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## OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
## ANALYSIS/MODEL COVER SHEET

1. QA: L

Page: 1 of: 17

*Complete Only Applicable Items*

2. ☑ Analysis — ☑ Engineering; ☐ Performance Assessment; ☐ Scientific

3. ☐ Model — ☐ Conceptual Model Documentation; ☐ Model Documentation; ☐ Model Validation Documentation

4. Title:
Evaluation of Alternative Materials for Emplacement Drift Ground Control

5. Document Identifier (including Rev. No. and Change No., if applicable):
BCAA00000-01717-0200-00013 REV 00

6. Total Attachments:
Three

7. Attachment Numbers - No. of Pages in Each:
I-1, II-2, III-12

| | Printed Name | Signature | Date |
|---|---|---|---|
| 8. Originator | Gerald Thiers | Gerald R. Thiers | 6/17/99 |
| 9. Checker | David Tang | David Tang | 6/17/99 |
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12. Remarks:

Typo corrected in header of Page II-2 of II-2 of Attachment II.
DGM III
7/19/99



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# OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
# ANALYSIS/MODEL REVISION RECORD



***Complete Only Applicable Items***

2. Analysis or Model Title:
Evaluation of Alternative Materials for Emplacement Drift Ground Control

3. Document Identifier (including Rev. No. and Change No., if applicable):

BCAA00000-01717-0200-00013 REV 00

| 4. Revision/Change No. | 5. Description of Revision/Change |
|---|---|
| 00 | Initial issue |
| | O:\RUD\Thiers\desan2.dbf |

# 1. PURPOSE

The section defines the purpose and scope of the analysis.

## 1.1 PURPOSE

The purpose of this analysis is to evaluate materials proposed for emplacement drift ground control, and to develop a recommendation for the material (s) to be used in License Application (LA) Design. The Work Direction is given in CRWMS M&O 1999a. A summary of previous work concerning possible materials for ground control is presented in Attachment III.

## 1.2 SCOPE

The materials are evaluated for the following repository design options:

- Viability Assessment (VA) Reference Design (CRWMS M&O 1999b)
- Proposed LA Design (CRWMS M&O 1999c)

Ground control includes the ground support (elements installed to prevent movement of rock into the drift) and invert structures (elements installed to provide a foundation for waste package handling and support systems, and in some cases to form a base for the ground support elements).

Based on the Work Direction, evaluation will be based solely on consideration of the potential postclosure effects on waste isolation.

Per the Work Direction, the analysis comprises the following tasks:

- Identify candidate ground control materials for use in emplacement drifts.
- Review existing documents concerning postclosure behavior of the repository, to identify 1) parameters and criteria to be used for evaluation of postclosure performance and 2) predicted potential postclosure effects of candidate ground control materials.
- Compare predicted effects to criteria, and recommend material (s) to be used in LA Design.

## 2. QUALITY ASSURANCE

An activity evaluation (CRWMS M&O 1999d) performed in accordance with QAP-2-0, *Conduct of Activities*, has determined that this analysis is subject to requirements described in the Quality Assurance Requirements and Description (QARD) document (DOE 1998a). The design analysis conforms to AP-3.10Q, *Analyses and Models.* (CRWMS M&O 1999e). Due to the conceptual nature of the evaluation, unqualified input is identified as TBV, but not tracked with a TBV number per NLP-3-15.

## 3. COMPUTER SOFTWARE AND MODEL USAGE

Not Used [No computer software or models were required for the evaluation.]

## 4. INPUTS

### 4.1 PARAMETERS

The results of analyses of the VA Reference Design are presented in the *Viability Assessment of a Repository at Yucca Mountain* (VA) (DOE 1998b). The critical dimensions and thermal loading used in the VA Analyses are listed in Table 4-1:

**Table 4-1 Critical Dimensions and Thermal Loading: VA Analyses**

| Dimension or Thermal Loading | Base Case Values | Source of Values[1] |
|---|---|---|
| Repository Area | 300 hectares[2] | Vol. 2, Sec. 4.2.1.2, p. 4-45 |
| Number of Waste Packages | 10,500[2] | Vol. 2, Sec. 4.2.1.2, p. 4-45 |
| Emplacement Drift Diameter | 5.5 m | Vol. 2, Sec. 4.2.1.2, p. 4-45 |
| Emplacement Drift Spacing | 28 m | Vol. 2, Sec. 4.2.1.2, p. 4-45 |
| Number of Emplacement Drifts | 105 | Vol. 2, Sec. 4.2.1.2, p. 4-45 |
| Thickness of Concrete Lining | 200 mm to 250 mm | Vol. 2, Figs. 4-25 & 4-26 |
| Steel Set Size | W6x20 | Vol.2 Fig. 4-27 |
| Waste Package Diameter | 1.3m to 2.0 m[2] | CRWMS M&O 1999b, pp. 39, 41 |
| Waste Package Outer Barrier Material and Thickness | A 516 Carbon Steel 100 mm | Vol. 2, Sec. 5.1.2.1, p. 5-8 |
| Waste Package Inner Barrier Material and Thickness | Alloy 22 20 mm | Vol. 2, Sec. 5.1.2.1, p. 5-8 |
| Thermal Loading | 80 to 100 MTU/acre | Vol. 2, Sec. 3.2.1, p. 3-4 |

[1] Source in DOE 1998b, plus reference cited for waste package diameters

[2] Values are approximate.

The hydrologic and geochemical parameters used in the VA analyses are listed in Table 4-2:

**Table 4-2 Hydrologic and Geochemical Parameters: VA Analyses**

| Parameter | Value for Base Case | Source[1] | Value for Concrete-Modified Water Case[2] | Source[1] |
|---|---|---|---|---|
| Percolation Rate- Current | 7.7 mm/year | p. 3-15, Table 3-5 | Same as Base Case | Same as Base Case |
| Percolation Rate-Long Term | 42 mm/year | p. 3-15, Table 3-5 | Same as Base Case | Same as Base Case |
| Percolation Rate-Superpluvial | 110 mm/year | p. 3-15, Table 3-5 | Same as Base Case | Same as Base Case |
| pH of Water In Drift | 8.1 to 10.2 | p. 3-69, Fig. 3-37a Middle Graph | 7.4 to 11.0 | p. 3-69, Fig. 3-37a Lower Graph |
| UZ Kd Values[3] [4] ml/g | | | | |
| Plutonium-D, V, & Z Rock | 100 | (4) | 0 | Sec. 5.3.2.1, p. 5-12 |
| Plutonium-Fe Rock | 3,000[5] | (4) | 0 | Sec. 5.3.2.1, p. 5-12 |
| Uranium-D, V, &Z Rock | 1 to 7 | (4) | 0 | Sec. 5.3.2.1, p. 5-12 |
| Uranium-Fe Rock | 550[5] | (4) | 0 | Sec. 5.3.2.1, p. 5-12 |
| Neptunium-D, V, & Z Rock | 1 to 4 | (4) | 0 | Sec. 5.3.2.1, p. 5-12 |
| Neptunium-Fe Rock | 750[5] | (4) | 0 | Sec. 5.3.2.1, p. 5-12 |
| Protactinium-D, V, & Z Rock | 50[5] | (4) | 0 | Sec. 5.3.2.1, p. 5-12 |
| Protactinium-Fe Rock | 750[5] | (4) | 0 | Sec. 5.3.2.1, p. 5-12 |

(1) Source in DOE 1998b, Vol. 3, except for base case Kd values. (See Footnote 4.)
(2) Concrete-modified water is described in DOE 1998b, Vol. 3, pp. 3-63 & 3-64, Sec. 3.3.2.2 & pp.5-11 & 5-12, Sec. 5.3.2.1.
(3) UZ = unsaturated zone. Kd = Sorption Coefficient. D Rock = devitrified rock. Fe Rock = iron-rich rock. V Rock = vitric rock. Z Rock = zeolitic rock.
(4) Base case Kd values from CRWMS M&O 1998a, Table 7-3.
(5) Kd values for uniform distribution computed as average of minimum and maximum.

