics: Would Design Alternative #3 increase or decrease</p> <ul style="list-style-type: none"> worker radiation safety industrial safety? 	3 2		<p>There is no affect to worker radiation safety. The additional drift development may increase the risk of industrial accidents.</p>

QUESTION ¹	SCALE ²	CONFIDENCE ³	RESPONSE
<ul style="list-style-type: none"> Would Design Alternative increase or decrease reliability, availability, maintainability, and inspectability of manufactured and constructed items? 	3		There is no equipment operation required for this alternative and the repository will be sealed. Therefore reliability, availability, maintainability and inspectability of manufactured and constructed items does not apply.
<ul style="list-style-type: none"> Would Design Alternative increase or decrease throughput capability? 	3		This is a post-closure activity.
<ul style="list-style-type: none"> Would Design Alternative improve or decrease the ability to perform performance confirmation activities? 	3		This is a post-closure activity.
6. Schedule	40 years	C	
<p>For Design Alternative #3, how does the LA schedule compare to that for the VA reference design?</p> <ul style="list-style-type: none"> Site characterization Design Licensing Construction 	<p>1 year</p> <p>1 year</p> <p>2 years</p> <p>38 years</p>		<p>Some additional site characterization activities may be required due to the increase in repository footprint. Design is anticipated to take minimal additional time. Additional time is anticipated for licensing because this violates the requirements for backfill included with "permanent closure." Construction of the closed/open-loop configuration is expected to take significantly longer than the VA design schedule. Further analysis is required to determine optimum layout for cooling drifts. The construction schedule will be affected by choice of location for cooling drifts and investment in additional boring equipment.</p>
7. Cost		B	
What is the difference in estimated total cost relative to the VA Reference Design? (Conceptual Design Estimating is applicable--±50%)	Not Available		Costs were not evaluated for this concept.
8. Environmental Considerations	⁴	Not Rated	
What are the environmental considerations associated with Design Alternative #3 relative to the VA Reference Design? (Pending completion of the formal evaluation of the environmental impacts by the EIS Contractor.)	Not Rated		The environmental considerations are discussed in the questionnaire in Appendix C.

¹ LADS Criteria Questions are detailed in LADS Evaluation Criteria, Appendix A.

² Scale ratings are detailed in LADS Evaluation Criteria, Appendix A.

³ Confidence ratings are detailed in Confidence Assessments, Appendix F. All assessments of confidence were made by the lead design engineer (LDE) except for post-closure performance, which had one assessment made by the LDE and another by the performance assessment (PA) analyst.

⁴ Environmental Considerations were not rated.

APPENDIX C
ENVIRONMENTAL CONSIDERATIONS

Author's Note: The following document was prepared to provide engineering and technical information about this alternative to the Environmental Impact Statement (EIS) contractor. The document consists of answers to questions posed by the environmental staff and was compiled in the early stages of the evaluation. For this reason, the numbers and concepts may not totally agree with those presented in this study. Details of this appendix are not subject to QARD (DOE 1998a) requirements.

Interview Notes: by G. K. Beall

Three primary concepts are considered:

1. Closed Loop airways will be connected underground but sealed to the surface.
2. Open Loop airways to the surface will remain open after closure.
3. Open/Closed Loop ventilation loops will be separated from the emplacement drifts.
Emplacement drifts will be sealed off, but ventilation loops would remain open to the surface after closure.

1. Impacts to land use and ownership

Land use – Muck piles would increase by less than 25%. Additional shafts may result in additional (small, relative to the reference design) disturbed areas for either open loop or open/closed loop designs. The disturbed areas may be either in the area between the portals or directly above the footprint of the repository.

Land ownership – Not applicable. Features and alternatives are not expected to change potential impacts to land ownership.

2. Impacts to air quality

Nonradiological impacts – more underground excavation (and localized rock falls) would result in generation of more dust. Effects are likely to be less than 25% relative to the reference design.

Radiological impacts – additional occupational exposure to Radon-222 (effects are likely to be less than 25% relative to the reference design)

- closed loop design- no long term negative impacts to above ground air quality
- open loop design – ventilation across waste package may result in additional air emissions if a waste package fails
- open/close loop design – waste package in sealed drifts, no negative long-term impacts to air at the surface

3. Impacts to hydrology, including surface water and groundwater

Post-closure ventilation would increase removal of moisture for a period of time (est. up to 1000-2000 years for the closed loop system), but eventually moisture would reestablish itself. In the open loop and open/closed loop systems, moisture would be ventilated to the atmosphere.

4. Impacts to biological resources and soils

Additional disturbed areas would be small. Volume of the muck pile would increase less than 25%. Surface temperature would increase less than in the reference design.

5. Impacts to cultural resources

None expected – location of exhaust shafts could be selected to avoid cultural sites.

