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Consulting Group, Inc.

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"NRC Technical Assistance
for Design Reviews"
Contract No. NRC-02-85-002
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Dear David:

Enclosed are the following Itasca Document Reviews, prepared under NRC Contract NRC-02-85-002, Task Order No. 006, Task 1.

(1) Itasca Review 006-01-43: "Exploratory Shaft Facility Water Inflow Design Calculations" by R. I. Watkins (RHO Computational Brief CB-00617, Feb. 1987)

(2) Itasca Review 001-02-45: "Character and Distribution of Borehole Breakouts and Their Relationship to in Situ Stresses in Deep Columbia River Basalts" by Frederick L. Paillet and Kunsoo Kim. J. Geophys. Res., 92 (B7), pp. 6223-6234 (1987).

(3) Itasca Review 001-02-47: "Exploratory Shaft Facility Design Basis Study Report," by A. L. Langstaff (RHO-SD-BWI-ER-108, June 1987)

(4) Itasca Review 001-02-48: "Site Characterization Plan Conceptual Design Report for BWIP High-Level Nuclear Waste Packages" by D. J. Myers (SD-BWI-CDR-005, April 1987)

(5) Itasca Review 006-01-50: "Performance Sensitivity Analysis of the Repository Seals Subsystem—Boreholes Drilled from Repository Excavations" (RHO-SD-BWI-TI-342).

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(6) Itasca Review 006-01-51: "Primary Fracture Frequency, RQD, and Core-Break Frequency Calculated from Cohassett Drill Core Data" by R.K. Ledgerwood (RHO Computational Brief DER-CB-0023, June 1987).

Please call me if you have any questions.

Sincerely,

Roger D. Hart
Program Manager

cc: R. Ballard, Engineering Branch
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encl.
rdh/ks

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w/ ltr. dtd. 4/20/88
To: David Tiktinsky
fm: Roger D. Hart

ITASCA DOCUMENT REVIEW

File No.: 006-01-43

Document Title: "Exploratory Shaft Facility Water Inflow Design Calculations" by R. I. Watkins (RHO Computational Brief CB-00617, February, 1987)

Reviewer: Itasca Consulting Group, Inc. (K. Wahi)

Approved: M Board

Date Approved: 3/25/88

Significance to NRC Waste Management Program

Calculations have been performed to estimate the water inflow into the Exploratory Shaft Facility (ESF) at the Hanford Site. The results of these calculations will be incorporated into the BWIP ESF Design Basis Study document (SD-BWI-ER-018). It is apparent that these calculations will be used to support the design of the ventilation and dewatering systems as well as to develop safety procedures (or to justify a lack thereof) for handling water inflow during site characterization. The same methodology could also be proposed for predicting inflows during repository construction and operation. Extensive use has been made of another study (Golder, 1986) in these calculations. Expert opinions were used in that study to assign ranges and distributions to hydrologic and geologic parameters. It is conceivable that the same methodology (indeed some of the same numerical values), would constitute certain elements of a performance assessment for the repository at BWIP. The document has potential significance for site characterization and licensing.

Summary of the Document

This Computational Brief presents parameter determination and calculations of water inflow quantities into the proposed ESF. Predictions are made at three different levels of confidence. The data and results are intended to be used in the design of the ventilation and dewatering systems for the ESF. Three phases of ESF development are addressed: (1) prior to connection of the exploratory shafts, (2) during proposed in-situ testing, and (3) during in-situ testing with 100% additional drifting. Water inflow is postulated to occur from six different types of geologic features within the Cohassett flow. Encoded Probability Distribution Functions (PDFs) from Golder (1986) and Chou (1987) have been utilized for several parameters of the calculations. These PDFs are for specific storage, hydraulic conductivity, flow top invasion (depth and frequency), thickness of pillow breccia zones, spiracles height, platy zones (extent and frequency), and faults and fractures (spacing and orientation). Assignments of parameters appropriate to an inflow scenario are made from these PDF curves. Total drifting lengths of 213 m, 1006 m, and 2012 m have been assumed for the three phases of development.

For the dense-interior inflow estimate, a steady-state model is taken from Watkins (1982). In this model, Q, the volumetric inflow rate (m^3/s) is defined as:

$$Q = K\ b\ \Delta h\ S_V \qquad (1)$$

where K is the hydraulic conductivity (m/s),

b is the drift length (m),

Δh is the drawdown (m), and

S_V is a geometric factor.

The results show a range of inflow rates (from the dense interior) between 3.7E-7 m^3/s and 1.0E-3 m^3/s.

For the vesicular zone inflow calculations, a transient inflow model proposed by Lohman (1972) is used. The inflow rate (m^3/s) is estimated by:

$$Q = 2\ \Delta h\ l\ [S_S b\ Kb/(\pi t)]^{1/2} \qquad (2)$$

where S_S is specific storage (m^{-1}),

t is time (s), and

l is drift length (m).

The transient estimates at 60 s and 6,000 s are based on a maximum drift length of 2 m; the steady state estimates use t=600,000 s and l=88 m. The transient inflow estimates range from 4.4E-7 m^3/s to 7.8E-5 m^3/s, whereas the steady-state estimates range between 1.94E-6 m^3/s to 3.43E-5 m^3/s.

Inflow from the Cohassett flow-top could occur due to an invasion of the flow top by an excavation (room) for conducting a hydrology cluster test. The likelihood of invasion and the average depth of invasion at three confidence levels are used to find the overall probability of intersection between the room and the flow top. Due to a very low calculated probability, no intersection is assumed which results in a prediction of no inflow from the flow top.

Inflow from the conical flow bottom features, known as spiracles, could occur if intersected by a drift. The encoded PDF gives spiracles heights of between 3.1 and 18.2 meters. However, no drifts are planned closer than 27 m from the flow bottom. Therefore, it is assumed that no intersection and, hence, no inflow occur from the spiracles. Similarly, another flow bottom feature, pillow breccia, are estimated to have thicknesses between 5.7 and 24.3 meters. Again, no intersection is assumed and, therefore, no inflow is predicted to occur from the pillow breccia.

Platy zones are horizontal fracture zones that can occur anywhere within the dense interior. Based on likelihoods of horizontal and vertical occurrences and overall likelihood of intersecting a Platy Zone, one intersection is assumed. The same transient hydrologic model as for the vesicular zone is used. Transient inflow rates of 1.92 E-5 m^3/s and 1.92 E-4 m^3/s (i.e., 3 GPM) are predicted at 6,000 s and 60 s. Flow rates become negligible after 2 weeks.

Inflow due to intersection of a drift with sub-vertical faults and fractures is estimated by using a model proposed by Jacob and Lohman (described in Lohman, 1972). The transient inflow rate Q is defined as:

$$Q(t) = 2\pi \; K \; b \; \Delta h \; W_\lambda \tag{3}$$

where b is the fault thickness, and

W is the "well function".

The dimension of the opening is represented in Eq. (3) through the "λ" term. Transient inflow rate estimates range from 1.0E-5 m^3/s to 5.18E-3 m^3/s (or 82.1 GPM). The range of steady state inflow rate is estimated to be between 4.0E-6 m^3/s and 1.85E-3 m^3/s (29.29 GPM).

The sum of all steady-state water inflows for each phase of the ESF development yields maximum rates of 1.05E-4 m^3/s (1.67 GPM) for the pre-connect phase, 3.54E-3 m^3/s (56.14 GPM) for the testing phase, and 4.04E-3 m^3/s (64.03 GPM) for the 100% additional drifting phase. Based on the estimates for different types of inflow, faults are seen as the only significant contributor toward peak inflow rates. It is recommended that the design allow for peak surges of 32 GPM in addition to the steady-state inflow. The capacity to handle peak and anomaly inflow can often be accommodated by additional surge storage capacity in the underground sumps rather than in oversizing of the pumps.

Problems, Limitations, Deficiencies

The document contains many errors which make it difficult to verify many of the results presented in the tables. Typographical errors generally do not impact the reliability of the numerical output. In this case, however, some equations are incorrect as presented. Without a thorough comparison with the original source, it is not advisable to use these equations. Some terms, such as S_v on p. 5 of the document, are not identified with respect to their physical context. Moreover, the units for some quantities included in the discussion are not always consistent with those given in the tables of results. For instance, S_v should be a dimensionless parameter according to the equations on p. 5; however, in Table 4.1, it has been labeled as having units of m^{-1}. The equation on p. 9 is missing the term "b" inside the square-root. The correct expression should be (see Lohman, 1972):

$$Q(t) = \frac{2s}{(\pi t)^{1/2}} (S_s \, b \, K \, b)^{1/2} \qquad (4)$$

The same error is repeated elsewhere in the document wherever that particular equation is stated. It is important to point out that the results in Tables 5.1 and 9.1 are consistent with the correct equation shown above.