## 4.2 CRITERIA

Based on a review of existing documents the following criteria pertinent to this study have been identified:

### 4.2.1 SDD Criteria

CRWMS M&O 1998b (G*round Control System Description Document)*, Section 1.2.2.1.1, specifies, "The system shall use materials having acceptable long-term effects on the ability of the engineered barrier system to assure waste isolation, including post closure conditions." Acceptability is to be based on the results of "waste isolation site impact evaluations."

### 4.2.2 Post Closure Acceptance Criteria

NRC 1999 (10 CFR 63.113 [b]) proposes, "The engineered barrier system shall be designed so that, working in combination with natural barriers, the expected annual dose to the average member of the critical group shall not exceed 0.25 mSv (25 mrem) TEDE [total effective dose equivalent] at any time during the first 10,000 years after permanent closure, as a result of radioactive materials released from the geologic repository" (TBV).

The CRWMS M&O 1999h, Attachment, "LADS Phase II Evaluation Criteria REV 00, 2/3/99," Screening Criteria, Item 1, states that, "The screening level is the anticipated regulatory level of 15 mrem/year within 10,000 years."

### 4.2.3 Safety/License Probability Criterion

The CRWMS M&O 1999h, Attachment, "LADS Phase II Evaluation Criteria REV 00, 2/3/99," Evaluation Criteria, specifies the following measures for the safety and licensing probability criterion:

- Safety margin, the difference between the calculated performance (central estimate) and the anticipated regulatory standard (15 mrem/year) within 10,000 years.
- Uncertainties in post-closure performance and the ability to reduce or mitigate those uncertainties.
- Peak dose rate (central estimate) within 1,000,000 years.

## 4.3 CODES AND STANDARDS

Not used. [No codes or standards were required in the analyses.]

## 5. ASSUMPTIONS

Not Used [No assumptions were required for the evaluation.]

## 6. ANALYSIS

### 6.1 CANDIDATE MATERIALS

The candidate materials for ground support are concrete (VA Design only, per CRWMS M&O 1999c, Sec. 7.1, P. 7-1), steel (carbon steel, galvanized steel, and stainless steel), ductile cast iron, and combinations of cementitious based materials and steel, as in the case of grouted rock bolts with wire mesh and steel channels. The candidate materials for the invert structure are concrete (VA Design only, per CRWMS M&O 1999c, Sec. 7.1, P. 7-1), steel, and crushed rock ballast.

### 6.2 POTENTIAL POST-CLOSURE EFFECTS OF CANDIDATE GROUND CONTROL MATERIALS – VA DESIGN

Discussions of the processes by which ground control materials containing cement could affect post-closure performance of the VA design are presented in CRWMS M&O 1998c and CRWMS M&O 1999f, Appendix B. [The mass of steel lining per meter of emplacement drift is a small fraction of the total mass of steel per meter of drift. Therefore, it has been assumed that the corrosion products from the steel lining will have negligible effect on sorption or colloid concentration in and below emplacement drifts in comparison to the effects from the corrosion products from the waste packages. (CRWMS M&O 1999f, Section 7.3.2) Thus a discussion of these effects is not required for the VA design.]

The potential effects of ground control materials on performance of the VA design have been analyzed in CRWMS M&O 1998c and *Design Input Transmittal for RIP Output for Design Feature (DF)#17 (Apatite Getters)*. (CRWMS M&O 1999g). The results of these analyses in terms of peak annual dose values for the first 10,000- and 1,000,000-year periods after closure are summarized below in Tables 6-1 and 6-2, respectively.

#### 6.2.1 10,000-Year Peak Annual Dose Values

Comparing the predicted 10,000-year peak annual dose values shown in Table 6-1 to the more stringent of the acceptance criteria given in Section 4.2.2 above (15 mrem/year) indicates that all materials meet this criterion, even for the concrete-modified water case (a case that is much more uncertain than the base case). Thus, from the perspective of meeting currently expected criteria, any of the materials shown would be acceptable. On the other hand, a comparison of the concrete-modified water cases indicates that the uncertainties associated with options involving concrete ground support or concrete invert result in doses that are two orders of magnitude greater than the corresponding doses resulting from the uncertainties associated with the options that do not involve

concrete. From this point of view the latter options would be favored for the VA Design case.

### 6.2.2 1,000,000-Year Peak Annual Dose Values

No specific numerical criteria exist for evaluating the predicted 1,000,000-year peak annual dose values shown in Table 6-2. For comparison of candidate materials the Safety/License Probability Criteria listed in Section 4.2.3 above may be used. The resulting comparison, presented in Table 6-3 below, may be summarized as follows:

- Safety margins are approximately the same for all materials.
- Uncertainties for the cases involving concrete could eliminate the safety margin for these cases, and reduction or mitigation of these uncertainties is considered impractical. (Sources of these uncertainties are discussed in CRWMS M&O 1998c.)
- Peak dose rates for the base case (within 1,000,000 years), while all of the same order of magnitude, clearly favor the all steel case over the all concrete case. The results for the cases that are mixtures of concrete and steel are ambiguous with respect to this factor.

Thus again the options that do not involve concrete ("2" and "4.b") are favored for the VA Design case.

**Table 6-1 Predicted 10,000-Year Peak Annual Dose Values for Candidate Ground Control Materials-VA Design[1]**

| Candidate Materials and Uses | VA Base Case (using expected values for all parameters)[1] | Source of Value | Concrete-Modified Water Case[1] [2] | Source of Value |
|---|---|---|---|---|
| 1. Concrete as ground support & invert | 0.04 | DOE 1998b, Vol. 3, p. 4-21, Sec. 4.2 | 14 | DOE 1998b, Vol. 3, p. 5-40, Fig. 5-46 |
| 2. Steel as ground support (steel sets w/wire mesh, steel channels, or steel panels) & steel invert | 0.14[3] | CRWMS M&O 1999g p. 20, Sec. 6 *(TBV)* | 0.14[4] | Same as base case[4] |
| 3. Rock bolts, wire mesh, & steel channels as ground support; concrete invert | 0.04 to 0.14[5] | See "1" and "2" | 0.14 to 14[5] | See "1" and "2" |
| 4. Crushed tuff as invert, | | | | |
| a. with concrete ground support, and concrete below tuff (for TBM rails) | 0.04 to 0.14 [6,7] | Same as "1" & "2" | 0.14 to 14[6,7] | Same as "1" & "2" |
| b. with steel ground support, and steel below tuff (for TBM rails) | 0.14[6] | Same as "2" | 0.14[6] | Same as "2" |
| c. with rock bolt ground support, and concrete below tuff (for TBM rails) | 0.04 to 0.14[5] | Same as "1" & "2" | 0.14 to 14[5] | Same as "1" & "2" |

(1) Peak annual dose (mrem/year) to average member of the critical group during the first 10,000 years after permanent closure.

