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ITASCA DOCUMENT REVIEW

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Document Title: "Technical Basis for Performance Goals, Design Requirements and Material Recommendations for the NNWSI Repository Sealing Program" by Joseph A. Fernandez, Peter C. Kelsall, John B. Case, and Dann Meyer (SAND84-1895, September 1987)

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Significance to NRC Waste Management Program

As indicated by the title, this document provides the technical basis for performance goals, design requirements, and material recommendations for the NNWSI repository sealing program. As such, it is the fundamental guiding document for the NNWSI sealing program. The document is referenced extensively in the Consultation Draft SCP, especially Section 8.3.3, "Seal Characteristics", and Section 8.4, "Planned Site Preparation Activities". It is essential, therefore, that all of the assumptions in the document be justifiable and that all calculations be reproducible.

The document develops the technical basis for sealing requirements starting from the NRC and EPA imposed limitations on radionuclide releases. From this basis, it establishes hydrological design requirements and seal performance allocation requirements. These are then translated into seal design objectives and requirements. The document is explicitly developed in support of the Advanced Conceptual Design effort. Because it is likely to form the major design basis with respect to sealing, it deserves close scrutiny. In particular, an in-depth review is needed of the radionuclide release data, assumptions, and calculations, as well as of the hydrological data, assumptions and calculations. The integration of these two aspects forms the basis for seal performance allocation. This, in turn, determines the seal design objectives. The report occasionally recognizes uncertainty in the basic hydrological information presently available but, nevertheless, already draws quite firm conclusions about sealing requirements. For this reason, it is essential that the underlying radionuclide release and hydrology conclusions be ascertained as indeed being appropriate.

Summary

This summary is taken from the document abstract, with some very minor editing. The abstract is fully representative of the report.

"This report presents the initial attempt to establish the technical basis for developing seal designs for the Nevada Nuclear Waste Storage Investigations Repository Sealing Program. This report supports the Advanced Conceptual Design effort, which is the next phase in the design process of evaluating a nuclear waste repository in the unsaturated zone at Yucca Mountain, Nye County, Nevada. Because the site geohydrologic data forming the basis for this report are preliminary, the technical basis for sealing designs may change as additional site information is acquired through site characterization activities. The specific objectives of this comprehensive study are to develop performance goals, to assess the need for seals, to define design requirements, and to recommend potential sealing materials for the sealing system. Performance goals are the allowable amounts of water that can enter the waste disposal areas directly from the rock mass above the repository and indirectly from shafts and ramps connecting to the underground facility. These goals are developed using a numerical model that calculates radionuclide releases. To determine the need for sealing, estimates of water flow into shafts, ramps, and the underground facility under anticipated conditions are developed and are compared with the performance goals. It is concluded that limited sealing measures (such as emplacement of shaft fill) are sufficient to properly isolate the radioactive waste in the repository. Nevertheless, a broad range of sealing design options and associated hydrologic design requirements are proposed to provide a greater degree of assurance that the hydrologic performance goals can be met even if unanticipated hydrologic flows enter the waste disposal areas. The hydrologic design requirements are specific hydraulic conductivity values selected for specific seal design options to achieve the performance goals. Using these hydrologic design requirements and additional design requirements, preferred materials are identified for continued design and laboratory analyses. In arriving at these preferred materials, results from previous laboratory testing are briefly discussed."

Problems, Limitations, Deficiencies

General — The document proposes a seal design concept which allows surface water to enter shafts and ramps and drain through bottoms of shafts below the repository horizon. Uncertainties about the planned drainage system remaining effective for a long time period during the post-closure phase are not addressed. A specific concern with the drainage concept is the potential for deposition of minerals in fractures and pores with time, thereby reducing free drainage.

Thermal effects do not appear to have been accounted for in hydrological calculations, which, as a result, seem extremely simplified. Air flow is calculated similarly by taking thermal effects into account on a relatively global scale—i.e., the scale of the overall repository. A considerable body of literature has been published concerning thermally-induced flow effects in an unsaturated repository. Although some of this literature is referenced (e.g., Pruess et al., 1986), it is not at all clear that thermal flow effects have been taken into account, except in the extremely simplified approach mentioned above.