6. Socioeconomic impacts

Overall, work force would increase less than 10%.

7. Impacts to occupational and public health and safety

More underground excavation would increase chances for industrial accidents.

In the open loop system – radioactive particulates may be released to the atmosphere, increasing impacts to public health. Likelihood of this occurrence and the quantities released are expected to be very small.

In the closed loop and open/closed systems – radiological releases would not be affected.

Long term, there would be potential for a reduced dose at the boundaries, and any releases would occur at a latter date.

8. Noise impacts

No significant impacts.

9. Impacts on aesthetics

Closed loop –larger muck piles

Open loop and open/closed loop – larger muck piles, additional (small) disturbed areas for ventilation shafts, possibility of a visible moisture plume in winter conditions when hot and humid air is exhausted to the cold atmosphere

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

Increased demand for power but no impacts on availability.

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

None

12. Impacts to environmental justice

None

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

The post closure ventilation concept may not be technically viable for the low thermal load, because there may not be sufficient temperature differential for the system to improve performance of the repository.

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

- Uncanistered (commercial fuel shipped by legal weight truck in transportation casks, and moved to disposal containers at YM site; DOE HLW and fuel shipped in DOE disposable canisters)
No impacts.
- DPC (dual purpose canisters will have to be cut open and fuel transferred to disposal canisters at YM site)
No impacts.
- Disposable canisters (DOE and commercial shipments arriving in canisters that can be placed in the disposal containers)

No impacts in conjunction with normal configuration, but disposable canisters may need to be specially designed for certain WP placement/ventilation configurations (for example, in vertical boreholes)

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

Increased volume of excavation, muck piles, and power usage (if electric fans are operated after closure). The open loop system may violate the concept of "closure".

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

Improvement of performance by retardation of WP corrosion.

The open loop system – ventilation to the atmosphere may have negative impacts on air quality.

APPENDIX D
ROCKFALL CALCULATIONS

Emplacement Shaft Rockfall Tonnage Calculation

DATA

Total Length (L), Shaft (m): 422 (Parameter 4.1.5)

ASSUMPTIONS

Estimate of rockfall frequency for shaft is not available, use the rockfall frequency for drift provided in Parameter 4.1.11:

Low Estimate for per unit length Rockfall Frequency (/km/yr): 9.40E-05
Best Estimate for per unit length Rockfall Frequency (/km/yr): 9.40E-04
High Estimate for per unit length Rockfall Frequency (/km/yr): 9.40E-03

NOTE: See Section 5.4.2 for discussion of the level of confidence in rockfall calculations.

Block size distribution for the Tptpmn unit oriented at N72W (Parameter 4.1.12) is used as the block size distribution along the entire length of the shaft.

Table D-1. Estimated Number of Rockfall per Year in Shaft

High estimate	Best estimate	Low estimate
L*9.40E-03/1000	L*9.40E-04/1000	L*9.40E-05/1000
3.97E-03	3.97E-04	3.97E-05

Table D-2. Rockfall Tonnage

Tptpmn Unit			Number of Rockfall per year			Calculated Tonnage per year		
Block Size (tonne)	Cumulative %	Probability Density (%)	High estimate	Best estimate	Low estimate	High estimate	Best estimate	Low estimate
Col A	Col B	Col C	Col D	Col E	Col F	Col G	Col H	Col I
Input: Parameter 4.1.12	Input: Parameter 4.1.12	Step Delta of Col B	3.97E-03*C	3.97E-04*C	3.97E-05*C	D*A	E*A	F*A
0.001	1.97%	1.97%	7.81E-05	7.81E-06	7.81E-07	7.81E-08	7.81E-09	7.81E-10
0.01	9.99%	8.02%	3.18E-04	3.18E-05	3.18E-06	3.18E-06	3.18E-07	3.18E-08
0.1	34.05%	24.06%	9.54E-04	9.54E-05	9.54E-06	9.54E-05	9.54E-06	9.54E-07
1	76.13%	42.08%	1.67E-03	1.67E-04	1.67E-05	1.67E-03	1.67E-04	1.67E-05
2	86.57%	10.44%	4.14E-04	4.14E-05	4.14E-06	8.28E-04	8.28E-05	8.28E-06
5	95.56%	8.99%	3.57E-04	3.57E-05	3.57E-06	1.78E-03	1.78E-04	1.78E-05
8	97.59%	2.03%	8.05E-05	8.05E-06	8.05E-07	6.44E-04	6.44E-05	6.44E-06
10	98.35%	.76%	3.01E-05	3.01E-06	3.01E-07	3.01E-04	3.01E-05	3.01E-06
20	99.65%	1.30%	5.16E-05	5.16E-06	5.16E-07	1.03E-03	1.03E-04	1.03E-05
30	99.87%	.22%	8.73E-06	8.73E-07	8.73E-08	2.62E-04	2.62E-05	2.62E-06
40	99.94%	.07%	2.78E-06	2.78E-07	2.78E-08	1.11E-04	1.11E-05	1.11E-06
50	99.97%	.03%	1.19E-06	1.19E-07	1.19E-08	5.95E-05	5.95E-06	5.95E-07
100	100.00%	.03%	1.19E-06	1.19E-07	1.19E-08	1.19E-04	1.19E-05	1.19E-06
More	100.00%							
			Sum of Tonnage			6.91E-03	6.91E-04	6.91E-05