Another significant error is that at the bottom of p. 13, where the overall likelihood of intersection ("Max" case) is calculated as being 2.0E-7. Performing the arithmetic correctly results in a probability of 1.92E-3. A decision of "no intersection" was made in this instance based on the very low (but wrong) probability.

Unconventional and misleading terminology has been used frequently. Expressions such as "average mean value" (pp. 13, 20, etc.) are used without definition. Statements such as, "Since specific storage values vary by only one order of magnitude" (p. 20 and p. 29) are incorrect and misleading. The alleged "one order of magnitude variation" occurs not in the specific storage values but in the interpreted mean at different confidence levels for the three different distributions of specific storage. Each distribution for specific storage happens to span several orders of magnitude.

There is also an inherent assumption of a large thickness of the dense interior that is laterally continuous. The manner in which single values of hydraulic conductivity have been obtained from different PDFs is a mystery. They do not appear to be arithmetic averages of the three "mean" values associated with the three distributions. A clear statement of the procedure used to obtain the various mean values and/or averages should be included in the document.

Recommendations

1. This document should go through a strict quality assurance exercise.

2. The NRC should have a qualified hydrologist review the document. In particular, the applicability of the models and the validity of the assumptions should be examined.

3. Because of the extensive use of Golder (1986) in the analysis, a review of that report is also recommended.

4. In many of the calculations, mean, instead of extreme, values have been used. A case could be made for using some extreme values of hydraulic conductivity. For instance, a hydraulic conductivity value of 6.0E-7 m/s is quoted as the "maximum" or 97% value (p. 20). In fact, the most conservative 97% value is that by 'Expert D' and is greater than 1.0E-3 m/s!

References

Chou, C. J. Statistical Study on the Transmissivity and Equivalent Hydraulic Conductivity of Grande Ronde Basalt Flow Interiors, Flow Tops, and Flow Bottoms," Data Evaluation Report #CB-006, Basalt Waste Isolation Project, Rockwell Hanford Operations, 1987.

Golder Associates. "Probability Encoding of Variables Affecting Inflow into the Exploratory Shaft Facility at the Basalt Waste Isolation Project," Report to Rockwell Hanford Operations, 1986.

Lohman, S. W. "Ground-Water Hydraulics", USGS Professional Paper 708, Washington, D.C., 1972.

Watkins, D. J. "Preliminary Concepts for a Large-Scale Hydrology Test for Phase II of the BWIP Exploratory Shaft Program," Lawrence Berkeley Laboratory letter report to Rockwell Hanford Operations December, 1982.

ITASCA DOCUMENT REVIEW

File No.: 001-02-45

Document Title: "Character and Distribution of Borehole Breakouts and Their Relationship to in Situ Stresses in Deep Columbia River Basalts" by Frederick L. Paillet and Kunsoo Kim. J. Geophys. Res., 92 (B7), pp. 6223-6234 (1987).

Reviewer: Itasca Consulting Group, Inc. (K. Wahi)

Approved: M Board, Itasca

Date Approved: April 19, 1988

Significance to NRC Waste Management Program

Borehole breakouts and core disking are symptomatic of in-situ stress conditions that may present practical difficulties during excavation and construction. Both phenomena have been observed in the Grande Ronde Basalts at the Hanford site when penetrating exploratory boreholes. The choice of excavation shapes (and possibly excavation methods) could be influenced by the stress field and the rock properties for the rock mass in which stable openings are desired. The failure mechanisms that come into play upon excavation could also adversely affect the long-term isolation capability of the previously undisturbed rock mass. An understanding of the causes and mechanisms of borehole breakouts and core disking is necessary for a proper design, construction, and remedial operation of large underground structures in such a rock mass.

Summary of Document

Borehole wall breakouts and core disking in deeply buried basalts at the Hanford site are examined. A series of boreholes penetrating the Grande Ronde Basalts were logged to examine the extent of breakouts near the 1000m depth. Three of the five boreholes examined are in the vicinity of the reference repository location (RRL); these are named RRL-2, RRL-6, and DC-4. The other two boreholes, DC-7 and DC-12, are several kilometers away from the RRL boundary. The lithology of the Grande Ronde basalts appears to allow for heterogeneous distribution of stresses in the earth's crust as indicated by in-situ stress measurements. Anisotropy in the horizontal stress components is observed with the maximum principal stress directed along a north-trending axis. The dense interiors are much stronger and more brittle than the interflow sediments. All but one of the boreholes were cored, and the cored boreholes had a diameter of 7.5 cm. Borehole DC-7 had a diameter of 20 cm.

Disking is a tendency for cylindrical core samples to break into saddle-shaped disks under the combined effects of in-situ stress, rock properties, and drill bit/rock interaction. Numerical modeling suggests that disking results from combined shear and unloading of high horizontal compressive stresses. Core disking and borehole breakout can both be related to the presence of high horizontal principal stresses; however, the rock failure mechanisms for disking and breakouts are different in detail.

Hydraulic fracture data from four boreholes was used to estimate the state of in-situ stress. The Cohassett data for maximum horizontal stress (σ_H), minimum horizontal stress (σ_h) and vertical stress (σ_v) indicate stress ratios of σ_H/σ_v that are between 2.28 and 2.73 and stress ratios of σ_H/σ_h that are between 1.73 and 2.01. The mean values for the maximum and minimum horizontal stresses from all tests are 61.1 MPa and 33.8 MPa, with standard deviations of 5.4 MPa and 2.7 MPa, respectively. The stresses are distributed normally about the mean. No substantial stress gradients can be discerned from profiles of minimum and maximum horizontal stresses in 300m test intervals between 900m and 1200m.

The five boreholes were logged using the acoustic televiewer and acoustic waveform logging system. The primary application of the waveform logging system in this study was to characterize the basalt behind the borehole wall breakouts. Televiewer logs show borehole wall breakouts throughout the interior of most flows and continuous breakouts in intervals of basalt with low fracture frequency. It has been theorized by other investigators that breakouts will form along azimuths given by the direction of minimum horizontal principal stress. Fewer intervals of breakout occur in borehole DC-12 compared to others. There is an apparent correlation between core disking and borehole wall breakouts. Both tend to be confined to the dense flow interiors of low fracture frequency. However, different failure mechanisms are thought to result in different details of the distribution of breakouts and disking. Destressing upon drilling of zones with high ratio of horizontal to vertical stress is apparently the cause of core disking. High differential horizontal stress is thought to result in borehole wall breakout.

Almost all flows have intervals of breakout-free rock at the top and bottom even though the appearance of the breakout-free basalt is no different from that of dense interior basalt. Moreover, the acoustic properties also do not show measurable changes. It is speculated that slight alteration of basalt at flow tops and bottoms has affected rock deformability such that core disking and breakout are suppressed but without change in the acoustic properties.

Problems, Limitations, and Deficiencies

Despite references to the possibility that borehole breakouts and disking are caused by different mechanisms, discussion of those mechanisms is extremely limited. The emphasis of the paper is more on the techniques and interpretations of measurements rather than a serious inquiry into how these phenomena are caused and what might be done to control them.

The authors offer no suggestion that perhaps the differences in rock structure in different portions of the flow might account for the absence of these phenomena near flow tops and flow bottoms. The frequency, orientation and properties of joints have not been considered as a factor.

It is unclear whether the stress ratios remain relatively constant through the flow thickness. Some of the data suggest that in a 300 m interval there is no significant stress gradient. Does that mean that the vertical to horizontal stress ratio decreases with depth? One other area that has not been addressed is the variation of the magnitude of stress ratio. Does the ratio vary within a flow? Is the stress ratio in the flow top different from that in the dense interior of the flow? No advice is offered regarding the excavation of larger openings (either shafts or drifts) in a rock mass where high stress conditions and core disking/borehole breakouts have been observed.

Recommendations

- Comparisons to case histories at other sites with similar stress conditions should be made to identify important mechanisms and empirical factors.
- Possible correlations between these phenomena and conditions that lead to rock bursts should be investigated.

- If disking or breakouts are known to occur at shallow depths, the mechanisms and conditions proposed in the document need to be revised.

- It needs to be investigated whether the stress ratios in the flow tops and flow bottoms are different from those in the dense interior of a flow.

ITASCA DOCUMENT REVIEW

File No.: 001-02-47

Document Title: "Exploratory Shaft Facility Design Basis Study Report," by A. L. Langstaff (RHO-SD-BWI-ER-108, June 1987)

Reviewer: Itasca Consulting Group, Inc. (K. Wahi)

Approved: M Board, Itasca

Date Approved: April 19, 1988

Significance to NRC Waste Management Program

This design basis study for the Exploratory Shaft Facility (ESF) makes recommendations concerning water and methane inflow values, facility layout, size of the second shaft, ventilation, and gassy mine requirements. The facility design and in-situ test plan are intimately related. The techniques and assumptions used in the design basis study are likely to be applied to the repository facility design as well. It is, therefore, an important document for site characterization, repository design and licensing issues.