The matrix inflow rate used throughout most of the report is 0.1 mm/yr (e.g., pp. 2-10, 4-5), although 1 mm/year is mentioned on p. A-21, 0.5 mm/yr on p. 4-22, and 1 mm/year is used (p. 4-31) for unanticipated flow. The predominantly used 0.1 mm/year is an order of magnitude less than the infiltration rate used in the Draft Environmental Assessment. Even the latter value of 1 mm/yr has been criticized by NRC staff as being potentially too low (U.S. NRC, 1985, p. 5; Comment 3-11, pp. 10-11; Comments 6-43, 6-45, pp. 61-63). If hydrological reviews and independent analyses confirm that potential inflow could be significantly higher than calculated here, the proposed design goals for sealing performance may be inadequate.

The report concludes that the maximum life required of shaft and ramp seals is 1,000 years, that of underground facility seals, 500 years. This is based on the calculation (resulting in Table 3-2) of the maximum allowable water inflow. These calculations are based on the assumptions identified in Section 3.1.1.1 (releases from matrix and non-matrix locations within fuel rods) and in Section 3.1.1.2 (failure of the waste package). Accepting that these assumptions are conservative (i.e., they suggest a faster than realistically likely release rate and, hence, result in a conservative estimate of the maximum allowable water inflow), is it possible that they could be unconservative with respect to seal longevity requirements? If radionuclide release is initiated later and/or progresses at a slower rate than that calculated here, is it possible that water inflow may have to be controlled for a longer period of time than concluded here? If that were the case, it could imply that seal longevity requirements may have been underestimated.

The sealing design objectives are based on the assumption of a uniform gradual failure of waste packages and fuel rods. It is not immediately obvious why a broader range of failure scenarios has not been considered. For example, more severe sealing design requirements might result from other failure assumptions, such as failure at a faster rate, even at a later time. Of course, radioactive decay reduces the inventory of radionuclides as time increases. Nevertheless, without calculations, it is not possible to assess whether the uniform gradual failure rate is reasonably conservative. Therefore, it would be desirable for the seal reviewers to obtain an indication from waste experts as to whether credible scenarios can exist under which these failures are not spread out uniformly over 1,000 or 2,000 years but occur in a shorter time period, regardless of whether this period occurred during or after the initial 1,300 or 2,300 years after closure. Equally important is the question as to whether scenarios exist in which radionuclide release is initiated only after 2,300 years, and whether such scenarios would require sealing longevity beyond the periods calculated here.

A more fundamental problem with the analyses presented in the document is that NRC may want DOE to assume that <u>all</u> packages have failed by 1,000 years (i.e., no waste package lifetime credit beyond 1,000 years)—in other words, interpret 10CFR60.113 (a)(1) (ii) (A) to mean that all radionuclides are available at the end of 1,000 years.

Of particular interest in this regard may be the response of packages and rods when, during cooling, the temperature drops below the boiling temperature. According to some scenarios, this may be the first time when packages are contacted by water.

The lack of detail given about the airflow calculations is so extreme as to make any comments highly uncertain. The presentation is entirely insufficient to allow independent review. This must be considered as a very serious shortcoming for a document that has become a major reference in the consultation draft SCP.

Detailed Comments

Page	Comment
1-2	How has the schematic given in Fig. 1-1 been utilized in the CDSCP documents?
1-10	Why can't the "design-basis performance goals" curve be modified such that <u>all</u> episodic flows due to unanticipated scenarios fall under that curve (see Fig. 1-4)? Figure 1-4 indicates that the design-basis-performance goals converge to the maximum allowable performance goals with time. Given the uncertainties in the analyses, the indicated safety margin appears to be minimal.
1-13	If, as stated in the next to the last paragraph, no storage capacity is assumed when computing the design goals for sealing components in the underground facility, it would seem more appropriate to immediately substitute $C_u(t)=0$ in the second expression. It may also be more appropriate to include an explicit drainage term in these equations. The top equation on p. 1-13 appears to have an inconsistency in units: S(t) is a flow rate, whereas $C_s(t)$ is a storage capacity. Also, it appears that a summation sign is missing from the first terms on the right-hand side of the equation.
2-3	Table 2-1 appears to indicate a water table that is not flat whereas, on p. 2-6, it is stated as being flat.
2-18	Figure 2-10 is not labeled.