(2) Parameters corresponding to concrete modified water. (See DOE 1998b, Vol. 3, pp. 5-11 & 5-12, Sec. 5.3.2.1, for characteristics of concrete-modified water.)

(3) Per source reference, Section 3.3, steel liner and invert will have no impact on radionuclide sorption. Thus the peak annual dose is the same as for the unlined drift, and does not include the absorptive effects of the concrete invert.

(4) Per CRWMS M&O 1999g, Page 7, Section 3.3, First Bullet, there are no postulated impacts to long-term peak dose due to steel ground support and invert. Thus peak annual dose for concrete-modified water case is the same as for base case.

(5) Per Attachment II, the quantity of cementitious material around the rock bolts will be about 2 to 18 % of that in the concrete lining, resulting in a reduced sorption capacity. At the same time, the potential for alkaline seepage contacting the waste package will still exist. Thus, peak doses for the rock bolt cases will between cases for "1" and "2."

(6) Per CRWMS M&O 1999g, Figures 1 and 3, crushed tuff as invert will have nearly no effect on 10,000-year dose rate.

(7) The concrete liner under the tuff will have a reduced sorption capacity as compared to the concrete invert, while the potential for alkaline seepage contacting the waste package (due to the rock bolt grout) will still exist. Thus, the peak dose rate will be between that for the concrete invert and the unlined drift cases. Value for unlined drift is given for steel in Case "2," per Footnote (3).

**Table 6-2 Predicted 1,000,000-Year Peak Annual Dose Values for Candidate Ground Control Materials-VA Design[1]**

| Candidate Materials and Uses | VA Base Case (using expected values for all parameters) [1] | Source of Value | Concrete-modified water Case[1][2] | Source of Value |
|---|---|---|---|---|
| 1. Concrete as ground support and invert | 300 | DOE 1998b, Vol. 3, p. 4-25, Sec. 4.2 | 500 [2] | DOE 1998b, Vol. 3 p. 5-40, Fig. 5-46 |
| 2. Steel as ground support (steel sets w/wire mesh, steel channels, or steel panels); steel invert | 181[3] | CRWMS M&O 1999g p. 20, Sec. 6 *(TBV)* | 181[4] | Same as for base case [4] |
| 3. Rock bolts, wire mesh, steel channels, ground support; concrete invert | 181 to 300[5] | See "1" and "2" | 181 to 500[5] | See Footnote [5] |
| 4. Crushed tuff as invert,<br>a. with concrete ground support, and concrete below tuff (for TBM rails) | 181 to 300[6,7] | See "1" and "2" | 181 to 500 [6,7] | Same as "3" |
| b. with steel ground support, and steel below tuff (for TBM rails) | 181[6] | Same as "2" | 181[6] | Same as "2" |
| c. with rock bolt ground support, and concrete below tuff (for TBM rails) | 181 to 300[5] | See "1" and "2" | 181 to 500[5] | Same as "3" |

(1) Peak annual dose (mrem/year) to average member of the critical group during the first 1,000,000 years after permanent closure.

(2) Parameters corresponding to concrete-modified water. (See DOE 1998b, Vol. 3, pp. 5-11 & 5-12, Sec. 5.3.2.1, for characteristics of concrete-modified water.)

(3) Per source reference, Section 3.3, steel liner and invert *(TBV)* will have no impact on radionuclide sorption. Thus the peak annual dose is the same as for the unlined drift, and does not include the absorptive effects of the concrete invert.

(4) Per CRWMS M&O 1999g, Page 7, Section 3.3, First Bullet, there are no postulated impacts to long-term peak dose due to steel ground support and invert. Thus peak annual dose for concrete-modified water case is the same as for base case.

(5) Per Attachment II, the quantity of cementitious material around the rock bolts will be about 2 to 18 % of that in the concrete lining, resulting in a reduced sorption capacity. At the same time, the potential for alkaline seepage contacting the waste package will still exist. Thus, peak dose rates for the rock bolt cases will between cases for "1" and "2."

(6) Per CRWMS M&O 1999g, Figures 2 and 4, crushed tuff as invert will have negligible effect on 1,000,000-year dose rate.

(7) The concrete liner under the tuff invert will have a reduced sorption capacity as compared to the concrete invert. Thus, the peak dose rate will be between that for the concrete invert and the unlined drift cases. Value for unlined drift is given for steel in Case"2," per Footnote (3).

**Table 6-3 Factor's for Evaluation of Candidate Materials Against Safety/License Probability Criteria-VA Design[1]**

| Candidate Materials and Uses | Safety Margin[2] (Base Case) | Effects of Uncertainties[3] | Peak Dose Rate Within 1,000,000 Years[4] |
|---|---|---|---|
| 1. Concrete as ground support and invert | 14.96 mrem/year | Concrete-modified water case results in safety margin = 1.0 mrem/year | 300 mrem/year |
| 2. Steel as ground support and invert | 14.86 mrem/year | Uncertainties are negligible | 181 mrem/year |
| 3. Rock bolts, wire mesh, steel channels, ground support; concrete invert. | 14.86 to 14.96 mrem/year | Concrete-modified water case may result in safety margin = 1.0 mrem/year | 181 to 300 mrem/year |
| 4. Crushed tuff as invert, | | | |
| a. with concrete ground support, and concrete below tuff (for TBM rails) | 14.86 to 14.96 mrem/year | Concrete-modified water case may result in safety margin = 1.0 mrem/year | 181 to 300 mrem/year |
| b. with steel ground support, and steel below tuff | 14.86 mrem/year | Uncertainties are negligible | 181 mrem/year |
| c. with rock bolt ground support, and concrete below tuff (for TBM rails) | 14.86 to 14.96 mrem/year | Concrete-modified water case may result in safety margin = 1.0 mrem/year | 181 to 300 mrem/year |

(1) See CRWMS M&O 1999h and Section 4.2.3, above.

(2) Difference between peak annual dose for base case and anticipated regulatory standard (within 10,000 years). See Table 6-1 and Section 4.2.2, Paragraph 2, above.

(3) See Table 6-1 above for concrete-modified water case values. Potential for reduction of uncertainties is low, as it would likely require two or more years of testing. Mitigation; i.e., designing to accommodate the uncertainties, is considered impractical.

(4) Peak annual dose (central estimate) within 1,000,000 years (base case). See Table 6-2 above.

