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MAR 24 1986

MEMORANDUM FOR: Paul Hildenbrand, Project Manager
Basalt Waste Isolation Project, WMRP
Division of Waste Management

FROM: Michael F. Weber, WMGT
Division of Waste Management

SUBJECT: REVIEW OF BWIP SHAFT SEAL SYSTEM CRITERIA, SD-BWI-CR-015

In response to a request from Wayne Walker, WMRP, please find enclosed my review of the document entitled "Preliminary Performance Requirements and Criteria for the Seal System of a Nuclear Waste Repository in Basalt," 1983, SD-BWI-CR-015. This document identifies preliminary performance requirements for sealing shafts, tunnels, and boreholes of a hypothetical repository at the Hanford Site. Based on my review of sections 4.2.2 and 6.2.3, and appendices A and C, I have concluded that the document is deficient in three primary areas and suffers from several limitations and errors. My review has been reviewed by Neil Coleman. Please contact me if you have any questions.

/S/
Michael F. Weber
Geotechnical Branch
Division of Waste Management

Enclosure:
Review of SD-BWI-CR-015

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WMGT DOCUMENT REVIEW SHEET

FILE #: 3101

DOCUMENT #: SD-BWI-CR-015

TITLE: Preliminary Performance Requirements and Criteria for the Seal System of a Nuclear Waste Repository in Basalt (1983), by Rockwell Hanford Operations.

REVIEWER: Michael Weber

DATE REVIEW COMPLETED: March 4, 1986

REVIEW ABSTRACT:

This document identifies preliminary performance requirements and criteria for sealing shafts, tunnels, and boreholes of a nuclear waste repository in basalt. Relevant to this review, Section 4.2.2 presents a simple algebraic model for estimating the proportion of groundwater that flows past waste packages and through the repository shafts following closure. RHO concludes using the model that sealed shafts will not be preferential pathways for radionuclide migration because greater than 99% of the water flowing past the waste packages never enters the shafts.

Based on this review of sections 4.2.2 and 6.2.3, and appendices A and C, RHO's conclusion is not presently defensible because of (1) the assumption of unreliable hydrogeologic characteristics of basalt flows at Hanford, (2) inadequate consideration of the potential significance of the disturbed rock zone as a pathway for radionuclide migration, and (3) non-conservative simplifications of the model used to assess flow to the shaft. In addition, the document contains errors and suffers several limitations.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

This document illustrates DOE's use of performance assessment to support the design of repository shafts and seals. DOE needs to demonstrate that repository shafts can be sealed effectively to ensure that the shafts will not become preferential pathways for radionuclide migration following closure. NRC needs to review these assessments to confirm that DOE's repository design complies with licensing requirements in 10 CFR Part 60 (e.g., §60.134).

PROBLEMS, DEFICIENCIES, OR LIMITATIONS:

Based on review of sections 4.2.2 and 6.2.3 and appendices A and C, the design criteria identified in the document are not currently defensible with respect to hydrological issues at the Hanford Site. The review indicated several deficiencies of the document, including: (1) the assumption of unreliable hydrogeologic characteristics of basalt flows at Hanford, (2) insufficient recognition of the disturbed rock zone as a potentially significant pathway for radionuclide migration, and (3) non-conservative simplifications of the model used to assess flow to the shaft. In addition, the document contains errors and suffers several limitations.

Unreliable Hydrogeologic Characteristics

Preliminary conclusions reached in the document are based on the results of a simple algebraic model of groundwater flow past waste packages to the shafts. The validity and accuracy of the model inherently depends upon the hydrogeologic characteristics assumed for engineered components and basalt. Because the characteristics assumed for the basalt are presently considered unreliable, conclusions developed based on the model are not currently defensible.