3-2 Since it is assumed that the releases from the fuel rod matrix are directly proportional to the volume of water that contacts the waste, it is important to use the proper flux value(s) in performing the analysis. Flux values of 0.1mm/yr, 0.5 mm/yr and 1.0 mm/yr have been referred to with varying qualifications in the document.

3-3 The use of a preferential dissolution factor of 10 for Tc-99 may speed calculated release. Is it possible that this conservatism in terms of early sealing requirements (i.e., up to 1,000 years) may result in an underestimate of later releases (e.g., especially beyond the 1,000-year seal longevity requirements)? (See, also, Fig. 3.2.) If this were true, it could also increase seal longevity requirements.

The term "failure", as applied to a fuel rod, has not been defined. It is loss of cladding as a result of uniform corrosion? What about clad ballooning, which is a failure mode of concern during reactor operation?

3-4 The basic corrosion calculation is performed for a constant temperature of 180°C for 10,000 years. According to St. John (1985, Abstract), the peak temperature at the canister wall for vertical emplacement may reach 215°C or 240°C, depending on ventilation conditions. Admittedly, this peak temperature would exist shortly after emplacement.

The actual value used in the calculation is twice the conversion rate at 100°C because water is assumed to be present on both sides of the cladding.

The appropriateness of these release rates deserves checking—e.g., including an evaluation of the thermal history, if only in part because Zr-93 may be one of the radionuclides whose release rate ultimately may govern acceptable water flow and, hence, minimum sealing requirements (Fig. 3-2).

The same concern needs to be expressed for C-14 release (top of p. 3-5).

It deserves pointing out that the assumption of uniform corrosion, and consideration of uniform corrosion only, has already been questioned by the NRC (U.S. NRC, 1985, p. 15).

Several of the assumptions used here may be conservative with respect to radionuclide release rate calculations—i.e., may overestimate early release rates and, hence, be conservative in terms of early (pre-1,000 years) sealing requirements and non-conservative with respect to later (post-1,000 year) sealing requirements.

3-5 Section 3.1.1.2 (Assumptions Concerning the Failure of the Waste Package) — This section needs to be reviewed by a radionuclide release rate expert in order to determine whether credible scenarios exist that could result in significantly faster release, slower release, or bunched-up release at some later time. Any of these could have an impact on seal design objectives. Is it consistent with 10CFR60 that waste package failure starts in Year 301?

The determination (next to the last paragraph of p. 3-5) that the last fuel rod is breached 2,300 years after closure assumes that the last fuel rod failure occurs in the last package to fail, a rather unlikely coincidence. A more appropriate statement may be that all fuel rods will be breached by 2,300 years after closure, or no later than 2,300 after closure.

The main limitation of this section probably is that it considers only an extremely narrow range of radionuclide release scenarios.

The DOE also needs to consider unanticipated events and fabrication flaws that could lead to waste package failure prior to 300 years

—i.e., the phrase "substantially complete" [10CFR60.113(a)(1)(ii)(A)] does not necessarily mean perfectly complete.

The assumption that "fuel rods will begin to fail immediately after closure at a rate of 0.01%" does not consider any uncertainty in the failure rate. Also, how reliable is the assumed initial fuel rod failure of 0.02%? Once out of the reactor, it is unclear what thermomechanical loads will be experienced by the fuel rods/cladding. The assumed figure of 0.02% failure at disposal time may be too low.

3-6 As pointed out on top of this page, a reasonable probability exists that containment may persist for much longer than the minimum requirement. It would appear, therefore, that, especially from a sealing longevity perspective, a scenario in which release starts at a significantly later time deserves attention.

It is not clear whether "tfr", in Eq. (3-1), refers to the total number of fuel rods at time zero or the total number of unfailed rods at a given point in time. From Fig. 3-1, it appears that the latter is the case.