## 6.3 POTENTIAL POST-CLOSURE EFFECTS OF CANDIDATE GROUND CONTROL MATERIALS –LA DESIGN

The proposed License Application (LA) Design (TBV) has new features that differ substantially from the VA Design and may affect the selection of ground control materials:

- A waste package that has a much longer-lived primary barrier (due to increased resistance to corrosion) than that of the VA Design Waste package (CRWMS M&O 1999c, Section 5.1.5.2),
- A drip shield placed above the waste packages, and
- Thermal loading and drift spacing that will avoid temperatures exceeding boiling at the centerlines of the pillars between emplacement drifts.

If adopted, these features may affect the selection of ground control materials as follows:

**Enhanced Waste Package, Reduced Thermal Loading, and Increased Drift Spacing**

The increased corrosion resistance of the waste package will reduce uncertainty regarding the potential effect of concrete ground support on corrosion of the waste packages. However, the following uncertainties would remain for the ground support options involving concrete (CRWMS M&O 1999f, Appendix B): glass waste form dissolution, alteration of fracture and matrix flow pathways, suppression of sorptive properties, enhanced colloid formation, and effects of organic additives. Thus, it will still be necessary to limit the consideration of cementitious materials to grouting of rock bolts as recommended in CRWMS M&O 1999f (Sections 9.1.3 and 9.2). Even this use of cementitious material must be evaluated if considered in LA Design.

**Drip Shield Above Waste Package**

The material that is proposed for construction of the drip shield is titanium. This could affect the selection of steel for the ground support system as follows: If the failure of a carbon steel ground support rib results in the rib falling across the drip shield, crevice type corrosion could accelerate deterioration of the shield. This could in turn increase the exposure of the waste package to dripping water, enhancing its corrosion and the rate of waste package failure and potentially increasing the rate of migration of radionuclides. Thus the use of steel ground support should also be evaluated as part of LA Design.

## 7. SUMMARY, CONCLUSIONS, AND RECOMMENDTIONS

### 7.1 SUMMARY

Candidate materials for use in emplacement drifts have been identified as follows:

- Concrete ground support and invert
- Steel ground support and invert
- Rock bolts, wire mesh, and steel channel ground support; concrete invert
- Crushed tuff invert, with
  - Concrete ground support and TBM rail support
  - Steel ground support and TBM rail support
  - Rock bolt, etc. ground support and concrete TBM rail support

A review of existing documents concerning post-closure requirements for the repository has resulted in identification of the following governing criteria and performance factors:

- Peak annual dose rate within 10,000 years not to exceed 15 mrem/year
- Safety/License probability factors to be considered:
  - Safety margin: difference between predicted dose rate and anticipated regulatory standard
  - Uncertainties in post-closure performance
  - 1,000,000-year peak annual dose

A comparison of the potential effects of the candidate materials on meeting the criteria and performance factors leads to the conclusions and recommendations listed below.

### 7.2 CONCLUSIONS AND RECOMMENDATIONS

The analyses performed in this study support the following conclusions:

**For VA Design:**

- For the VA Design all of the candidate materials meet the anticipated regulatory level for peak annual dose rate within 10,000 years; i.e., 15 mrem/year.
- Uncertainties associated with the options that involve concrete ground support or invert for the VA Design and the corresponding potential 1,000,000-year peak dose rates for these options are significantly more adverse than the corresponding factors for the VA options that do not involve concrete.

**For LA Design:**

- Uncertainties regarding the potential effects of concrete ground support and inverts on corrosion of the waste package proposed for LA Design are low.

However, uncertainties regarding the potential effects of concrete on contaminant migration are still significant.

- The potential effects of rock bolt grout on radionuclide transport for LA Design should be evaluated.
- The potential effects of steel ground support on the LA Design drip shield and waste package should be determined.
- For steel inverts the potential for galvanic reactions between the invert and the pedestal supporting the waste package, and between the invert and the waste package itself (when the pedestal fails and the waste package contacts the invert directly), must be accounted for.

Therefore, it is recommended:

- That final selection of ground control materials include evaluation of the potential effects on drip shield and waste package corrosion and transport of radionuclides to the critical receptor.
- That candidate materials to be evaluated for ground control in LA Design should include:
  - Steel ground support and invert, with or without crushed tuff invert infill
  - Grouted rock bolts, with wire mesh, and steel channels as ground support, and steel invert, with or without crushed tuff invert infill.

## 8. REFERENCES

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CRWMS M&O 1998b. *Ground Control System Description Document.* BCA000000-01717-1705-00011 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980825.0286.

CRWMS M&O 1998c. *Total System Performance Assessment – Viability Assessment (TSPA-VA) Analyses Technical Basis Document, Chapter 4, Near Field Geochemical Environment.* B00000000-01717-4301-00004 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981008.0004.

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## 9. ATTACHMENTS

Attachment I- Acronyms and Abbreviations

Attachment II- Calculation of Weights of Cement: Rock Bolt and Concrete Ground Support Systems

Attachment III- Summary of Previous Work Concerning Ground Control Materials

## Attachment I – Acronyms and Abbreviations

| | |
|---|---|
| D Rock | Devitrified Rock |
| EDA | Enhanced Design Alternative |
| Fe Rock | Iron-rich Rock |
| Kd | Sorption Coefficient |
| LA Design | License Application Design |
| LADS | License Application Design Selection |
| Mrem | millirem |
| NRC | U.S. Nuclear Regulatory Commission |
| TBM | Tunnel Boring Machine |
| TBV | To Be Verified |
| TEDE | Total Effective Dose Equivalent |
| UZ | Unsaturated Zone |
| VA Design | Viability Assessment Design |
| V Rock | Vitric Rock |
| Z Rock | Zeolitic Rock |

**Attachment II**

**Calculation of Weights of Cement: Rock Bolt & Concrete Ground Support Systems**

**Cement Content of Grout:**

Assume w/c = 0.35, Specific Gravity of Cement = 3.15.

Wt. w = 0.35 x Wt. cem; Wt. grout = Wt. w + Wt. cem = 1.35 Wt. cem.

Wt. cem = Wt. grout / 1.35 = 0.74 x Wt. grout.
Wt. w = (1-0.74) x Wt grout = 0.26 x Wt grout.

Vol. Grout = Wt. cem / SpG cem + Wt. w / SpG w
= 0.74 Wt grout / (3.15 g/cc) + 0.26 Wt. grout / (1.00 g/cc)
= (0.495 cc/g) x Wt grout.

Unit Wt of Grout = 1 /[(0.495 cc/g) x 1000g/kg x 1 cubic meter/1,000,000 cc]
= 2,020 kg/cubic meter

Wt. cem/cubic meter of grout = 0.74 x 2,020 kg/cubic meter
= 1,495 kg cement/cubic meter of grout.

**Cement in Rock Bolt Grout:**

**Minimum Case:** 2.5-m long, 1-inch diameter bolt in 1.5-inch diameter hole:

Annulus = $(3.14/4)\,[(1.5)^2 - (1)^2]\,(2.5)\,(1/39.37)^2$ = 0.00158 cubic meters

Weight of cement per bolt = (1,495 kg/cubic meter of grout) x 0.00158 cubic meters/bolt
= 2.4 kg cement/bolt

**Maximum Case:** 2.5-m long, 1-1/8-inch diameter bolt in 2.5-inch diameter hole:

Annulus = $(3.14 / 4)\,[(2.5)^2 - (1.125)^2]\,(2.5)\,(1/39.37)^2$ = 0.00631 cubic meters

Assume up to 2 additional volumes of the grout may penetrate into the cracks and voids around the hole. Thus total volume = (1 + 2 =3) x 0.00631 = 0.01893 cubic meters/bolt.