The model assumes parameter ranges for hydraulic conductivity values whose reliability has been seriously questioned. For example, Comment 6-15 of NRC's comments on the draft Environmental Assessment for the Hanford Site describes problems with the reliability of DOE's preliminary tests of horizontal hydraulic conductivity. The hydraulic conductivity values assumed in the model were based on the results of these tests. Problems with the tests were caused by irregularities in test procedures, improper test analysis, temperature effects, effects of dissolved gas and solids, and the effects of large- and small-scale heterogeneities in basalt flows. In addition, existing testing results demonstrate a large variability in horizontal hydraulic conductivity values. Because of their restricted scale, these tests may not have interrogated anomalous zones of high conductivity that may significantly affect radionuclide migration from the underground facility. [cf. Letter to Olson from Wright, "NRC review of BWIP hydrogeologic test data," May 29, 1984]. Further, reliable field data do not exist to characterize vertical hydraulic conductivity of basalt flows at Hanford

Appendix C (pg. 80) cites Long (1983) to indicate that vertical hydraulic conductivities are two to three times the horizontal conductivities of dense basalts. Long (1983; pg. I-292), in turn, references Sagar and Runchal (1982) to support the statement that the maximum anisotropy ratio of vertical to horizontal conductivity is about 3.5. Sagar and Runchal (1982), however, only provide estimates of equivalent hydraulic conductivity as the results of a demonstration of their analytical approach rather than as a characterization of the Hanford basalts. In fact, they state that the demonstration is ". . . intended as an illustrative example and not as a definitive statement on the hydraulic conductivity of the fractured basalt at Gable Mountain." Despite this obvious caveat, RHO appears to have adopted anisotropy ratios calculated from Sagar and Runchal (1982) as definitive characteristics of basalt flows at Hanford.

Even if Sagar and Runchal (1982) intended to characterize basalt flows at Hanford, the representativeness of their estimates of equivalent hydraulic conductivities would be questionable [cf. Memorandum from M. Gordon to M. Fliegel on October 24, 1984, WM File 101]. To demonstrate their analytical approach, Sagar and Runchal (1982) assumed (1) uniform distributions of orientations for three fracture sets based on field data, (2) a fracture density of 8 fractures per elemental cube 5 m on a side without any basis, (3) the mean and standard deviation of fracture apertures without any basis, and (4) the mean and standard deviation of fracture lengths without any basis. The authors do not demonstrate that the assumed fracture characteristics are representative of actual fractures in the Pomona Member at Gable Mountain. With the exception of the orientation characteristics derived from field observations, the other characteristics may bear little resemblance to the actual characteristics of the fractures at Gable Mountain. Even the orientation data may not be representative of portions of the entablature of the Pomona Member [cf. NRC comments on draft Hanford Environmental Assessment, Major Comment 1, 1985].

Orientations of fracture sets would be expected to vary considerably within the entablature of a basalt flow and among flows. Fractures may be oriented predominantly subhorizontal near the top of the entablature in contrast with subvertical fractures deeper in the zone. Near the base of the entablature, horizontal joints may dominate fracture orientations. Based on observations of fracture orientations, the ratio of vertical hydraulic conductivity to horizontal conductivity could be expected to vary as a function of location within the entablature. Sagar and Runchal (1982) do not report the location within the entablature where the orientation data were collected. The reported data may be a composite of fracture characteristics observed throughout the entablature. Conversely, the orientation data may have been collected in only one section that would not be representative of the entire entablature. Similarly, fracture characteristics observed at Gable Mountain may not be representative of fractures in the Pomona Member or other basalt flows elsewhere at the Hanford Site.

DOE should revise the document by systematically examining the sensitivity of model results to plausible ranges in hydraulic parameter values. The document should also indicate that the lack of defensible estimates of such parameters as vertical hydraulic conductivities precludes high confidence in results calculated using the simple model described in the document.

REFERENCES: Long, P. E. (Ed.) (1983). Repository Horizon Identification Report, RHO-BW-ST-28 P.

Sagar, B., and A. Runchal (1982). "Permeability of Fractured Rock: Effect of Fracture Size and Data Uncertainties," Water Resources Research, v. 18, pp. 266-274.