Summary of Document

This study has been carried out to address concerns related to the design basis and safety margins for the ESF. Details of four separate studies are reported in Appendices A through D on topics of water and methane inflow, flexibility, gassy mine impacts, and second shaft scoping.

The water and methane inflow study provides the basis for recommended design values or criteria for dewatering and ventilation of the ESF. The study presents geologic and hydrologic data as well as analytical and numerical models for computing groundwater inflows. "Probability Encoding" has been used to assign ranges, distributions, and point values (at selected confidence levels) for geologic and hydrologic parameters or characteristics. Three types of geologic information (primary cooling fracture data, location of intraflow structures, and extent of tectonic discontinuities) have been utilized. The hydrologic data are based on well tests and on the probability encoding process reported elsewhere. The hydrological representation of the ESF is made as a series of drains within the flow interior with discrete features acting as localized areas of increased groundwater flow. Estimates of probable methane concentrations are derived using probability encoding. Methane concentrations of 1,050 mg/L (or less) with a 90% probability are projected.

The flexibility study establishes the flexibility parameters for personnel, equipment, hardware, and facilities required to support the ESF Program through different stages. One parameter that is common to all the questions raised in the study is the ventilation requirement. Five flexibility scenarios were considered to determine the ability of the ESF design to support programmatic changes. The scenarios are as follows.

Scenario 1 — underground construction after completion of the ES-I but prior to connection to ES-II

Scenario 2 — underground construction after connection to the ES-II but prior to start of in-situ testing

Scenario 3 — in-situ testing for site characterization from completion of construction to the license application

Scenario 4 — performance confirmation testing, from license application to construction authorization

Scenario 5 — initial repository construction, from construction authorization to connection with the first repository shaft.

Major conclusions and recommendations of the flexibility study are that:

(1) the underground facility needs to be expanded from 1,500 to 3,300 feet of drifting;

(2) the second shaft diameter (ID) needs to be increased to about 10 feet to provide adequate ventilation for the larger facility; and

(3) the construction duration will increase by 5 weeks and the testing duration will increase by 1 month for the larger (roughly twice in size) facility with a program of testing that is 50% larger in scope.

The gassy mines impacts study assessed the design, cost, and schedule impacts of classifying the ESF as gassy. Design components examined included underground layout, development sequence and schedule, mining and electrical equipment, communications and monitoring, blasting materials, and ventilation system. Three sets of MSHA regulations (current, proposed Category III, and proposed Category IV) were applied to examine impacts due to gassy mines classification. A summary of gassy regulation impacts is given in Table 1 (Table 2 on p. 16 of the document).

Table 1

SUMMARY OF GASSY REGULATION IMPACTS

Requirements	Impacts			
	Design	Construction cost		Construction schedule (wk)
		(%) Increase	Δ ($ 000)	
Current regulations	Major[a]	+ 33	5,530	+ 20
Category III[b] regulations	Minor	+ 6	1,070	+ 2
Category IV[b] regulations	Minimal	--	--	--
Retrofit	Minor	+ 32	5,310	+ 18

[a]Design impacts would be mitigated if variances were obtained from the crosscut requirements.
[b]From proposed MSHA regulations (MSHA 1985b). PST87-2126-35

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Conclusions and preliminary recommendations of the gassy mine impacts study are that:

- Formal classification of the ESF as gassy (under current regulations) is premature.
- "Permissible" electrical equipment and permissible main fan should be used. Continuous monitoring for methane should be conducted.
- Exemption from the DOE requirement to follow California Mine Safety Orders should be requested.
- Use of permissible or intrinsically safe testing equipment should be considered.

The second shaft (ES II) scoping study evaluated the capacity and cost of blind-bored and lined shafts with finished diameters of 6, 8, 10 and 12 feet. Ventilation and hoisting capacities for men, materials and rock as well as for cost, schedule and risk impacts were examined. The study assumed that ES-I is an air exhaust shaft with a finished diameter of 6 feet. A ranking matrix was developed in a pseudo-quantitative fashion by polling an expert panel. Maximum capacities for second shafts (with varying diameters) were derived based on the rankings and regulatory criteria and are shown in Table 2 (Table 3 on p. 18 of the document).

Table 2

SECOND SHAFT SUMMARY COMPARISON

Second Shaft Summary Comparison.[a]

	Second shaft (ES-II) diameter			
	6 ft	8 ft	10 ft	12 ft
Ventilation capacity (ft^3/min)	66,600	94,700	123,300	146,300
Fan horsepower	820	1,030	1,340	1,400
Personnel hoisting capacity (people/h @1,000 ft/min)	20	45	80	115
Rock hoisting capacity (tons/h @2,100 ft/min)	48	94	161	192
Hoist size (horsepower (rms))	630	1,225	2,070	2,380
Confidence factor for liner installation (%)[b]	90	86	85	83
Shaft construction time (wk)	44	51	55	60
Second shaft cost (M$)	$71	$84	$101	$127

[a]Based on final configurations and 6-ft ID ES-I.
[b]Expert advice panel's level of confidence for completing the task as scheduled.

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The results of the four separate studies were systematically integrated and certain design basis recommendations made for inclusion in a site-specific, design requirements document. Calculated values of water inflow predict maximum short-term peak and anomalous inflows of 32 gal/min for a probe hole intersecting a fault (or fracture), and 82 gal/min for a drift intersecting the feature. A methane content of 1,050 mg/L of water, predicted at the 90% confidence level, could result in 0.2 ft^3 of methane/gal of water. The gassy mine study also recommends that the Category III MSHA regulations be used as the design basis. The maximum muck and personnel hoisting rates through the recommended 10-ft. ES-II are 2,400 tons/d and 80 persons/hr. The key recommendation for the ventilation system is to reverse the presently planned air flow direction—i.e., make the ES-II the intake shaft. The final configuration of the ESF and cost estimates are to be determined during the definitive design process.

Problems, Limitations, and Deficiencies

The use of probability "encoding" for the methane and water inflow study, though referenced, needs a better discussion and justification. In a number of cases, a whole distribution appears to have been constructed from extremely limited data. Even if one accepts the validity of the approach, the numerical design values that result from the analysis may not be representative or conservative.

The statement, on p. 11, that "Methane concentrations should be directly related to groundwater inflow" is incorrect; it should state instead that, "Methane release should be directly related to groundwater inflow". Only methane dissolved in groundwater has been considered; the likelihood and quantities of methane associated with gas pockets have not been considered.

As indicated in the review of a related document (Watkins, 1987), the manner in which widely disparate estimates provided by experts have been combined is subject to question.

The statement, on p. 28, that "Currently, no minimum air requirements are mandated for the equipment as proposed for use," appears to suggest that no heat is generated by electrically powered equipment; this, of course, is not the case. In the evaluation of Scenario 3, the impact of a gassy mine assumption has not been considered in estimating water inflow and ventilation requirements. There is a discrepancy of $8.6M in the cost increase for a 10-ft diameter shaft; Table 3 shows an increase of $30M whereas Table 7 shows an increase of $38.6M.

On p. 44 of Appendix A, it is stated that methane concentration data had been collected at 10 boreholes but were considered too sparse for meaningful statistical analysis. How, then, is the use of probability encoding (presumably a statistical technique!) to determine methane distribution justified? The units of specific storage should be m^{-1} and not L/m as indicated on p. 73 and p. 102 of Appendix A. The vertical hydraulic gradient measurement of 10^{-2} m/m quoted on p. 73 is based on two measurements in a single borehole. Potentially large vertical flows are implied by the statement on top of page 82 of Appendix A.

The assumption, on p. 148 (Appendix B), that the "total thickness of the Cohassett flow, excluding the vesicular zone, will be available for ESF drift development" is inconsistent with other related analyses in which the probability of intersecting certain geologic features is calculated based on minimum standoff distances from flow top and flow bottom. It is not clear whether the 79,000 ft^3/min airflow given on p. 162 for the proposed ESF layout provides for water inflow. The computer codes used in the ventilation study have not been described at all; are they proprietary?

In Appendix C, Gassy Mine Impacts Study, the stated overall objective does not include safety. The concerns focus on cost and schedule impacts. The conclusion that "An assumption of gassy classification is premature" is premature in its own right. The judgment is made based on extremely limited data and uses faulty rationale when it states that large water inflow causes other impacts on the ESF systems that might be greater than the impact of compliance with a gassy mine classification.

In Appendix D (Second Shaft Scoping Study), the statement on p. 217, that the overall capabilities could only be improved if ES-I were used as an exhaust shaft, is not valid if ES-II also has a diameter of 6 feet.

<u>Recommendations</u>

Unless additional data support the assumptions regarding input values used in the four studies presented in the design basis study, more conservative values than have been assigned should be utilized.