Weight of cement per bolt = (1,495) x 0.01893 = 28 kg cement/bolt.

Bolts are on 1 m square pattern, spring line to spring line (CRWMS M&O 1998d, p 12).

This gives (3.14 x 5.5m /2) / 1 m = 9 spaces, spring line to spring line, or 10 bolts / meter.

For minimum and maximum cases, weight of cement / linear meter of drift

= (2.4 to 28) kg / bolt x 10 bolts / meter = 24 to 280 kg cement / linear meter of drift.

**Cement in Concrete Lined Drift:**

Weight of cement = 1,530 kg cement / linear meter of drift (CRWMS M&O 1997, p. 60)

**Ratio of Cement for Grout Bolts to Cement for Concrete Lined Drift:**

[(24 to 280)kg / m] / (1,530 kg / m) = 1.6 to 18.3 %

**Check Against Field Experience at Site:**

Per 05/03/99, 04:24 PM, e-mail, Robert Skorseth to Kenneth Herold, grout use for Williams Rockbolts from Station 07+19.91 through 7+34.52 averaged 0.75 cubic feet per 3-meter long x 1 1/8 inch diameter rockbolt in 2 1/4-inch diameter hole.

0.75 cubic feet per bolt / (35.320 cubic feet per cubic meter) = 0.02 cubic meters per bolt.

This is slightly more than 0.01893, the value estimated for the maximum case on Page II-1, possibly due to differences in bolt length and hole diameter.

Annulus = $(3.14/4)\,[(2.25)^2 - (1.125)^2]\,(3.0)\,(1/39.37)^2 = 0.00577$ cubic meters / bolt, vs 0.00631 cubic meters / bolt for Maximum Case estimate.

Thus based on the difference in annulus volume one would expect field case to give at most: (0.00631 / 0.00577) x 0.02 = 0.022.

Thus the field case roughly confirms that the maximum case estimate is an upper bound for conditions similar to those in the reach from Station 07+19.91 through 7+34.52.

Because the reach analyzed is in an area of high fractures but low lithophysae, the upper bound for regions of high lithophysae may be greater. If necessary to conform to a requirement to limit the amount of cementitious material in the drifts, properly designed perforated grout tubes or other means of safely limiting grout take may be used in zones of high lithophysae content.

## Attachment III

## Summary of Previous Work Concerning Ground Control Materials

### Introduction

The purpose of this Attachment is to briefly summarize the approach and results of selected previous studies pertaining to the capabilities, geochemical effects, and longevity of various ground support systems, particularly regarding the types of materials to be used. A companion purpose of this Attachment is to provide an historical context regarding the issues surrounding ground support systems that have been examined. This review will also report the evolution and outcome of screening studies directed at identifying potentially optimum ground support systems and components based on the then-existing criteria.

Three references constitute the basis for this summary review:

CRWMS M&O 1997. *Materials for Emplacement Drift Ground Support,*

CRWMS M&O 1998d. *Ground Support Alternatives Evaluation for Emplacement Drifts, and*

CRWMS M&O 1999f. *Evaluation of Design Feature #20.*

These references are summarized below.

### CRWMS M&O 1997. *Materials for Emplacement Drift Ground Support:*

The major issue associated with this work product was to characterize the behavior of Portland cement-based concrete and steel as ground support materials for emplacement drifts, including performance in an elevated temperature environment. One concern was that upon prolonged exposure to the elevated temperature regime within the waste emplacement drifts after drift closure Portland cement-based concrete may deteriorate, yielding a weakend product that would no longer provide adequate ground support. Another concern related to the potential for aggressive bacteriological attack on the concrete, which might also result in an unacceptably deteriorated product. For comparative purposes the behavior of steel ground support components was also examined. Three permanent ground support systems were examined in this study: precast concrete, cast-in-place concrete linings, and steel sets. A component of this study also led to the development of two specific concrete formulations. Although this report acknowledged the potential postclosure effects of concrete on radionuclide transport and host rock alteration, including the effects of elevated pH, these were not a primary focus of this analysis.

The bulk of this report discussed the effects of prolonged exposure to elevated temperatures on the mechanical properties of the concrete. Specific mechanical properties that were discussed include: compressive strength, deformability, creep/stress relaxation, shrinkage, durability, and permeability. These items were also examined relative to thermal cycling, elevated radiation exposure, and the effects of different water to cement ratios, aggregates, admixtures, and curing conditions. The study then examined the thermal properties of concrete including expansion, conductivity, and specific heat.

A discussion was then provided relating to the processes, their effects, and activities targeted to minimize these effects for carbonation, sulfate attack, alkali-aggregate reaction, biological attack, resistance to abrasion, and freezing and thawing.

A discussion of cement types, aggregate, and pozzolanic materials that might be considered for use was then provided. Because of its potential benefits in enhancing the performance of Portland cement-based concrete, particularly in reducing pH, a goal directed at enhancing post-closure repository performance, a lengthy discussion pertaining to the characteristics and effects of silica fume was included. A more concise discussion was then provided related to the use of steel fibers, as an additive to the cement.

Two concrete mix designs are considered, a "moderate silica" option and a "high silica" option. The moderate silica option is intended to develop a moderate reduction in pH, the high silica option a greater reduction.

Based on the absolute volume method of proportioning the following reagent formula was developed for the moderate silica option:

| **Component** | **Concentration** |
|---|---|
| Portland cement | 670 lb./cu yd (398 kg/m$^3$) |
| Water | 270 lb./cu yd (160 kg/m$^3$) |
| Coarse Aggregate | 1690 lb./cu yd (1003 kg/m$^3$) |
| Fine Aggregate | 1310 lb./cu yd (777 kg/m$^3$) |
| Silica Fume | 100 lb./cu yd (59 kg/m$^3$) |
| Superplasticizer | 12 lb./cu yd (7.1 kg/m$^3$) |
| Steel Fiber | 66 lb./cu yd (39 kg/m$^3$) |

The high silica option, a modified version of a design by Atomic Energy of Canada Limited (CRWMS M&O 1997, Table 7.6) contains a relatively high amount of silica (in the form of silica fume and silica flour), lower cement content, and more than normal amounts of superplasticizer. Exact proportions for this option are not presented.

Estimates for the amount of concrete per linear meter of lining are then provided.

Characteristics of steel ground support elements are then discussed. This discussion provides information pertaining to the mechanical properties of carbon (or low-alloy) steel in terms of strength, modulus of elasticity, toughness and ductility. The thermal properties of steel are then discussed including information on the thermal expansion coefficient, thermal conductivity, and specific heat. The durability of steel and especially the impact of corrosion are presented along with the possible effects of biological and radiation phenomena.

This study includes the following summary:

POST CLOSURE EFFECTS OF MATERIALS:

Concrete:

The post closure evolution of cementitious materials in the repository emplacement drifts has potential detrimental effects on waste isolation:

1) Concrete pore solutions with high pH have the potential to increase radionuclide solubility.