3-9 The statement near the bottom of the page, "Because 'q' is indirectly proportional to the annual release of any radionuclide ...", is incorrect. The water influx, 'q', is independent of annual RN release; it is 'D_j' that is proportional to 'q'.

3-10 A conceptual interpretation of 'q' is lacking. Is it the amount of water contacting a waste package? Is the surface area of the waste package one of the parameters that determine 'q'?

3-12 Section 3.1.4 (Sensitivity of the Assumptions Used to Compute the Hydrologic Performance Goals) — It is important to note, as pointed out by the authors, that the sensitivity analysis concerns only matrix dissolution and immediate releases—not package or rod failures. The sensitivity analyses indicate that the basic hydrological goal, the basis for the seal design objectives, changes by substantially more than an order of magnitude for some assumptions (Fig. 3-3). These extremes are not included in seal design decisions. It would be helpful to have an evaluation by radionuclide release experts as to the likely occurrence of these extreme conditions.

Also of interest, for reasons identified earlier, would be an evaluation as to whether the discontinuities observed at 1,300 years (Fig. 3-3) or at 400 years (Fig. 3-4) could occur at some later time, especially after 1,000 or 500 years (corresponding to the proposed design life of shaft/ramp seals and underground facility seals, respectively).

3-18 to 3-20 The last paragraph of this section concludes that "some variation in the modeling assumptions .. . can occur and not significantly reduce the hydrologic performance goals". This is true. It is also true that some of the presented analyses would reduce the goal by 25%. Moreover, the performance goal established here for the baseline SPARTAN analysis case (Fig. 3-2) appears to have a very small safety margin with respect to Pu-242, Zr-93, Tc-99, and C-14.

3-20 Section 3.2 (Development of the Airborne Performance Goal for the Sealing Subsystem) — There may be some inconsistency between the containment period underlying gaseous releases (300-1,000 years) and that underlying package failure assumptions in the preceding hydrological goal determinations, where it is assumed that failure starts in Year 301 after closure (p. 3-5).

It would be desirable to have a radionuclide release expert assess whether it is correct that some potential gaseous species (Xe isotopes, Rn, Kr-85, and H-3) can be eliminated from concern because of their short half-lives.

The analysis in support of this section (Appendix C) appears extremely simplified. It is far from certain that it is conservative. It does not mention faults, potentially a major air flow path which could drastically alter the conclusions (e.g., by placing far more emphasis on drift backfill and/or sealing requirements). The stated objective that not more than 25% of the total air flow should exit from the shafts is questionable, in that it by no means ensures that the total repository release rates will remain within regulatory requirements. An immediate ambiguity arises because the first basic mechanism (Mechanism A, second paragraph, p. 3-22; also, Appendix C, C-1, p. C-2, third sentence) assumes that no flow occurs through the rock. Hence, it is unclear with respect to which flow the imposed 25% limit is determined. A second ambiguity arises because it is not clear which of the drifts are included in the analysis. Although a network is shown in Fig. C-2, it appears to cover only a very small section of the repository and, hence, could significantly overestimate the resistance to air flow, thus underestimating air flow. In addition, this network would significantly underestimate the air flow through the rock mass above the repository. It deserves stressing that all comments about air must be qualified as being highly uncertain, given the absence of specific precise information (e.g., extreme vagueness in network descriptions, last two paragraphs of p. C-9).

In sum, the development of the airborne performance goal for the sealing subsystems can only be considered as very preliminary. Moreover, the complete absence of numerical details in the supporting Appendix C make an independent review very difficult.

3-21 Table 3-2 compares maximum-allowable performance goals and design-basis performance goals. In the period from 1,000 to 10,000 years following repository closure, the performance goal ratio of "maximum allowable" to "design-basis" decreases from 2.8 to 1.0. Given the degree of uncertainty in analyses, it is questionable whether an adequate safety margin is provided by the design-basis performance goals.

3-22 The performance goal that "no more than 25% of the total air flow should exit from the shafts" cannot possibly be satisfied if one considers "Mechanism A" as the flow model. Note that "Mechanism A" assumes that flow out of the repository occurs only through ES1 and ES2.