The probability encoding technique and its applicability to these problems needs to be justified. Also, how the wide variation in expert judgment is reconciled needs to be addressed.

The analyses and the approach appear to be adequate if one can accept the data ranges and extrapolation of the data. The quality and amount of available data need to be carefully examined.

Impacts on the testing program of a gassy mine classification need to be quantified.

References

Watkins, R. I. "Exploratory Shaft Design Basis Study Flexibility Task, Testing Input," Rockwell Hanford Operations, BWIP Computational Brief No. DER-CB-004 (Rev. 0), 1987.

ITASCA DOCUMENT REVIEW

File No.: 001-02-48

Document Title: "Site characterization Plan Conceptual Design Report for BWIP High-Level Nuclear Waste Packages" by D. J. Myers (SD-BWI-CDR-005, April 1987)

Reviewer: Itasca Consulting Group, Inc. (K. Wahi)

Approved: M Board Itasca

Date Approved: April 20, 1988

Significance to NRC Waste Management Program

The waste package in a repository for High-level nuclear waste (consisting of multiple barriers) is an important component of the engineered barrier system. Specific technical criteria in Subpart E of the 10CFR60 rule apply to the performance of the waste package subsystem. The waste package design is also intimately related to the repository design at a given site. Therefore, in addition to satisfying its own performance objective in the post-closure phase, the waste package design must also take into account numerous repository design objectives in the pre-closure phase. The design methodology, analytical techniques and data base used in the waste package design are extremely important in the evaluation of a license application and important,as well, to the site characterization plan. The assumptions, idealizations and extrapolations used in predicting the waste package behavior for up to 1,000 years must be examined critically. This document presents much of the type of information that is necessary in the evaluation of waste package design.

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Summary of Document

A Waste Package Reference Design is developed in support of the Conceptual Design Site Characterization Plan (CDSCP). Previous BWIP Waste package concepts have been refined and the short horizontal borehole (SHB) concept is implemented. Certain differences between this document (Waste Package) and the Repository CDSCP Report are anticipated due to the different start times and different design criteria documents on which the two efforts are based. However, the inconsistencies between the Waste package and Repository CDSCP reports are not expected to result in a significant effect on the repository concept.

The three waste forms considered are intact Westinghouse 15x15 PWR spent fuel assemblies (SFA), consolidated Westinghouse 15x15 PWR rods, and West Valley high-level waste (WVHLW) canisters. Remaining waste forms such as BWR spent fuel, defense high-level waste (DHLW) and transuranic (TRU) waste will be considered in the advanced conceptual design (ACD) phase. Major components of the reference design are:

(1) a thick-walled steel container that provides the primary containment of corrosion rates during the 300-1,000 year period;

(2) packing material (crushed basalt and sodium bentonite clay) surrounding the container that controls water and radionuclide (RN) movement and acts as a chemical buffer; and

(3) a thin metal shell (overpack) around the packing to facilitate emplacement and retrieval.

An alternate design, that uses a much thicker packing, was developed for the consolidated spent fuel (CSF) waste form in addition to the reference design. The number of assemblies in the alternate design (with 1 m packing thickness) must be lowered to three in order to satisfy the maximum temperature allowed the waste form. This reduction implies an increase in: the number of waste packages, the mining volume, the material quantities, and closure sealing and handling operations. The CDSCP waste package and repository design characteristics for reference and alternate designs are summarized in Table 1.

Table 1

CDSCP WASTE PACKAGE CHARACTERISTICS SUMMARY

Characteristic	Metric Units (Engl)	Spent fuel PWR 15 x 15 Westinghouse			West Valley High Level Waste
		Consolidated Rods (4 PWRs)	Intact Assemblies	Alternate Consolidated Rods (3 PWRs)	Vitrified Waste Canister
A. WASTE FORM					
1. Number of rods	EACH	816		612	
2. Number of assemblies/ canisters	EACH	—	4	—	1
3. Diameter/cross section	cm/in	1.07 (0.42)	21.4 (8.4) SQ	1.07 (0.42)	61(24)
4. Overall length	cm/in	384 (157)	406 (160)	384 (151)	300 (118)
5. Initial heat load	watts	2069	2069	1552	225
6. Total weight	kg (lb)	2424 (5344)	2524 (5564)	1818 (4008)	2712 (5978)
B. WASTE CONTAINER					
1. Outside diameter	cm (in)	54.1 (21.3)	80.5 (31.7)	49.0 (19.3)	81.3 (32.0)
2. Overall length (w/o pintle)	cm (in)	412 (162)	437 (172)	412 (162)	325 (128)
3. Wall thickness	cm (in)	8.5 (3.35)	8.5 (3.35)	8.5 (3.35)	8.9 (3.5)
4. Weight loaded	kg (lb)	6618 (14591)	10955 (24154)	5521 (12171)	8632 (19030)
5. Material	ASTM	A-27-84, Grade 6030	→	→	→
6. Surface dose rate					
- gamma	mrad/hr	158×10^3	34.1×10^3	1.63×10^3	19.8×10^3
- neutron	mrad/hr	0.74×10^3	0.40×10^3	0.646×10^3	negligible
C. PACKING					
1. Outside diameter	cm (in)	87.1 (34.3)	113.5 (44.7)	82.0 (32.3)	114.6 (45.1)
2. Thickness	cm (in)	15.2 (6.0)	→	→	→
3. Material		75% basalt/25% bentonite	→	→	→
4. Outside dia. backfill	cm (in)	—	—	256 (101)	—
5. Thickness backfill	cm (in)	—	—	84.8 (33.4)	—
D. SHELL					
1. Inside diameter	cm (in)	87.8 (34.6)	114.2 (45.0)	82.7 (32.6)	115.2 (45.4)
2. Thickness	cm (in)	0.8 (0.31)	→	→	→
3. Weight	kg (lb)	917 (2022)	1235 (2723)	1004 (2215)	1030 (2271)
E. WASTE PACKAGE					
1. Outside diameter (shell)	cm (in)	89.4 (35.2)	115.8 (45.6)	84.3 (33.2)	116.8 (46)
2. Overall length	cm (in)	525 (206)	540 (212)	614 (242)	427 (168)
3. Weight					
- Packing and shell only	kg (lb)	3930 (8666)	5546 (12229)	3757 (8284)	5358 (11814)
- Total package	kg (lb)	12168 (26830)	19126 (42173)	10810 (23836)	15623 (34449)
F. REPOSITORY					
1. Borehole					
- Diameter	cm (in)	90.2 (35.5)	116.8 (46.0)	256 (101)	117.6 (46.3)
- Length	cm (in)	523 (206)	538 (212)	613 (241)	426 (168)
- Pitch	m (ft)	6.7 (22)	→	→	→
- Number of waste pkgs	EACH	1	→	→	→
2. Placement room					
- Width (inside)	m (ft)	6.7 (22)	→	→	→
- Height (inside)	m (ft)	3.3 (10.7)	→	→	→
3. Closure plate					
- Thickness	cm (in)	3.5 (1.38)	→	→	→
- Diameter	cm (in)	89.4 (35.2)	115.8 (45.6)	84.3 (32.2)	116.8 (46.0)
- Weight	kg (lb)	171 (377)	284 (634)	152 (335)	288 (634)
4. Rock temperature Maximum allowable	°C	450	→	→	→
5. Waste handling shaft					
- Diameter	m (ft)	3.7 (12.1)	→	→	→
- Gross capacity of cage	tonne (ton)	42 (46.3)	→	→	→

Assembly of waste packages (reference design) is to occur in three locations of the GROA. Waste form is transferred into an empty container in a Hot Cell facility at the surface and appropriate diaphragm and head welded.

Electron beam welding (EBW) is the reference welding method with other possible alternatives. The shell is loaded with preformed packing in a nonradioactive area of the surface facilities, transported to the subsurface, and inserted into the borehole. The loaded container is transported in a shielded cask to the same subsurface location, aligned with the borehole (with shell and packing), and inserted. Appropriate shield packing and closure plates are installed to complete the emplacement operation.

Thermal, structural, radiation, and corrosion analyses have been conducted for single waste packages with the above conceptual design(s). In addition to some discussion in the main text, analysis methods are described in greater detail in several appendices.

The report contains Waste Package (WP) engineering drawings and the specific analytical methods used are described in Appendices A through J. The WP design analysis logic is illustrated by the diagram in Fig. 1. The previous conceptual design of a long horizontal borehole was abandoned due to retrieval and emplacement complexities. Twenty-three alternative designs were evaluated by varying emplacement geometry, container material, packing form, and the spent fuel configuration. The SHB design was selected for its high emplacement, retrieval, and economic rating. In this design, one thick-walled WP container and packing material sections are emplaced in each SHB. Important guidelines and assumptions for the designs are as follows.