2) Dissolved constituents of concrete formed at high pH could reduce sorption of radionuclides by natural barrier components such as zeolites.

3) Water from dehydration reactions within the cement could be produced in the near-field environment and possibly increase the relative humidity within the tunnel.

4) The porosity and permeability of the host rock could be changed by increases in silica solubility.

5) The introduction of organic materials such as superplasticizers in concrete in the emplacement drifts may have impacts on performance through changes in the concentrations of organic acids and organic colloids which can increase waste package corrosion, radionuclide solubility and transport, and silicate mineral dissolution. In addition, organics may promote microbial activity, which is another factor leading to waste package corrosion.

Steel:

From the viewpoint of Performance Assessment (PA), there is little concern about the introduction of steel sets (or other steel ground support elements) in the repository. A large number of waste packages, of which the outer barrier material is carbon steel, will be emplaced in the emplacement drifts. The carbon steel in the waste packages is very similar to the material for the steel sets. In the postclosure period, however, especially after the temperature cools off and relative humidity is increased, the potential for steel corrosion could probably be higher. Since there are many uncertainties and variables involved in the mechanism and prediction of corrosion during the postclosure period, it is beyond the scope of this study to investigate this issue.

CHARACTERISTICS OF CONCRETE:

Strength:

- For temperatures up to 200°C (392°F), which is the temperature limit in the repository emplacement drifts, the compressive strength of concrete can be assumed to be reduced up to 30% compared with the ambient temperature strength.

- Most of the strength loss of concrete takes place within the first few months of exposure, which indicates that long-term exposure of concrete within a waste emplacement drift does not result in sustained degradation during the design life, which suggests that a relatively short-term test program (e.g. less than 2 years) may provide sufficient basis to determine concrete behavior for the duration of the repository preclosure period

- For the same water/cement (w/c) ratio, the higher the silica fume content, the higher will be the compressive strength. For the same content of silica fume, strength increases as w/c ratio decreases. The impact of cyclic varying temperature in unventilated emplacement drifts should be insignificant since the temperature increase is expected to be slow and uniform with the exception of a potential blast-cooling event. Even so, repeated cycles of cooling and heating should be avoided.

Deformability:

- For a temperature of 200°C (or 392°F) which is the temperature limit in the repository emplacement drift, and prolonged periods of heating above 100°C, it is reasonably conservative to assume that the modulus of elasticity of concrete may be reduced about 50 percent compared with ambient temperature modulus of elasticity.

- Long-term exposure to elevated temperatures produces losses in concrete modulus larger than those determined from relatively short-term tests. This difference is more noticeable at 232°C (450°F), where short-term test results indicated moduli losses on the order of 35 percent, whereas long-term test results show moduli losses almost twice as large as this.

- Poisson's ratio shows no well-defined relationship with respect to time and temperature.

- For concrete containing silica fume, Young's modulus does not continue to increase with increasing compressive strength. It was indicated in one study that for concrete containing 25% silica fume, the compressive strength increase is 43% whereas the Young's modulus increase is only 7% compared to concrete lacking silica fume.

Creep and Shrinkage:

- The effects of creep may be harmful but, on the whole, creep, unlike shrinkage, is beneficial in relieving stress concentrations. It has contributed to the success of concrete as a structural member, which is very important for the structural design of concrete linings for the emplacement drift exposed to high temperatures for a prolonged period.

- In order to minimize drying shrinkage, the water content of concrete needs to be kept as low as possible. This can be achieved by keeping the total coarse aggregate content of the concrete as high as possible, using low slumps, and placing methods that minimizing water requirements. Silica fume has no effect on basic creep, but significantly reduces the drying creep, or shrinkage. Steam curing will also reduce drying shrinkage.

- An empirical equation for predicting the creep strain under elevated temperature has been derived by PCA. It may be reasonable to apply this equation in the structural analysis of concrete linings for emplacement drift stability when no test data are available for the repository

site. However, it needs to be emphasized that creep tests of the proposed concrete mix should be conducted and further work to verify the applicability of the equation should also be done. If any change is found to be necessary, then the modified or newly developed equation for predicting the creep should be used.

Thermal Properties:

- The coefficient of thermal expansion of concrete is nearly directly proportional to that of the contained aggregate, with the main controlling factor being the proportion of quartz present. Rocks with a high quartz content have the lowest coefficient. An average value of coefficient of thermal expansion of concrete is $9.9 \times 10^{-6}$/C. In general, the coefficient of thermal expansion tends to increase with temperature.

- The thermal conductivity of concrete is independent of temperature within the normal climatic range. In general, the thermal conductivity of normal weight concrete ranges from 1.5 to 3.5 W/m•K with an average of 2.5 W/m•K. Conductivity of concrete decreases with increasing temperature. For temperatures between 100°C and 400°C, thermal conductivity decreases linearly with temperature.

- The specific heat of concrete is strongly dependent on porosity (w/c ratio), water content, and temperature. Typical specific heat values for concretes with normal-weight aggregates range from 840 to 1170 J/kg•K with an average of 1005 J/kg•K.

Radiation and Biological Effects:

- The radiation exposure that results in significant loss in concrete compressive strength is much larger than the reasonably predicted radiation exposures for concrete within the waste emplacement drifts during the retrieval period. Gamma and radiation field strengths for an integrated exposure for 150 years, assuming no decay, are about four orders of magnitude below an approximate threshold value, above which measurable degradation of concrete occurs. Neutron radiation field strength is much less than that from gamma radiation.

- The combined radiation and heat will pose lethal challenges to all bacteria. The heat will dry the drifts, eliminating a water source for the bacteria. Even the most thermophilic bacteria cannot withstand 160°C temperatures. Temperatures exceeding 120°C will develop in the drifts within nominally 20 years after waste emplacement (CRWMS M&O 1999i, p. 23), preventing any bacterial activity for the remainder of the 150-year operation life.

Durability:

- The single parameter that has the largest influence on durability is the water/cement (w/c) ratio. As the w/c ratio is decreased, the porosity of the paste is decreased, and the concrete becomes more impermeable, which also increases the strength.

- The major effects of carbonation are 1) increased shrinkage upon drying and 2) lower alkalinity of concrete. Although it is not desirable to have shrinkage by carbonation, it is beneficial to have a low pH value for reducing the radionuclide solubility, which is desirable from the long-term geochemical viewpoint during the postclosure period.

- Resistance to sulfate attack is one of the major concerns about the durability of concrete. Since sulfate resistance related to the mechanical properties of concrete is a long-term consideration, use of Type V Portland cement appears to be more desirable. The resistance is enhanced for concrete with higher cement content and for cement low in $C_3A$ content. Silica fume provides excellent sulfate resistance to concrete, better than fly ash or ground slag. Another way of reducing sulfate attack that can be used for precast concrete is high-pressure steam curing.

- Alkali-silica reaction can affect the performance of concrete. It is desirable to try to avoid using the susceptible aggregate. However, it is usually not a practical or an economical solution. If a reactive aggregate must be used, several measures can be taken to minimize the reaction. Most important is to use low-alkali cement. A limit of 0.6 percent total alkali in the cement is commonly specified. Use of pozzolana, such as silica fume, fly ash, and ground granulated blast-furnace slag, also can significantly reduce the alkali-silica reaction.