3-23 The conclusion at the top of the page, that MPZ around the shaft does not significantly affect the flow rates out of the shafts, needs to be qualified. First, for low values of shaft fill air conductivity, the statement is not valid. Second, the <u>inflow</u> into the repository occurs primarily through the MPZ and shaft fill.

The position adopted with respect to borehole seals, that the NRC 10CFR60 requirement is satisfied if the potential for vertical flow through boreholes is less than or equal to 1% of the total vertical flow through the rock mass, can be easily challenged. No basis is given for the 1% value. Moreover, the total cross-sectional area of all the boreholes is a negligible fraction (<<1%) of the rock mass cross-section. Extremely large hydraulic conductivities would, therefore, be permissible for these boreholes in order to satisfy the one-percent criterion.

3-23 and 3-24	Section 3.3 (Development of the Performance Goal for Boreholes) — This section is purely qualitative. The statement that "if a fully saturated condition does not exist, the borehole would act as a capillary barrier" is ambiguous, at best. It is not clear what is meant by fully-saturated condition. It is presumably <u>not</u> implied that the entire repository host rock must be saturated in order to have locally-saturated (e.g., borehole) flow conditions. Also, air flow is not considered.
4-1	Section 4.1.1 (Surface-Water Inflow) — It is to be noted that the analysis in support of this section is based on the earlier location of the exploratory shafts (p. A-3, Section A-1.1.1, second paragraph).
4-4	No basis is given for assuming 15 m shaft fill settlement.
4-5	Calculated matrix inflows to the shaft are given to be $2x10^{-14}$ m^3/s for clay. Either the values for sand and clay have been transposed by mistake, or an explanation is necessary as to why the permeability for sand is four orders of magnitude <u>lower</u> than for clay.
4-6 and 4-7	It is not at all clear whether these assumptions are based on or derived from the flooding calculations in Appendix A-1. It clearly would seem desirable to relate water supply, water depth and flow duration to such calculations.
4-9	An assumed zero initial saturation may not be conservative.
4-15	The amount of flow through the shaft is computed using two different models (top paragraph). Why is the lower, rather than the higher, amount used as the result?

4-16 An alluvium porosity of 0.30 is not necessarily conservative (Appendix D of the report gives relevant data.)

4-22 The flux used for inflow calculations is 0.1 mm/yr (last paragraph), even though 0.5 mm/yr is listed as an upper limit in the preceding paragraph, and 1 mm/yr is listed as such on p. A-21. Appendix H (p. H-3) lists a RIB value of 0.722 mm/yr. All indications are that the matrix inflow may have been underestimated.

The results presented in Section 4.2.1 appear to be strictly a function of the ratio of permeabilities of backfill and rock mass matrix.

4-23 In the last sentence of the second paragraph, the document states as conclusions from a reference (presumably, Mondy et al., 1985) that "Flow past the waste package was 91% of the influx rate for the case of clay backfill and 81% of the influx rate for sand backfill." The results in Mondy et al. (1985) are actually given as ranges 91% to 96% and 81% to 92%, respectively.

4-24 The postulate, in the first paragraph, that "If recharge occurs only directly below the intersection of the fault and a wash, possibly only nine rooms would experience inflow after rainfall" appears to contradict the inflow calculation models in Appendix A (e.g., very specifically, the last sentence on p. A-40).

The recommendation that "Depending on the observations of water flows into the underground facility, repository layout modification in the vicinity of the Ghost Dance Fault may be desirable" is very ambiguous, raises many questions, and could have major implications: Any water inflow? Continuous water inflow? Water inflow during or shortly after rainstorms? Flooding? Amplification and clarification of this statement would be highly desirable.

4-26 What is the conceptual flow model for fracture flow?

4-29 It would be instructive to know the appropriate K and n values for the "U12e" tunnel system in order to properly assess the fracture flow characteristics.

4-32 Two references are quoted that analyze thermal effects on flow. For purposes of the present report, "it is assumed that such phenomena would balance out over the life of the repository". No justification is given for this drastic simplification, which the authors invoke to neglect accounting for thermal effects on water flow.