- Consider thermal response, rock mechanics, emplacement, and retrievability in the design.
- Include a metal shell external to the WP Packing material.
- Take into account the potential radiolytic enhancement of corrosion rates.
- The maximum thermal load per borehole is 2.2 KW.
- Hydrostatic pressure is the only significant external load on the container.
- The reference design material is A27-84, Grade 60-30 steel; assume carbon steel SA-352, Grade LCA properties as being representative of A27-84.

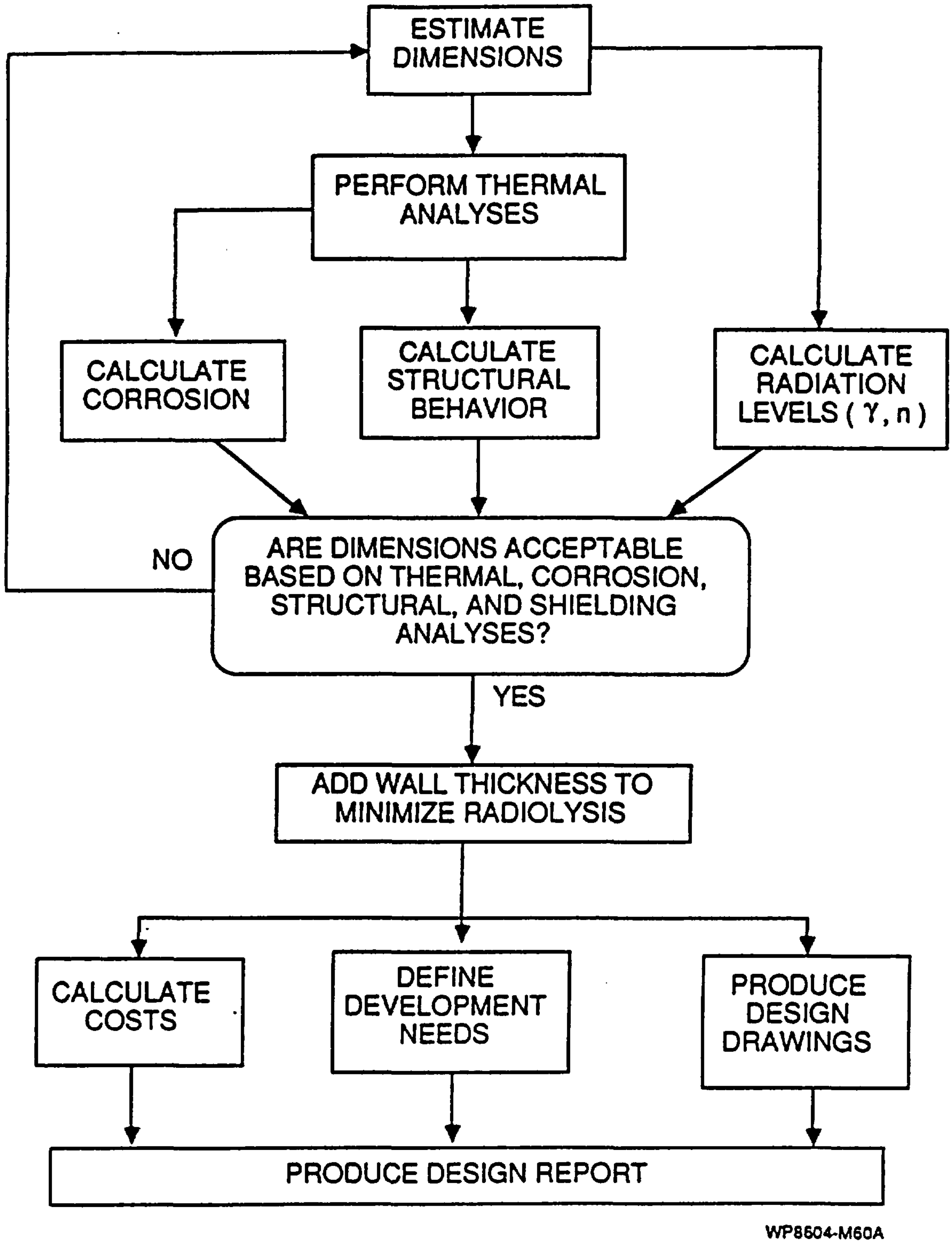

Fig. 1 Waste Package Design Analyses Logic

The host rock is the Cohassett flow of the Grande Ronde Basalt with the repository horizon at a depth of 969.6 m. The layout consists of four large emplacement compartments around a central shaft pillar area. Each compartment consists of 10 panels, and each panel has 4 emplacement rooms. The panels contain 946 boreholes each, implying a total of roughly 38,000 containers. The WP boreholes are located perpendicular to the room walls at a 6.7 m centerline spacing. The WP terminology is illustrated in Fig. 2.

The functional requirements of the WP are to provide containment of radionuclides (RNs) for at least 1,000 years and to contribute in limiting RN release rates at the WP boundary to a maximum of 10^{-5} part per year. The waste form, canister (WVHLW case only), container, packing and shell are the design components of the WP. No release requirements have been assigned to the waste forms (PWR CSF rods, Intact PWR SFA, WVHLW) considered. The packing material specified is a mixture of 25% sodium bentonite and 75% crushed basalt by weight. The proposed shell is a thin-walled carbon steel vessel. The design and fabrication of the containers should meet the intent of the ASME B&PV Code, Section III, Division 1, Subsection NB for an external pressure of 9.4 MPa. Internal pressures are considered to be negligible but are planned for verification by future studies. Seismic analyses are also a future design effort. The shock and handling constraints are that the container withstand a vertical free fall for a distance of 7.3 m (or 1.2 times container length) without RN release or loss of retrieval or handling capability. Corrosion from the inside is assumed to be negligible, and evaluations of stress corrosion cracking and pitting are deferred. Evidence exists that corrosion is enhanced by radiolysis of groundwater. The minimum container thickness required is the sum of the corrosion allowance and that needed for structural integrity. Radiolysis evaluation resulted in calculated container thickness of 85 mm for the spent fuel and 70 mm for the WVHLW waste forms. The void, if any, between the waste form and container wall is to be filled with crushed basalt. Design configurations must preserve a continuous envelope of the packing material around the container. A minimum packing thickness of 152 mm is prescribed for the "Reference" concept and a packing thickness of 1 m is assumed for the "Alternate" concept.