Significance of the Disturbed Rock Zone

Appendix A summarizes rock disturbances caused by excavation and stress redistribution without providing sufficient information about the hydraulic properties of the disturbed rock zone. This zone appears to be a significant pathway for potential radionuclide migration because of its increased conductivity relative to surrounding rock. The document does not adequately consider the significance of the disturbed rock zone or identify appropriate evaluation approaches relative to shaft seal design.

The appendix cites several references that describe general effects of excavation on rock properties, including qualitative and semi-quantitative estimates of hydraulic conductivity changes. The excavation disturbance creates a disturbed rock zone (DRZ; as opposed to the "Disturbed Zone" in 10 CFR Part 60) around shafts and tunnels. Defensible estimates of the hydraulic conductivity and effective porosity are not currently available to describe the disturbed rock zone in basalt around shafts proposed for the Hanford repository.

The document indirectly mentions the potential significance of the disturbed rock zone. Based on the simple model described in the document, RHO has concluded that the fraction of potentially contaminated groundwater flowing along the shaft through the DRZ is more than 260,000 times the design requirement (cf. pg. 92). Thus, the DRZ may be a preferential pathway for radionuclide migration. In addition to radionuclide migration to the DRZ around the shafts through tunnels, migration could also occur through the basalt overlying the waste and the overlying flow top to the DRZ. Once in the DRZ, migration could occur through the DRZ to flow tops and interbeds above the host rock. Consistent with this conceptual model, characterization of the DRZ should be recognized as a primary objective of site characterization. Testing in the Exploratory Shaft facility should be designed and conducted to provide necessary information on the hydraulic characteristics of the DRZ.

The document should be revised to recognize the potential significance of the DRZ, evaluate available information on the hydraulic characteristics of DRZ's in rocks of similar characteristics and geologic settings, and identify appropriate testing approaches to characterize the hydraulic characteristics (hydraulic conductivity, effective porosity, characteristics of flow regime) of the DRZ.

Non-Conservative Simplifications of the Model

Design requirements and criteria described in the document are based on the results of the model presented in Appendix C. The model attempts to demonstrate that less than 1% of groundwater flowing past waste packages flows up through the shaft. Notwithstanding the previous comments, the model fails to demonstrate satisfaction of the design assumption because of non-conservative simplifications of the model.

The model described in Appendix C is based on a decision network, in which groundwater flow directions are determined at decision points. At each decision point, the fraction of flow is systematically reduced according to the ratio between the products of hydraulic conductivity, cross-sectional area, and hydraulic gradient along each flow path. For example, groundwater flows away from the waste packages either upward through the basalt flow interior or laterally into emplacement rooms. To flow up the shaft, groundwater in the emplacement rooms must flow through the access tunnels and avoid the disturbed rock zone around the shaft. The model simplifies the groundwater flow system by assuming that groundwater, and hence radionuclides, will not enter the shaft if it deviates from this pathway.

In the real system, however, groundwater that flows upward into the host rock will reach a flow top where it may flow to a shaft or the DRZ around a shaft. Thus, the model would be expected to underestimate the fraction of flow up the shaft and its DRZ because it ignores groundwater pathways to the shaft that deviate from the network. In addition, the model neglects flow up the DRZ. If this flow were considered, however, the fraction of flow up the shafts or their DRZ's may increase significantly. Further, modifications to the calculations to remedy errors and to consider potential perturbations to hydraulic gradients indicate that the fraction of flow reaching the overlying flow top using the network would be approximately 10% rather than 0.14% as calculated in the document.