- Abrasion resistance is closely related to the compressive strength of concrete. A low water-cement ratio and adequate curing are necessary for abrasion resistance. The types of aggregate and surface finish or treatment used also have a strong influence of abrasion resistance. The addition of steel fiber to the concrete will increase the ductility and the energy absorption capacity to inhibit the cracking caused by the handling and erection of the concrete segments.

CHARACTERISTICS OF STEEL:

Strength and Modulus of Elasticity:

- Up to about 370°C, the yield and ultimate strength of carbon steels can be used essentially as they would for design of components at room temperature. Creep is not observed in these steels until temperatures are above 370°C. The modulus of elasticity of structural steel decreases from an initial value of 200 GPa (29,0000 ksi) at about 20°C to about 172 GPa (25,000 ksi) at 480°C, or 189 GPa (27,400 ksi) at 200°C, which is about a 5% decrease in comparison to that at 20°C.

- For the repository emplacement drift environment, which has a limiting temperature of 200°C, carbon steels may experience modest, but insignificant, decreases in strength (up to about 9 percent) and modulus of elasticity (up to about 5 percent) in comparison to these same parameters at 20°C.

Thermal Properties:

- Structural steels have a coefficient of thermal expansion that varies from about $11.5 \times 10^{-6}$/°C at 20°C to $13.8 \times 10^{-6}$/C at 200°C. The thermal expansion coefficient for tuff for near-field considerations is shown to vary from about $5.07 \times 10^{-6}$/C at 25°C to $8.97 \times 10^{-6}$/C at 200°C. These data show differences in expansion coefficients between tuff (or concrete with a tuff aggregate) and steel decrease from about $6.5 \times 10^{-6}$/°C at 25°C, to about $5 \times 10^{-6}$/°C at 200°C. Because differences in expansion coefficients are relatively small and the rate of repository heating is expected to be slow, the effects of differential expansion are anticipated to be minor. For steel-fiber reinforced concrete, the effect due to different thermal expansion is insignificant because steel fibers are discretely and uniformly distributed in the concrete.

- The average thermal conductivity of the carbon steel for temperature 0 to 200°C is 50.67 W/m•K, ranging from 51.9 to 49.0 W/m•K, with higher values for lower temperatures. The average specific heat of carbon steel for temperature 50 to 200°C is 502.5 J/kg•K, ranging from 486 to 519 J/kg•K, with higher values for higher temperatures.

Radiation Effect:

- Generally, the only type of radiation emanating from the high-level waste packages that may affect steel is the neutron field. The neutron radiation field expected from any single waste package is not expected to exceed $3.3 \times 10^{20}$ n/m$^2$ for 150 years based upon estimated values from bare fuel assemblies. The expected increase in the ductile-brittle transition temperature is not more than 0.9K for a 150-year service life, which indicates the effect of neutron radiation of steel, is minimal. It should also be noted that $3.3 \times 10^{20}$ n/m$^2$ is very conservative because in practice the radiation field would be expected to be several orders of magnitude lower due to shielding from the waste package walls, decay of radioactivity, and geometric divergence. Therefore, radiation effects are believed to be insignificant and not expected to degrade the steel properties.

Durability:

- Steel sets are susceptible to corrosion under certain conditions. Since the repository emplacement drift environment is not conducive to corrosion due to its high temperature, minimum presence of water, and very low amount of chloride, the effect of corrosion on the steel strength is very insignificant during the service life of 150 years.

- Steel biodegradation occurs when sulfate-reducing bacteria (SRB) consume hydrogen during sulfate reduction. The presence of oxygen, excessively high temperatures, and inadequate sources of sulfate and carbon create an environment hostile to SRB. In the absence of the specialized environment required for SRB metabolism, corrosion of steel by SRB is not expected to occur.

- As discussed in the section for concrete, the combined radiation and heat will pose lethal challenges to all bacteria. Elevated temperatures in the emplacement drifts will ultimately eliminate liquid water, eliminating a water source for the bacteria. Even the most thermophilic bacteria cannot withstand 160°C temperatures. Temperatures exceeding 120°C will develop in the drifts within nominally 20 years after waste emplacement (CRWMS M&O 1999i, p. 25), preventing any bacterial activity for the remainder of the 150-year service life.

**CRWMS M&O 1998d. *Ground Support Alternatives Evaluation for Emplacement Drifts:***

Having identified that both concrete and steel ground support elements could potentially fulfill the design requirements, specific alternatives were developed for examination and ranking. This study was directed at the examination of 12 ground support alternatives. These alternatives consisted of:

Rockbolts, wire mesh, and channel
Rockbolts and shotcrete
Cast-in-place concrete
Bolted precast concrete segments

Expanded precast concrete segments
Steel sets and steel channel lagging
Steel sets and wire mesh
Steel sets and steel panel lagging
Steel sets and shotcrete
Steel segments
Cast iron segments
Steel tube

These alternatives covered the range of possible alternatives using concrete and steel, either singularly or in combination. The objective of this study was to perform a technical comparison and provide the basis for a cost appraisal. The technical comparison considered the material behavior, durability, structural stability, constructibility, quality control, and maintainability of each ground support alternative considered. The cost appraisal included an estimate of relative cost for materials, installation, and maintenance. Although it was acknowledged that this evaluation was only qualitatively done an attempt was made to quantify these subjective evaluations in order to provide a quantitative basis for comparisons for the various ground support alternatives. At the point in time of this study it was also considered appropriate to examine the use of only one ground support alternative at a time to address all ground support challenges.

All alternatives had to meet certain basic requirements and criteria that included:
Confine and support rock surrounding the opening to minimize potential rock surface deterioration, rock fracturing, block loosening, and rock falls
Maintain the physical space (e.g., as defined by clearance envelopes) required for operations, including performance confirmation and retrievability
Provide for worker safety
Accommodate necessary monitoring and data collection
Meet a service life criterion of 150 years
Accommodate geologic mapping
Assure waste isolation

Conclusions reached by this study include:

Both rock bolts with wire mesh and steel sets with wire mesh received the lowest rating on undesirable characteristics, and are the two favorite ground supports systems, though they are contingent on the satisfactory performance of wire mesh under the emplacement drift environmental conditions. In this respect, rockbolts, wire mesh and steel sets form another contingent ground support alternative to deal with emplacement drift ground conditions.

For an all-steel ground support option, the system consisting of steel sets and steel channel lagging, in conjunction with a steel invert is a clear choice.

For an all-concrete ground support option, the precast concrete segmental lining, either bolted or expanded, is preferable to ground support alternatives involving concrete or shotcrete that is bonded to the rock. However, the use of concrete containing organics must be determined to be suitable to the emplacement drift environment with acceptable post closure effects on waste isolation (CRWMS M&O 1998d, Section 6.3.5).

This report also recommends the following future work:

- Developing cost estimates for each of the ground support alternatives in order to support final recommendations for the ground support systems of emplacement drifts.

- Recognition that the final selection of ground support would depend on resolution of such issues as material longevity, thermal stress relief through the adoption of special relief elements or mechanisms, long term performance, postclosure chemical effects of ground support materials, including organics, on waste isolation and other aspects identified as undesirable in this evaluation report.