It is stated, at the start of the third paragraph, that no analyses have been performed to determine water flow under elevated temperature conditions. This is followed by other phenomenological arguments. These do not automatically lead to the determination "that such phenomena would balance out over the life of the repository", thus relieving the analysts of considering elevated temperatures in their analyses.

4-35 This first sentence on this page states, "If the total floor area of the repository, including the projected floor area of the ramps, is 5,588,850 m^2 (Table 2-6) . . . ." It should be noted that Table 2-6 gives 5,588,850 m^2 as the sum of the area within the repository boundary plus the total projected floor area of ramps for the vertical emplacement configuration.

5-3 The storage (sump) volume below the repository station listed in Table 5-2 on p. 5-3 are not calculated by multiplying the cross-sectional area by the sump depth. The storage (sump) volumes calculated by this method are compared to those listed in Table 5-2 below.

Shaft	Table 5-2	Area•Sump Depth
EES	34 m^3	32.25 m^3
MMS	270 m^3	258 m^3
ES-1	659 m^3	1,505 m^3

Furthermore, it is not clear what criteria were used to determine required sump values.

The yearly drainage through unlined shafts in Table 5-2 lists 50,000 m^3 for the value in ES-1 calculated by the Nasberg-Terletskata data method. Using Eq. (A-5.6) with

$K = 10^{-7}$ m/sec, $H = 140$ m, and $r = 2.2$ m

gives a value of 69,379 m^3.

For $r = 3.7$, the value is 77,769 m^3. It is not clear how the values for yearly drainage by the Nasberg-Terletskata method in Table 5-2 were determined.

5-5 Although it is true that the referenced DOE source postulates an expected container lifetime of 10,000 years, it recognizes that "the containment period of the waste package could range from 3,000 to 30,000 years if waste disposal container failure through mechanisms other than uniform corrosion can be confidently excluded." NRC itself has expressed reservations about the latter (U.S. NRC, 1985, Comment 10, p. 15; Comments 6-116, p. 106; Comment 6-114, pp. 104-105).

5-6 to 5-8

Section 5.2 (Shafts and Boreholes as Preferential Pathways) and Section 5.3 (Conclusions) — Firm conclusions are drawn from uncertain and not necessarily conservative assumptions underlying highly-simplified models.

No thermal flow effects are mentioned.

No airborne radionuclide release is mentioned (e.g., p. 5-8): "[T]here is no known mechanism for waste transport upwards in the shafts."

The first paragraph of Section 5.2 quotes 10CFR60.134.b, requiring that "materials and placement methods for seals shall be selected to reduce, to the extent practicable: (1) the potential for creating a preferential pathway for ground water".

The second paragraph admits that "The shafts do clearly provide preferential pathways for water movement".

The first sentence of the next section then draws the conclusion that "sealing is not necessary". (Section 5.1, to which explicit reference is also made, does not address airborne releases either.)

The final paragraph of this section does allow that "some sealing to address extreme conditions will also address the 10CFR60 guidelines that some measures should be taken so that the penetrations will not act as preferential pathways."

6-4

In the first paragraph here (and elsewhere in the document), "higher performance goal", in fact, means a less stringent performance requirement. In other words, larger flow rates are implied by higher performance goals. This unconventional use of performance goal is contrary to intuition.

6-8

No basis is given in Section 6.6.2 for selecting 10% of the drainage capacity as the design goal for flow restriction through the seal.

6-12

It is unlikely that shaft seals would deter human entry to the repository.

6-15

The design requirement for shaft fill given in Fig. 6-4 is that the saturated hydraulic conductivity be less than 10^{-2} cm/sec. As discussed on p. 6-14 (paragraph 1), this design requirement appears to be driven primarily by air flow considerations. Figure F-10 (p. F-12) indicates that neither of the hydrological design goals given in Table 6-2 are met by fill with a conductivity of 10^{-2} cm/sec. The consequences of this are not clear. (See, also, the detailed comment for p. F-12.)

6-17 and 6-18

Table 6-4 — It would seem that horizontal and vertical acceleration are the only seismic parameters to be considered. Potentially more important may be deformation and strain of the openings/plugs.

Similarly, structural stability considerations should include deformations and strains (e.g., uplift) resulting from waste emplacement.