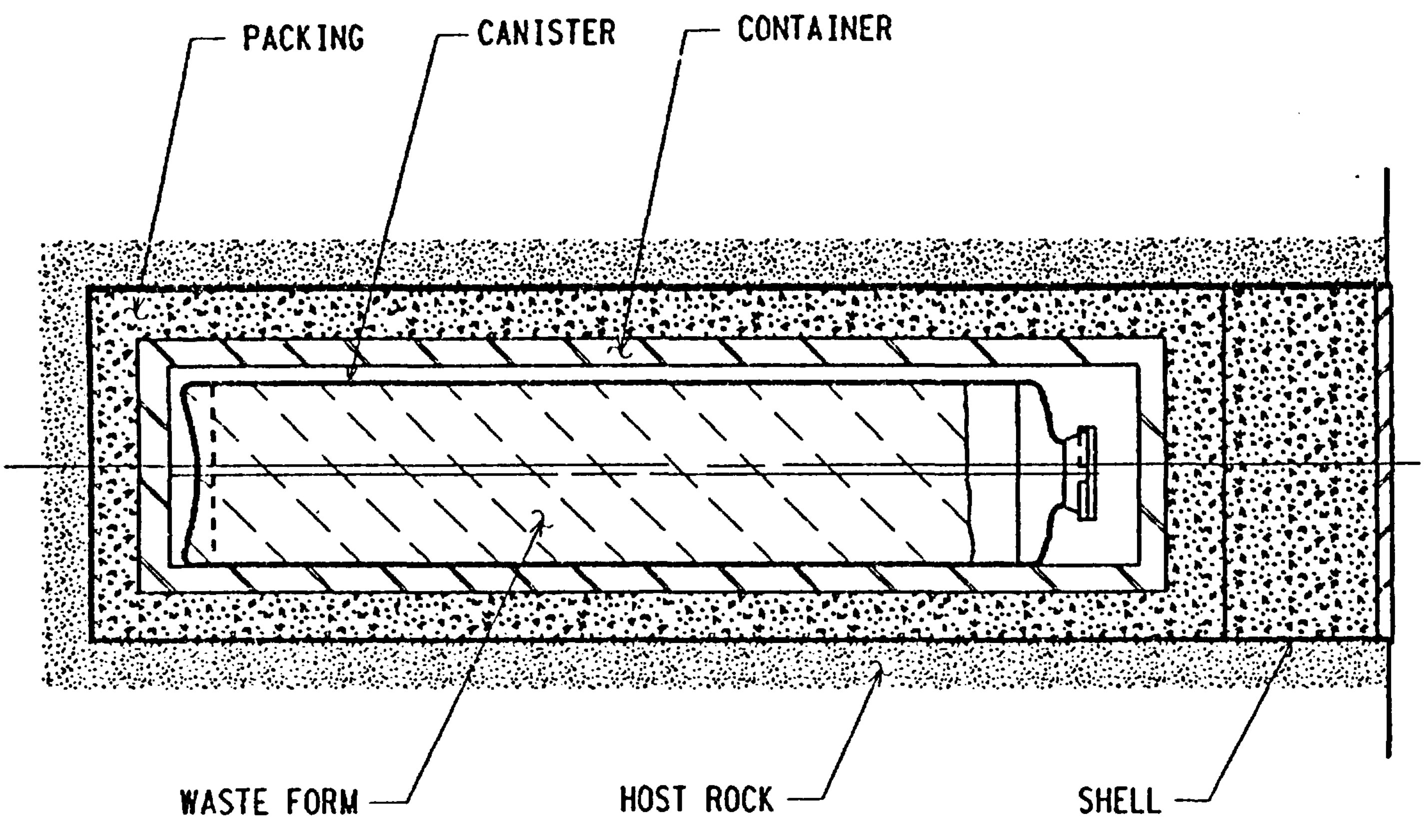

Fig. 2 Diagram Illustrating Waste Package Terminology

Retrieval of the WP is to be accomplished by remote removal of the container into a transfer cask after removing the closure plate, shield packing, and end packing. In addition to the functional requirements, the following objectives were employed:

(1) use of current technology;

(2) increase of reliability and reduction of operation by simplicity of design;

(3) ease of operation; and

(4) design to facilitate container retrieval

The CSF WP consists of the CSF waste form, carbon steel container, preformed packing material sections, and steel shell. It is assumed that the fuel rods will be consolidated at the repository in a hot cell environment. Electron beam welding is the proposed head sealing method with brazing as an alternate. A maximum heat generation rate of 2,069 W is used for the CSF WP. The retrieval method details have not yet been developed. Manufacturing of packing may require special facilities. A separate analysis is being conducted for the packing performance. The packing surface is protected by a carbon steel shell (87 cm diameter) during horizontal emplacement. It is assumed that the shell is vented such that pressure buildup due to steam generation cannot occur.

The SFA WP consists of the SFA waste form, carbon steel container, preformed packing material sections, and steel shell. The SFAs are roughly 4 m long and have a square cross-section of 214 mm. The maximum heat generation rate is 2,069 W for four SFAs (same as one CSF). The SFA WP does not require any waste form processing at the repository. Borehole preparation and WP emplacement is identical to the CSF WP.

The WVHLW waste form is a West Valley-produced canister of waste in borosilicate glass. Other components of the WVHLW WP are a carbon steel container, preformed packing material sections, and steel shell. The canisters are about 3 m long and 0.61 m in diameter, with a maximum thermal output of 255 W. Due to the low thermal output that keeps the maximum canister temperature below 125 °C, a protective coating is **not** formed, and the predicted corrosion rate is much higher. This results in the container thickness being dictated by corrosion rather than limited by radiolysis, as is the case for SFA and CSF containers.

An alternate WP design for the CSF waste form considered a much thicker packing surrounding the container. Three major differences between the "Reference" and "Alternate" designs are:

(1) packing thickness (1 m versus 152 mm);

(2) large portion of packing material preplaced in the borehole prior to emplacement of the shell (alternate design); and

(3) three consolidated SFAs in the Alternate Design, instead of four as in the Reference Design.

The retrievable portion of the WP is considered to be the container, with sequential removal of the closure plate, shield packing, and end packing being the initial steps. Possible contingency methods for component fragment removal include core drilling, impact hammering, or extraction. It should be assumed that no components can be removed in the same manner as when installed. Load limits for retrieval must be established on that basis.

Results of the analyses completed for each reference WP, with details presented in Appendices, are summarized next. Sets of WP analyses performed include thermal, structural, tensile stress (using fracture mechanics approach), corrosion, radiation, WP lifetime, and handling loads on shell. Sensitivity evaluations are carried out for the thermal response. These sets of analyses have been carried out for the CSF WP, SFA WP, WVHLW WP, and the Alternate Design CSF WP. The results of thermal analyses are temperature histories at various locations in the package—i.e., from the waste form to the borehole wall. Minimum thicknesses of container wall required for structural adequacy were calculated in accordance with the ASME B&PV code. In addition, detailed stress analyses were performed with the ADINA finite element computer program to confirm the head design. The tensile stress analysis provided an evaluation for protection against non-ductile failure, with the key parameter being non-ductility transition temperature. Stress intensity factors resulting from a thermal gradient through the container thickness were calculated by hand. The ratio of the allowable stress intensity to the calculated stress intensity for the SA352, Grade LCA cast steel material for the four designs was found to be 1.9 to 4.3 times the minimum safety margin required by the code. The corrosion penetration of each type of container is calculated using the corrosion models (described in Appendix C) without the radiation enhancement factor. Dose rates in contact and adjacent to the container at 10, 25, 50, 100 and 1,000 years after emplacement were calculated using the QADMOD-G computer code.

Dose rates from the container during handling, for radiolysis effects, and at borehole closure plate of emplaced WP are within radiation design requirement limits. Container lifetime analyses were performed to determine the time necessary to produce structural failure or collapse by methods given in Appendix G. The ability of the shell structure to withstand severe handling loads was analyzed by calculating the maximum bending and shear stresses in the shell. The maximum shell stresses were found to be <20% of yield stress for any of the WP designs. Using an allowable stress equal to 75% of yield strength, a maximum allowable pushing force of 40.9 metric tons (90,000 lbs) is estimated. Some of the more significant results are summarized in Table 2 for the various WP designs.

Table 2

SUMMARY OF SELECTED RESULTS

	CSF	SFA	WVHLW	ALTERNATE CSF (w/ 3 SFAS)
Peak Container Temp.* (°C)	271	231	76	294
Peak Basalt Temp.* (°C)	207	197	68	143
Corrosion Penetration at 50 yr (mm)	1.15	0.82	2.0	2.10
Corrosion Penetration at 1,000 yr (mm)	5.93	5.60	45.7	6.85
Container Body Collapse Thickness (mm)	22.0	33.0	32.0	19.0
Flat Head Collapse Thickness (mm)	15.0	14.0	18.0	8.0
Time to reach Collapse Thickness (yr)	12,335	10,215	1,225	12,620

*Thermal Conductivity: Packing = 0.50 W/m-K
Basalt = 1.42 W/m-K

Cost estimates were developed, reported in July 1985 dollars, for design services, fabrication, assembly, and emplacement for the four designs. The unit cost for fabrication of the container, shell, and closure plate, without and with pre-formed, packing is estimated as:

	w/o Packing	w/Packing
CSF	$ 23,600	$ 27,620
Alternate CSF	$ 25,100	$ 59,700
WVHLW	$ 30,200	$ 35,230
SFA	$ 41,900	$ 47,850

A number of design options were considered. Reasons for rejecting or not using certain options have been documented. Options with respect to canister for CSF, container shape, type of container closure seal (welding method), container handling provisions, packing emplacement design and method, and WP assembly operations have been evaluated. Based on the evaluations and analyses performed in support of this work and the results obtained, certain data needs are identified for the following areas.

1. Waste Form

   . effective thermal conductivity of spent fuel waste forms

   . crushed basalt and zircaloy-cladding interactions

   . variation of waste form dimensions and decay heat

   . condition of waste form

2. Container

   . design standards

   . material properties

   . closure seal techniques (welding and/or brazing)

   . brazing materials properties including corrosion rates and mechanisms

   . corrosion models and radiation enhancement

   . fabrication techniques

3. Packing

   . mechanical and thermal properties, chemical stability, manufacturing tolerances, and inspection techniques

   . material performance effects (e.g., steam, void space)

4. Handling, Emplacement, and Retrieval

   . interface with emplacement room and handling equipment

   . interface with container assembly hot cell

   . evaluation of installation and handling aids

5. Borehole Tolerances

   . geometric

   . alignment

   . surface finish

Design, developmental, and experimental programs for each of the five areas listed above are recommended. The CDSCP work for the SHB concept has shown that the WP design concepts presented can meet the functional requirements. The WP performance indicates that other waste forms such as BWR SF, CHLW and DHLW may be accommodated by the reference designs presented. It is recommended that:

(1) the WVHLW disposal concept be modified to increase the peak container temperature to reduce the corrosion allowance;

(2) based on the Reference Design WP, the BWIP design should be updated;

(3) upon availability of data on the characteristics of pre-formed packing, studies should be performed on packing design, the interface seams, packing assembly and emplacement;

(4) studies to determine or assign other functions to the shell should be performed, and it should be ascer-

tained that the shell will not adversely affect WP performance;

(5) work should be initiated to study, coordinate, and develop QA requirements for the fabrication, assembly, and emplacement of the waste package; and

(6) inspection and testing methods for determining closure seal integrity, Container material quality, packing density, and emplaced package material quality be developed.