Rock Density = 2.34 t/m³ (Parameter 4.1.6)

Bulking Factor = 1.5 (Assumption 4.4.2.2)

Bulk Density = 1.56 t/m³ (Rock Density/Bulking Factor)

Rock tonnage required to block sump and drift at base of emplacement shaft:

Shaft Diameter = 6.7 m (Parameter 4.1.7)

Sump depth = 5.0 m (Parameter 4.1.5)

Access Drift Height = 7.0 m (Parameter 4.1.9)

Blockage Height = 10.0 m (Assumption 4.4.2.3)

Approximate volume of rock to fill sump and access drift opening:

(Volume = Sump Vol. plus C/S Area of Shaft times Height of Access Drift plus 10 m)

$$\pi/4[(6.7)^2 \times 5 + (6.7)^2 \times (7+10)] = 775.55 \text{ m}^3$$

Approximate tonnage to fill sump and drift at base of emplacement shaft:

(Tonnage = Volume times Bulk Density)

$$775.55 \text{ m}^3 \times 1.56 \text{ t/m}^3 = 1209.853 \text{ tonnes}$$

Approximate time for blockage to occur:

(Time = Tonnes Rock divided by the High Estimate Calculated tonnes of Rockfall per Year from Table D-2)

$$1209.853 \text{ t} / 6.91\text{E-}03 \text{ t/y} = 175145 \text{ years}$$

(Rounded) 175000 years

Raise Rockfall Tonnage Calculation

DATA

Total Length (L) of Raise (m): 19.4 (Assumption 4.4.1.6)

ASSUMPTIONS

Estimate of rockfall frequency for shaft is not available, use the rockfall frequency for drift provided in Parameter 4.1.11:

Low Estimate for per unit length Rockfall Frequency (/km/yr): 9.40E-05
 Best Estimate for per unit length Rockfall Frequency (/km/yr): 9.40E-04
 High Estimate for per unit length Rockfall Frequency (/km/yr): 9.40E-03

NOTE: See Section 5.4.2 for discussion of the level of confidence in rockfall calculations.

Block size distribution for the Tptpmn unit oriented at N72W (Parameter 4.1.12) is used as the block size distribution along the entire length of the raise.

Table D-3. Estimated Number of Rockfall per Year in Raise

High estimate	Best estimate	Low estimate
L*9.40E-03/1000	L*9.40E-04/1000	L*9.40E-05/1000
1.82E-04	1.82E-05	1.82E-06

Table D-4. Rockfall Tonnage

Tptpmn Unit			Number of Rockfall per year			Calculated Tonnage per year		
Block Size (tonne)	Cumulative %	Probability Density (%)	High estimate	Best estimate	Low estimate	High estimate	Best estimate	Low estimate
Col A	Col B	Col C	Col D	Col E	Col F	Col G	Col H	Col I
Input: Parameter 4.1.12	Input: Parameter 4.1.12	Step delta of Col B	1.82E-04°C	1.82E-05°C	1.82E-06°C	D*A	E*A	F*A
0.001	1.97%	1.97%	3.59E-06	3.59E-07	3.59E-08	3.59E-09	3.59E-10	3.59E-11
0.01	9.99%	8.02%	1.46E-05	1.46E-06	1.46E-07	1.46E-07	1.46E-08	1.46E-09
0.1	34.05%	24.06%	4.39E-05	4.39E-06	4.39E-07	4.39E-06	4.39E-07	4.39E-08
1	76.13%	42.08%	7.67E-05	7.67E-06	7.67E-07	7.67E-05	7.67E-06	7.67E-07
2	86.57%	10.44%	1.90E-05	1.90E-06	1.90E-07	3.81E-05	3.81E-06	3.81E-07
5	95.56%	8.99%	1.64E-05	1.64E-06	1.64E-07	8.20E-05	8.20E-06	8.20E-07
8	97.59%	2.03%	3.70E-06	3.70E-07	3.70E-08	2.96E-05	2.96E-06	2.96E-07
10	98.35%	.76%	1.39E-06	1.39E-07	1.39E-08	1.39E-05	1.39E-06	1.39E-07
20	99.65%	1.30%	2.37E-06	2.37E-07	2.37E-08	4.74E-05	4.74E-06	4.74E-07
30	99.87%	.22%	4.01E-07	4.01E-08	4.01E-09	1.20E-05	1.20E-06	1.20E-07
40	99.94%	.07%	1.28E-07	1.28E-08	1.28E-09	5.11E-06	5.11E-07	5.11E-08
50	99.97%	.03%	5.47E-08	5.47E-09	5.47E-10	2.74E-06	2.74E-07	2.74E-08
100	100.00%	.03%	5.47E-08	5.47E-09	5.47E-10	5.47E-06	5.47E-07	5.47E-08
More	100.00%							
					Sum of Tonnage	3.18E-04	3.18E-05	3.18E-06