6-23 and 6-24

Table 6-5 — See the comments for Table 6-4 (pp. 6-17 and 6-18), above.

6-27

In discussing design requirements for seals in the underground facility (vertical emplacement), "it is noted that the effects of elevated temperature could alter the state of stress below the sump and possibly change the drainage capacity of the welded tuff floor." As noted previously under "General Problems, Limitations and Deficiencies", considerable uncertainty exists regarding the ability of the planned drainage system remaining effective for a long period of time during the post-closure phase. As also stated previously, a specific concern with the drainage concept is the potential for deposition of minerals in fractures and pores with time, thereby reducing free drainage.

6-30 The second paragraph contains the statement "As with other bulkheads, the host rock conductivity adjacent to the bulkhead must be reduced to the same value as the seal material." How does the DOE propose to accomplish this? How far into the rock mass is it necessary to "reduce" the conductivity?

6-37 and 6-38 Fault seal design including grouting appears to be in conflict with the second paragraph on p.6-34, where serious doubts are expressed about the longevity and the feasibility of demonstrating the effectiveness of such procedures.

6-41 Table 6-7 — See the comments for Table 6-4 (pp. 6-17 and 6-18), above.

6-47 Section 6.7.3 (Performance Goals and Design Requirements for Borehole Seals) — This document adopts the position that the 10CFR60 requirement that "boreholes shall be designed so that following closure they do not become pathways that compromise the geologic repository's ability to meet the performance objectives" is satisfied if the potential for vertical flow through boreholes is only 1% of the potential for vertical flow through the host rock mass. Presumably, in accordance with the presentation in Sections 5.2 and 5.3, this also covers the regulatory "preferential pathway" requirement.

It may require an NRC decision as to whether this is an acceptable position. Clearly, in order for 1% of the total flow to occur through boreholes, which have a total cross-sectional area far below 1% of the repository host rock mass, they would have to be some type of preferential flow path.

Here, the performance goals and design requirements for borehole seals are discussed. Limiting the potential for vertical flow through boreholes to 1% of the flow through the host rock mass is considered to satisfy the NRC requirement. An equation is given that allows a calculation of the permissible hydraulic conductivity of the seal material. Not surprisingly, some very large conductivities are found to be permissible. Looking at the problem from the NRC's perspective, it is interesting to compute the "permissible" total area of boreholes which would limit the potential for vertical flow through boreholes to 1%, as proposed in the document. Table 1, below, gives the "permissible" total area for a range of rock mass and seal material conductivities. The heavy line through the chart divides conductivity combinations which would permit less than thirty (30) 150mm-diameter boreholes from combinations which would permit more than thirty.

Table 1

"PERMISSIBLE" BOREHOLE TOTAL AREA (m^2) ASSUMING THE POTENTIAL FOR VERTICAL FLOW IS 1% OF THE FLOW THROUGH THE HOST ROCK*

Host Rock Conductivity (cm/sec)	Seal Material Conductivity (cm/sec) 10^2	10^1	1	10^{-1}	10^{-2}	10^{-3}
10^{-4}	0.056	0.56	5.6	56	560	5600
10^{-5}	5.6E-3	0.056	0.56	5.6	56	560
10^{-6}	5.6E-4	5.6E-3	0.056	0.56	5.6	56
10^{-7}	5.6E-5	5.6E-4	5.6E-3	0.056	0.56	5.6
10^{-8}	5.6E-6	5.6E-5	5.6E-4	5.6E-3	0.056	0.56

less than thirty 150mm-diameter boreholes "permitted"

*Total Area of Boreholes = 0.01 * repository area * K_{rock}/K_{seals}

Repository Area = $6*10^7$ ft^2 = 5.6×10^6 m^2

Borehole Area = $(\pi/4)*(0.15)^2 = 0.018$ m^2

Appendix A-5

Appendix A-5 is based on the assumption that the liner is removed. It should be noted that liner removal is not a trivial exercise. Removing a concrete liner cast-in-place against rock is likely to extend the disturbed zone beyond that at construction time. There is no discussion of the procedures or possible adverse effects caused by liner removal.