As the conclusions are affected by Performance Assessment (PA) of ground support materials, revisions of this evaluation or an impact study is necessary when PA results on the suitability issues of ground support materials become available.

**CRWMS M&O 1999f.** ***Evaluation of Design Feature #20:***

This report focused on the evaluation of ground support options pertaining to waste emplacement drifts and addressed 1) unlined drifts supported by rockbolts and wire mesh; 2) metal-lined drifts supported by steel sets and steel lagging (i.e., wire mesh, channels, and panels); and 3) the postclosure acceptability of the presence of concrete for concrete-lined drifts. The objective of this study was to determine the potential for this engineered feature to enhance repository performance so that input could be provided for reevaluating and revising the Viability Assessment (VA) reference design in order to produce a reference design for License Application (LA).

The VA reference ground support design calls for installing a precast concrete segmental lining in the 90 percent of emplacement drifts that are not to be mapped, and installing steel sets in the remaining 10 percent of the emplacement drifts that are to be mapped. A concrete invert is also placed to support waste packages and gantry rails. Therefore, the VA reference ground support design relies principally on the usage of cementitious materials. In contrast, the ground support options evaluated for the License Application Design Selection (LADS) either minimize the presence of cementitious materials by using rockbolts and wire mesh for the unlined drift scenario, or eliminate the presence of cementitious materials by considering all-steel ground support for the metal-lined drifts scenario.

The results of this study related to ground support materials are summarized below.

Unlined Drifts and Metal-lined Drifts:

For both unlined (rockbolt supported) and metal-lined drifts the estimated peak annual dose rate for an average individual of a critical group at a distance of 20 km from the site varies as follows:

- For the time period less than 10,000 years, the estimated peak dose rate is 0.13507 mrem per year, and is anticipated to occur at 9,400 years. For the time period between 10,000 and 1,000,000 years, the peak dose rate of 181.078 mrem per year is anticipated to occur at 338,000

years. A figure of merit of the integrated dose is estimated to be 32.5713. The potential for juvenile failure has been considered in Performance Assessment models for calculating dose released rates.

Post-Closure Acceptability of Concrete in Concrete-Lined Drifts:

Appendix B to the Report, an evaluation of postclosure acceptance of ground support materials, shows that uncertainties exist for repository performance from the presence of concrete in emplacement drifts. At issue is the postclosure chemical effect of cementitious materials. In this respect, uncertainties also exist for postclosure performance of steel, but given the steel VA waste package design, the uncertainties associated with steel ground support systems are considered insignificant. It will be difficult to resolve the uncertainties associated with cementitious materials in the concrete lining. A practical solution would be to restrict the use of concrete within the VA design. Should the use of a limited amount of cementitious materials such as shotcrete for filling voids or sealing the rock surface be considered it remains to be seen how much cementitious material is acceptable from a Performance Assessment perspective.

Overall Summary:

This evaluation concludes that the ground support option for unlined emplacement drifts using rockbolts and wire mesh should be considered for LA design, provided that a change in design criteria can be instituted that permits performance confirmation by other than in-drift monitoring. Ground support options for metal-lined drifts have the potential to enhance repository performance of the VA design by eliminating the use of cementitious materials. In considering the three steel ground support options for LA design, priority should first be given to steel sets with wire mesh, then to steel sets with panel lagging. Steel sets and channel lagging should only be considered for partial lagging, e.g., covering the crown area only, in order to reduce costs.

This evaluation also recommends that the presence of a limited amount of cementitious materials such as grout for grouting rockbolts and shotcrete for filling voids needs to be assessed for postclosure acceptance, in conjunction with other features of the LA reference design. In this respect, the postclosure acceptability of the presence of a large quantity of concrete such as cast-in place concrete lining in non-emplacement drifts and openings also needs to be evaluated.

The second part of this report discussed the geochemical issues associated with the use of concrete. This subsection noted that whereas the structural capabilities of concrete may last for only a few hundred years the geochemical impacts of collapsed concrete may persist for thousands of years. Therefore, the technological challenges associated with design of the proposed repository, including the criteria imposed to ensure protection of human health and the environment, dictate that the geochemical impacts of concrete be well understood.

This report also noted that the primary concern associated with the use of a large volume of concrete is the tendency to produce alkaline (high pH) pore water that may be released from the concrete into the near-field environment. This alkaline pore water could be the dominant influence on water composition in the near field and, therefore, is a major source of uncertainty in the water composition because of its ultimate potential effect on accelerating the release and migration of radionuclides to receptors through a variety of mechanisms.

A further complicating factor in the analysis of these potential concrete-related geochemical impacts is the fact that many of the processes to be discussed are poorly understood. This incomplete understanding is exacerbated by the long periods of time available (before the radionuclides decay to innocuous levels) for otherwise slow reactions to occur. Thus, the results of these reactions must be extrapolated far into the future. Moreover, there is the potential for competing phenomena to result in processes that may be simultaneously enhancing and impeding the release and transport of radionuclides.

Specific concerns related to the use of concrete included:

a) Increase in the waste package corrosion rate
b) Increase in the waste form dissolution rate
c) Changes in solubility-limited radionuclide concentrations
d) Changes in secondary-phase-development limited radionuclide concentrations
e) Changes in the hydrologic properties of the engineered barrier system
f) Enhanced radionuclide transport through the engineered barrier system
g) Creation of alkaline plume carrying radionuclides through the geosphere
h) Changes in geosphere hydrologic and transport pathways
i) Organics in concrete and the potential stimulation of microbial processes

This study reported that ultimately the complexity of the geochemical issues associated with the proposed use of concrete has caused this material to be discounted as a major element of any ground support system, particularly within the waste emplacement drifts. There may be limited, site-specific use of concrete that provides sufficient ground support benefits (for example, in the grouting of rockbolts) to overcome the potential for equally limited geochemical impacts due to the small amount of cementitious material employed.

**Overview of Previous Work Concerning Ground Control Materials:**

The above review documents the evolution of the thought processes related to identification of optimum ground support systems. Concrete and steel ground systems were initially considered as viable and essentially equal alternatives. Design using both end-member systems proceeded in parallel.

The first study discussed above addressed the major concern that concrete might be unable to survive the high temperature environment within the waste emplacement drifts. It was feared that rapid temperature-induced loss in strength could lead to premature failure of ground support systems. Instead, the results of the first study under discussion documented that the potential loss in strength would be modest and could be accommodated during the design process. Whereas it was acknowledged that concrete had potential adverse geochemical effects in terms of future radionuclide release and transport, concrete usage continued to be considered pending more comprehensive information.

The second study revealed that both specific concrete and steel ground support systems could be developed to fulfill the waste emplacement drift requirements.

The third study revealed that the combination of potentially premature waste package failure and accelerated radionuclide transport through the vadose zone induced by the presence of large amounts of concrete argued against its use. In the final analysis, the uncertainty associated with

the potential adverse post-closure effects of concrete and the inability to categorically and unequivocally refute these concerns led to the conclusion, that due to less uncertainty, steel-based ground support systems were the preferred alternative.