Rock Density = 2.34 t/m³ (Parameter 4.1.6)

Bulking Factor = 1.5 (Assumption 4.4.1.5)

Bulk Density = 1.56 t/m³ (Rock Density/Bulking Factor)

Rock tonnage required to block sump and emplacement drift at base of raise:

Raise Diameter = 5.5 m (Assumption 4.4.1.7)

Main Height = 7.62 m (Parameter 4.1.10)

Blockage Height = 10.0 m (Assumption 4.4.1.8)

Approximate volume of rock to fill drift opening and bottom of raise:

(Volume = C/S Area of Raise times Height of Main plus 10.0 m)

$$\pi/4 (5.5)^2 \times (7.62 + 10) = 418.57 \text{ m}^3$$

Approximate tonnage to fill drift at base of the raise:

(Tonnage = Volume times Bulk Density)

$$418.57 \text{ m}^3 \times 1.56 \text{ t/m}^3 = 652.97 \text{ tonnes}$$

Approximate time for blockage to occur:

(Time = Tonnes rock divided by the High Estimate Calculated tonnes of Rockfall per Year from Table D-4)

$$652.97 \text{ t} / 3.18\text{E-}04 \text{ t/y} = 2056212 \text{ years}$$

(Rounded) 2050000 years

APPENDIX E
COST ESTIMATE

Table E-1. Design Alternative Evaluation #3 – Post-Closure Ventilation Estimate Summary

[illegible]

APPENDIX F
CONFIDENCE ASSESSMENTS

Author's Note: The following confidence assessment provides the scales of confidence used in the assessment, and the results of the assessment, for design alternative #3 – post-closure ventilation. This information was reproduced from CRWMS M&O (1999e, pages 1, 22 and 23). The confidence assessments and explanations for these items are provided herein for the first time.

SCALES OF CONFIDENCE

- High level of confidence (A): the assessment is readily supported, defensible, and not subject to much 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 weaknesses in terms of defensibility, and subject to considerable uncertainty.

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

DA 3 – CONTINUOUS POST-CLOSURE VENTILATION DESIGN

Three options are considered: a closed-loop concept, an open-loop concept and a closed/open-loop concept. The latter option is not as well developed as the former two.

Post-closure Performance (LDE)

Moderate (C) level of confidence. PA models are straightforward. Rockfall has not been completely modeled and incorporated.

Post-closure Performance (PA Analyst)

Low (E) level of confidence. Additional work is needed to integrate ventilation issues into PA. Preliminary results are similar to VA base case results. Failure modes are not incorporated. Thermodynamic equilibrium assumptions may not be correct.

Preclosure Performance

High (A) level of confidence. This alternative may not affect preclosure performance.

Assurance of Safety

Moderate (C) level of confidence. Long-term survivability of open drifts and shafts is uncertain. Obstruction from rockfalls could negate the system; this possible scenario will be difficult to defend in the licensing stage. The potential for air-borne releases is uncertain.

Engineering Acceptance

Closed-loop option: moderately high (C+) level of confidence. The amount of moisture that will be re-circulated is uncertain.

Open-loop option: high (A) level of confidence. This alternative is similar to the VA base case.

Closed/open-loop option: moderate (C) level of confidence. This alternative would require additional study.

It has not been clearly demonstrated that moisture removal is effective protection for the waste packages. There is moderate confidence that the ventilation system will operate for more than 10,000 years, but rockfall effects are a fundamental question.

Construction, Operations, and Maintenance

Moderately high (B) level of confidence. The construction of a larger number of drifts will result in greater risk to workers.

Schedule

Moderate (C) level of confidence. The open-loop option could require additional time for licensing questions. The closed/open-loop would require additional construction (separate shafts, ramps, and access points) beyond what is planned for the VA base case.

Cost

Moderately high (B) level of confidence for closed-loop and open-loop options. A design has not been developed for the closed/open-loop option, so no cost estimates are available. Further analysis of the closed/open-loop option could be very useful; drift cost would probably be about 2x the VA base case design.