As another simplification, DOE's approach assumes porous media flow along the entire pathway from waste packages up through the shafts. The list of codes identified in Section 6.2.3 indicates that future assessments of the shaft system will continue this approach because none of the codes identified is capable of simulating fracture flow. At the scale of the underground facility, however, groundwater flow along discrete features may be significant with respect to releases from the engineered barrier system. The document does not justify the assumption of porous media flow. For example, Section 4.2.2 indicates that flow along the gap at the grout/rock interface will be modeled as equivalent porous media flow. Representation of the interface as a porous medium may considerably underestimate the velocities of flow in discrete discontinuities that may exist along the interface. Similarly, the modeling does not consider annular flow along the interface between the shaft backfill and liner. Even flow in basalt, in which groundwater flows predominantly through fractures, is treated in the model as equivalent porous media flow.

The document needs to justify the assumption of equivalent porous media flow at the scales under consideration.

The document should describe and evaluate assumptions invoked in developing the model. This description should include evaluations of whether these assumptions are indeed conservative as claimed in the document.

Other Comments

1. The document does not assess potential effects of the shafts on groundwater flow and the hydraulic gradient in the vicinity of the underground facility. Because the hydraulic conductivities of the shaft backfill, disturbed rock zone, and grout may differ significantly from those of the basalt flows, flow near the underground facility may be perturbed from ambient conditions. The buoyancy gradients caused by repository heating could conceivably amplify the perturbations caused by contrasts of hydraulic conductivities between engineered components and the host rock. These perturbations could significantly alter groundwater flow directions and rates from pre-emplacement conditions. Thus, the document should evaluate potential effects of shaft and repository construction on hydraulic gradients before and after closure.

2. Section 4.2.2 (pg. 38) implies that groundwater supply to the waste panels in the host rock will be diffusion-limited. This implication appears to be inconsistent with available information about the nature of groundwater flow through basalts, where groundwater predominantly moves through fractures and joints. Thus, the supply of groundwater would be limited by advection through the discontinuities. The document should be revised to eliminate the implication of diffusion-limited groundwater supply or to justify the implication that groundwater supply to the underground facility will be controlled by diffusion.

3. Although it recognizes an exception for highly anisotropic conditions, the first sentence of paragraph 5 (pg. 70) states that fracturing of intact, competent rock due to stress redistribution is unlikely. The statement, however, is not related to conditions at the Hanford Site. In light of high, predominantly horizontal in-situ stresses observed at BWIP, the discussion should determine whether fracturing of the Columbia River Basalt is expected as a result of stress redistribution. Prior to release to DOE, this comment should be coordinated with engineering review comments prepared by WMEG staff.

4. Section A.1 mentions that longitudinal flow around a shaft plug may increase as a result of minor "slabbing." The document does not define "slabbing," provide estimates of the range of magnitudes of increases in flow caused by "slabbing", or assess whether "slabbing" is expected at the Hanford Site. The document should be revised to define "slabbing" and to estimate the potential magnitude of flow increases attributable to "slabbing" at Hanford.

5. Section A.3 asserts that the assumption of fractures normal to the direction of maximum stress change is conservative in analyses of fracture flow. This assumption is not necessarily conservative, however, because movement in the plane of a fracture may cause wedging of the fracture at irregularities on the fracture surface. Thus, the fracture aperture may actually increase as a result of shear stress which would cause a cubic increase in the effective hydraulic conductivity of the fracture. The document should be revised to evaluate whether the assumption is conservative or to delete the statement.

6. Section A.3 asserts that up to 80% of the potential increase in flow through the disturbed rock zone is predicted to occur within 1 m of the wall of a 3-m radius shaft excavated by blasting. The document should be revised to provide an assessment or reference that supports the assertion.

7. Section C.1 (pg. 80) states the assumption upon which the shaft design requirements and criteria have been developed as " . . . [less than] 1% of the radionuclides released from the engineered system could be transported up the shaft to the accessible environment [i]f it can be shown that [less than] 1% of the fluid passing near the waste packages could move up the shaft. . ." The assumption appears to be an appropriate working hypothesis for preliminary designs of the shaft seal system. However, this assumption implicitly assumes that the amount of flow is directly proportional to radionuclide releases, which has not been demonstrated through performance modeling of the repository. Such modeling should consider variables that would influence radionuclide releases, including radionuclide solubilities, attenuation characteristics of the engineered system, waste package failure rates, and the configuration of the groundwater flow system at and after the time of release. The document should be revised to evaluate the validity of this assumption and include additional variables that may significantly affect its validity.