Problems, Limitations, and Deficiencies

This is one of the more comprehensive analyses that has been performed on waste package design. Consideration has been given to all relevant processes, whether one agrees with all the details of the analyses presented. Concerns expressed below are either related to conclusions in the document that are inadequately supported, or with specific approaches that need better justification, or inconsistencies that are significant.

In addition to the higher temperatures predicted for the Alternate Design WP, other problems can be expected that have not been recognized. Drilling a borehole that is over 2.5 m in diameter and 6 m long can cause practical problems with respect to equipment, size of the disturbed zone, height of the emplacement drift, and proximity to the next hole (i.e., WP pitch). It may be difficult to maintain a stable hole that large in the high stress environment at BWIP.

The assumption that "the only significant external container load is hydrostatic pressure" is not necessarily valid and is not conservative. Larger radial stress could be transferred to the container surface due to a combination of thermal stresses, an initially tight fit, and rock creep. Pressure buildup of steam inside the shell could be a contributing factor. Due to the fact that no performance allocation has been assigned to the waste form, the container and the packing must help meet the WP lifetime criterion.

Seismic analyses have not been conducted and a design basis earthquake has not been defined. Effect of shaking (due to earthquakes) on the structural integrity of the packing has also been ignored.

The assumptions of negligible internal pressure and internal corrosion need careful re-examination.

A protective iron-rich smectite coating on the container surface is assumed to form at temperatures above 125 °C. The corrosion rates without this coating are predicted to be substantially higher. The uncertainty of such a coating forming in the first place and remaining intact through 1,000 years has not been addressed in predicting the corrosion rates and assumed corrosion allowances. In fact, the corrosion models used are totally empirical and have little or no physical basis. This raises serious concerns about extrapolations to thousands of years.

On p. 93, the ID for the alternate waste container is given as 18.6 in; the proper dimension is 12.6 in.

The retrievability discussion is extremely cursory and, for all practical purposes, deferred to future development efforts.

Contradictory statements have been made throughout the document regarding electron beam welding (EBW). The BWIP has apparently selected EBW for the CDSCP (p. 22); on p. 98, it is stated that the entire EBW procedure requires development effort. On p. 191, it is said that the CDSCP reference container design uses a welded closure seal because of the uncertainties of brazing.

Although it is recognized in the document that no components may be removed in the same manner as they were installed, the degree of adversity at retrieval time is not characterized.

The results presented on p. 111 show a peak basalt temperature of 207 °C for both values of packing conductivity (0.35 W/mK and 0.50 W/mK), even though the peak packing temperatures are not the same. It is suspected that coarse discretization is the reason for this apparent insensitivity.

In the ADINA model results given on p. 114, it is unclear whether, and how, thermal stresses were included in the analyses.

The container lifetime analyses only consider uniform thinning (i.e., uniform corrosion). Pitting corrosion, statistical failures due to fabrication flaws, and weldment stresses could all lead to localized failure of the container. The impact of these failure modes has not been assessed.

The formula for calculating the maximum bending and shear stresses is not given or referenced. Also, it is not clear whether degradation of yield strength with temperature has been accounted for in determining the allowable pushing force (e.g., p. 123).

The statement at the bottom of p. 130, "The corrosion penetration for the SFA is less than that determined for the CSF package due to the lower container temperatures," needs elaboration. On the one hand, if temperatures are always below 125 °C, corrosion rates are significantly higher than when they go above 125 °C (presumably due to a protective coating at higher temperatures). On the other hand, the quoted statement suggests that at temperatures above 125 °C, corrosion rates are higher as temperature increases.

Waste form conductivity is shown to have a significant effect on peak temperatures. However, in Figs. 34 and 35, no sensitivity is indicated at locations outside the waste form. Either the temperature curves need more complete labels, or an explanation is needed as to why temperature at container surface (and beyond) is insensitive to waste form effective conductivity.

The waste form conductivity for WVHLW is not given. Is it possible that a volumetric heat source represented by a single node was used?

The container lifetime prediction of 1,225 years for the WVHLW design provides a small margin of safety, given that other corrosion modes or statistical failures have not been considered.

On p. 191, reference is made to the "uncertainties of brazing", which is used to justify the selection of EBW as the reference method. However, on p. 192, it is stated that brazing technology is reasonably well developed.

It is not clear what is implied, on p. 203, by "a continuous surface on which container can slide . . . . " Is it a reference to guide rails or in-situ emplacement of packing?

The analyses have not considered potentially large uncertainties in inventory and/or decay heat loads.

In the discussion on "Thermal Analysis Methods" (p. A-2, Appendix A), it appears that the model assumes an infinite extent. However, the statement that "practically, the distance can be limited to 300 m without significantly affecting the results" is confusing.

Assumption of no temperature gradient along the length of the waste container (p. A-4) is a poor one. It would be difficult to verify the assumption when the possibility is precluded by representing the entire length of the container with a single node!

It is unclear whether an emplacement drift is considered in the thermal analysis. A circular opening is indicated in the drawings. The numerical convergence criterion used in the TSAP computer code is not specified.

Fully implicit, fully explicit, and semi-explicit algorithms are permitted for transient solutions (p. A-14). This is contradicted by the statement (p. A-1) that mentions a standard implicit finite-difference technique.

The statement in regard to stability criterion near bottom of p. A-15 is in error; it should state: stability criterion needed when B<0.5.

Without access to the charts for the SA352 material, it is difficult to verify the data presented in Table B-4.

Equation (4), at the bottom of p. B-9, should show the Poisson's ratio as a parameter in case the value substituted (0.3) is not applicable.

It appears that the results of ADINA stress analyses were ignored (p. B-12) and an alternate method chosen because inadequate margins of safety were predicted by ADINA. If this is the case, a better justification for doing so is in order; otherwise, important decisions could be based on non-conservative analyses.

The limiting value of 0.24 in/in (top of p.B-12) is probably meant to be 0.0024 in/in.

The definition of "Stress Intensity" given on p. B-19 appears to be wrong. It needs verification.

The empirical expressions given for corrosion rates for different environmental conditions appear to have no physical basis. Equations (3) and (4) on p. C-2 do not contain temperature as a parameter.

The "analysis" presented in Appendix E does not adequately present the trade-offs associated with packing thickness. The CDSCP thickness values are based essentially on thermal analysis because there are insufficient data currently available on buffering capacity and sorption of the packing.

Two models for container failure analysis, one due to buckling and the other due to bending in the head/wall junction, are employed in Appendix G. It is not clear what happens "numerically" to indicate onset of buckling. One possibility is monitoring of equivalent strain as it reaches a critical value.

Shell handling analyses for two configurations are referred to in Appendix G. However, no results are given.

Recommendations

Considering the status of BWIP, it may not be meaningful to make site-specific or design-specific recommendations. Nevertheless, the following suggestions are considered relevant to the overall waste management activities.

- Due to the thoroughness of the consideration of appropriate processes, the concepts and conclusions of this document should be studied for potential application at other sites.
- The reasons for a decision at BWIP to abandon the long borehole horizontal emplacement concept should be investigated. Waste emplacement configurations at other sites that propose the long borehole concept should be evaluated in light of the problems cited by BWIP.
- Corrosion models utilized in the analyses are primitive and need considerable improvement and justification. Experiments and model development efforts should concentrate on a more fundamental understanding. Proper consideration should be given to pitting corrosion and intergranular stress corrosion cracking.
- Post-welding treatment of containers needs to be addressed on a more practical level.
- Uncertainties in the radiation and thermal decay characteristics of the waste in a given container should be incorporated by considering a range rather than a single point value for the inventory.

ITASCA DOCUMENT REVIEW

File No.: 006-01-50

Document Title: "Performance Sensitivity Analysis of the Repository Seals Subsystem—Boreholes Drilled from Repository Excavations" (RHO-SD-BWI-TI-342).

Reviewer: Itasca Consulting Group, Inc. (K. Wahi)

Approved: M Board Itasca

Date Approved: April 19, 1988

Significance to NRC Waste Management Program

The document presents an evaluation of the sensitivity of cumulative radionuclide (RN) releases to parameters characterizing sealed boreholes drilled from repository excavations. The computer codes utilized in these analyses are likely to be used in generating results in support of a license application. The analyses presented also provide DOE's understanding of the relevant processes that control transport of RNs through the rock mass to the aquifer system. The backfill design and testing may be guided, in part, by the results of the present and similar future analyses.