8. Several of the shaft cross-sectional areas listed in Table C-1 have been calculated incorrectly. Based on the excavation diameters (in m) reported in the left column, the cross-sectional area for the confinement air exhaust shaft should be 18.1 m^2; 35.3 m^2 for the service shaft; and 27.3 m^2 for the basalt transport shaft. These areas were calculated using the simple formula:

$$\text{area} = \pi r^2,$$ where r is the excavated radius.

With these corrections, the total cross-sectional area is calculated to be 121.5 m^2 rather than the 118.7 m^2 as reported in the document. This area is then equilibrated to the area of an equivalent shaft with an excavated radius of 12.44 m (reported as 12.3 m). The document, however, does not demonstrate the equivalence of the single shaft and the multiple shafts, which is questionable considering potential overlaps of the disturbed rock zones associated with individual shafts.

9. Section C.2.3 describes hydraulic gradients in the vicinity of the underground facility. The description, however, does not reference or provide assessments that support the estimated "repository-scale equivalent head gradient created by buoyancy effects of the temperature field." Further, the description states that ignoring local-scale increases in the hydraulic gradient is conservative because it underestimates the fraction of groundwater flowing past the waste packages into basalt. As stated in comment 1, however, BWIP has not assessed the magnitude and transient nature of the gradients that may increase in the lateral direction as well as the vertical. Consequently, BWIP has not demonstrated that ignoring local-scale hydraulic gradients is necessarily conservative. For example based on NRC staff non-isothermal modeling of groundwater flow in the vicinity of a hypothetical repository at Hanford, lateral gradients near the underground facility may increase from 0.001 to 0.04 m/m (cf. Gordon and Weber, 1983). Thus, assuming increased vertical gradients that ignore local-scale increases in conjunction with ambient lateral gradients does not constitute a demonstrably conservative approach to estimate groundwater flow in the vicinity of the waste packages.

REFERENCE: Gordon, M. and M. Weber (1983). Non-isothermal Flow Modeling of the Hanford Site. U. S. Nuclear Regulatory Commission, Division of Waste Management, Docket File 101.

10. Table C-2 and Section C.4 identify an eighth node (emplacement horizon shaft seal) that is not described as a node in the flow network. The document should be revised to delete mention of this node or to describe what the node represents and assess its significance.

11. Section C.2.3 incorrectly states that Area 2 of the underground facility represents 20% of the total repository. Consistent with the dimensions provided in Figure C-1, Area 2 represents approximately 27% of the total area of the underground facility (i.e., sum of the areas of section 1 through 4).

12. Equation C-3 miscalculates the value for Q(1b). The hydraulic gradient vector multiplier should be 0.7 rather than 0.07, which increases the proportion of flow into the emplacement rooms from 34% to 83%. As noted in comment 9, this proportion could be greater considering increases in the lateral gradient above ambient conditions.

13. Section C.3.5 states that the average "effective thickness" of flow tops in the Grande Ronde Basalts is 8 meters. The document, however, does not define "effective thickness" or reference a supporting assessment for this average estimate. Relevant to groundwater travel time analyses, effective thickness is defined as the product of the effective porosity of a unit and the thickness of the predominant contributing zone in that unit. In comparison with the 8-meter average stated in the document, the two field-measured values of flow effective thickness at Hanford are both less than 0.01 meters (DOE,

Draft Hanford EA, 1984). Section C.3.5 appears to use the term in a different context because there is no discussion of effective porosity with respect to the model calculations. The document should be revised to define "effective thickness" consistent with other BWIP assessments and reference supporting assessments as a basis for the average value.