Document Summary

An initial assessment of the sensitivity of cumulative radionuclide releases at the accessible environment to the presence of sealed boreholes drilled from repository excavations has been made. The repository is assumed to exist in the Cohassett flow interior of basalt beneath the Hanford Site. The Vantage Interbed, which is about 150 m above the storage horizon, is considered as the accessible environment in these calculations. Coupled, partial differential equations for flow and transport are solved numerically using different input sets. The parameters below are varied in the analysis either because they have significant uncertainty or can be controlled by design:

(1) length and diameter of borehole;

(2) hydraulic conductivity of borehole backfill;

(3) extent of damaged rock zone (DRZ) around borehole;

(4) molecular diffusion coefficient;

(5) hydraulic conductivity of DRZ around borehole;

(6) effective porosity of backfill in emplacement room; and

(7) concentrations and transport properties of important radionuclides.

Numerical simulations of groundwater flow with MAGNUM-2D and of radionuclide transport with CHAINT computer codes were made. The processes modelled by CHAINT include advection, dispersion, sorption, chain decay and mass release. These codes are of a preliminary nature; however, documentation and testing of these codes is being conducted in accordance with NUREG-0856. The data used for the computer runs consist of measured or estimated deterministic values. The simulations begin at 1,000 years after emplacement and span a 9,000-year period during which flow and transport through a vertical borehole and the surrounding rock are modeled in an axisymmetric geometry. The inventory of two waste packages is available to each borehole in the conceptual model. An initial vertical hydraulic head gradient of 0.08 m/m (that is largely due to thermal buoyancy) is assumed. The top boundary of the model is a zero concentration boundary, the bottom has prescribed fixed concentrations of up to four radionuclides. The side (left and right) boundaries are no-flux boundaries. Borehole diameters of 6 cm and 16 cm, with corresponding DRZ annulus thickness of 0.5 and 1.0 cm, are considered. Borehole lengths are varied from one-fourth the distance to the Cohassett flow top to penetration of the Cohassett flow top. Two control cases (no borehole), a baseline case, and twelve variations of the baseline case are solved with MAGNUM-2D and CHAINT. A combination of two-dimensional continuum elements and one-dimensional line elements is used to accommodate size disparities of different features. The analysis considered two non-sorbing radionuclides, ^{14}C and ^{129}I, and two sorbing radionuclides, ^{99}Tc and ^{79}Se. The model domain is divided into several material types, each of which represents a different unit of rock or backfill.

The measure of performance used in these simulations is the cumulative release of radionuclides to the Vantage interbed. Results of computer calculations are presented as concentration profiles and cumulative releases. Releases from shafts are not included in these calculations. A "sensitivity factor" that is defined as the ratio of the case-specific cumulative release to the corresponding control case release has been calculated and is used to cross compare the results. The results indicate that cases in which the hydraulic conductivity of the borehole backfill is the largest have the largest releases. The case with the larger borehole, but with other parameters the same as those for the base case, has ten times the release calculated for the base case. The worst-case (Case 9) predicts releases that give a sensitivity factor of 300 for ^{14}C release compared to a sensitivity factor of 4 for the base case ^{14}C release. Molecular diffusion through the rock mass contributes significantly to cumulative releases at the Vantage interbed. Advective transport through high-conductivity borehole backfill results in significantly higher concentrations in the Cohassett flow top. Contribution of diffusion to transport through borehole backfill is minimal. Repository performance appears to be insensitive to boreholes that do not penetrate the Cohassett flow top. Even a minimal credit for sorption significantly reduces cumulative release of ^{79}Se at the Vantage interbed.

Problems, Limitations, Deficiencies

An average temperature increase is applied uniformly by increasing the initial hydraulic gradient; this is not necessarily conservative. The MAGNUM-2D code does have a capability to model coupled transient heat flow and groundwater flow. Why was this capability not used?

It is unclear whether the stated dual porosity capability of MAGNUM-2D was actually used. Because an axisymmetric geometry was chosen, it would be difficult to justify the "parallel plate" assumption if dual porosity has indeed been used.

If more than one waste package is placed in each emplacement hole, the results would need to be scaled up due to the higher inventory. The statement on p. 13, "because the concentration of radionuclides remains fixed at the initial concentration throughout the simulation, the inventory of each radionuclide is assumed to be infinite," is incorrect and misleading. "Infinite inventories" would give indeterminate concentrations! The proper translation of the applied fixed concentration boundary condition is that there is no depletion of the finite (initial) inventory. On the other hand, solubility limits could put an upper bound on the concentration; however, solubility limits have not been invoked in the present analysis.

No justification is provided for the selection of up to only four radionuclides (RNs) nor is there a rationale for the specific Runs chosen.

The damaged rock zone extent appears to be too small (0.5 cm for a 6cm-diameter hole and 1.0 cm for 16cm-diameter hole). Borehole breakouts observed at BWIP could alone cause more damage than that. In addition, stress redistribution and movement along joints and fractures caused by excavation (or drilling) create a damaged zone. The primary reason that the repository performance has been found to be insensitive to changes in the hydraulic conductivity of the DRZ is that the extent (and, therefore, rock volume) of the DRZ is extremely small.

The concept of a control case is very useful; however, it has not been defined properly. Also, it has not been stated clearly that only two control cases were necessary.

Recommendations

Despite certain deficiencies, the analyses presented are systematic and fairly realistic. A possible next step is to investigate the performance of shaft seals and boreholes from the surface.

At this time, two-dimensional idealizations appear to be adequate. The effect of early waste package failures should also be investigated by starting the simulations at, say, 100 years. At 100 years after emplacement, the thermal gradients are also relatively high so that the transient and non-uniform hydraulic gradients must also be considered.

ITASCA DOCUMENT REVIEW

File No.: 006-01-51

Document Title: "Primary Fracture Frequency, RQD, and Core-Break Frequency Calculated from Cohassett Drill Core Data" by R.K. Ledgerwood (RHO Computational Brief DER-CB-0023, June 1987).

Reviewer: Itasca Consulting Group, Inc. (K. Wahi)

Approved: M Board, Itasca

Date Approved: April 20, 1988

Significance to NRC Waste Management Program

This computational brief is a support document for the ESF Design Basis Study. Data on fracture frequency, rock quality designation, and core breaks per unit length are needed for geotechnical evaluations. Access to raw data of this nature can help in the assessment of design assumptions, conceptual models, and numerical models. It can also be useful in a preliminary determination of support requirements. The statistical manipulations presented give some indication of rock mass variability as well.

Summary of Document

Drill core data derived from Cohassett flow core samples of two exploratory holes, McGee and DC-16A, are presented. Primary fracture frequency, Rock Quality Designation (RQD), and core-break frequency are reported. The core logs were made on 5-ft. interval data forms. Primary fractures are defined as those formed during the cooling process of the basalt flow. Core breaks in the recovered core are not necessarily at the location of primary fractures. Breaks per foot are summarized as the ratio of number of core breaks on one page (i.e., core length of 5 feet or less) of the core logs and the number of feet of core on that page. Fracture frequency (number of fractures per foot) is expressed in a like manner. The RQD data are taken directly from the logs. Averages of primary fracture frequency, core-break frequency and RQD for each intraflow structure type (namely, entablature, columnar entablature, vesicular zone, and colonnade) have been calculated. The standard deviation of the distribution of fracture frequency averages has been calculated by applying the Central Limit Theorem. This Theorem permits a calculation of the population standard deviation (σ) from the sample standard deviation (σ_y) provided that the number of observations in each sample (n) is large. The relation between these parameters is given by:

$$\sigma = \sigma_y \, (n)^{1/2} \qquad (1)$$

The sample mean, standard deviation of sample mean, and population standard deviation of fracture frequency for different intraflow structures of Cohassett flow (McGee hole) are tabulated below.

	Sample Mean (fractures/ft)	Sample Standard Deviation (fractures/ft)	Population Standard Deviation (fractures/ft)
Entablature	11.77	4.45	9.95
Columnar Entablature	7.12	2.96	6.62
Vesicular Zone	4.36	1.54	1.54
Colonnade	6.15	2.11	4.72

Problems, Limitations, Deficiencies

It is likely that many of the cooling fractures are vertical or subvertical. Apparently, what has been reported and logged are the subhorizontal fractures. Information, qualitative or quantitative, on the vertical fractures is lacking.

The description of the calculation of standard deviation is poorly organized and somewhat misleading. Specifically, by mentioning the number of samples (39), it is implied that the requirement of the number of measurements in a sample (n) is large. In fact, n is five (or less) and, in one instance, n is one! The applicability of the Central Limit Theorem is questionable because n is not sufficiently large.

The mean and sample standard deviation were calculated for the McGee hole data only. Although the core lengths for the DC-16A hole were variable, it should still be possible to find the mean and sample standard deviation. This was not done.

Recommendations

1. Core logs of other boreholes should be used to calculate similar parameters in order to quantify rock mass variability in an areal sense.

2. The RQD data should be compared to strength measurements in the laboratory.

3. Possible correlation between core breaks and disking should be examined.