Appendix C

The information given on the method of analysis is minimal. A "network resistance" model is employed which appears to be a reasonable choice. Whereas the one-dimensional nature of the model (Item 4, top of p. C-6) permits a fair simulation of the flow path, it cannot represent areal variations of conductivity in a given cross-section. The document does not indicate how the different air conductivities of the shaft fill and MPZ at a given horizon were considered in the model. In other words, certain two-dimensional aspects of the flow problem apparently have been considered in a one-dimensional model. Many questions, such as coupling between shaft fill and MPZ, remain unanswered. It is possible that independent solutions for MPZ, shaft fill and rock mass were obtained and then superimposed. Without such information, it is difficult to comment on the adequacy of the model employed.

The discussion of results indicates clearly that the percentage of flow through shafts and ramps, as well as total flow, are significantly lower when the shaft fill conductivity is low. Other arguments notwithstanding, it seems that the letter and the spirit of the NRC requirements (concerning shafts not becoming preferential pathways) would be satisfied if a low conductivity backfill were used in the shafts. The document has, therefore, inadvertently demonstrated the need for a properly designed shaft backfill.

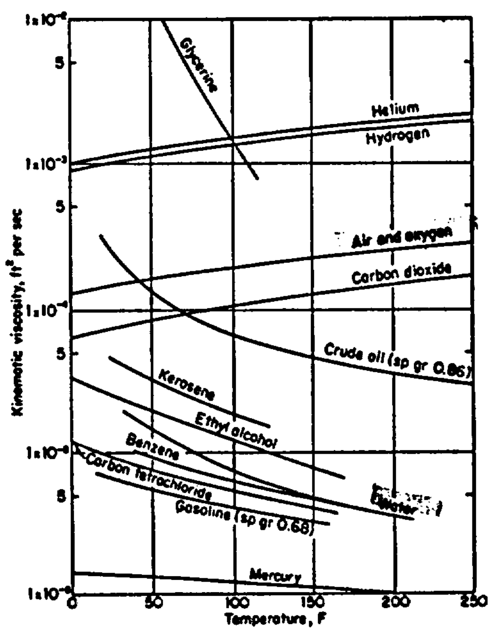
C-2 The method of analysis is described as being "similar to that used in mine ventilation studies (Hartman, 1982, pp. 239-245)." Hartman (1982, pp. 239-245) includes a listing of five very different methods for calculating natural ventilation. No indication is given as to which of the methods is used. Moreover, the paragraph continues with the statement that "Flow is calculated using Darcy's law." This is usually not acceptable in mine ventilation calculations [e.g., Hartman, 1982, p. 247, Eqs. (9-7)]. The applicability of Darcy's law, described on p. C-4 remains totally unquantified, because basic data used to determine Reynold's number are not provided. Hence, its validity cannot be assessed.

C-5 The assumption of incompressible flow in the interest of simplicity may result in a gross violation of physical laws governing gases. The assumption should be verified by applying the ideal gas law, the equation of continuity, and the extremes of isothermal and adiabatic conditions. For instance, if the continuity equation is not satisfied, energy would not balance and the results may be physically meaningless.

C-7 The results of a more rigorous analysis, assuming adiabatic compression, yielded pressures that are "three to four times higher than the previous calculation". This reinforces the previous comment.

It is not explained why an MPZ around the drifts was <u>not</u> considered, but the MPZ around shafts and ramps was considered.

C-8 The air conductivity values assumed are a constant fraction (1/20) of the corresponding hydraulic conductivity values. Presumably, a relationship given by Freeze and Cherry (1979) has been used. An air-to-water kinematic viscosity (i.e., the factor μ/ρ) ratio of 20 is, therefore, implied. This ratio is not constant. At least one order of magnitude variation in this ratio can be expected in the temperature range of 50°F to 250°F. (See figure, below, from the Standard Handbook for Mechanical Engineers.)



[Standard Handbook for Mechanical Engineers, p. 3-51]

The assertion that "the equivalent conductivity of strata in series tends to be dominated by the unit with the lowest conductivity" is valid for units of equal (or similar) thicknesses. A low conductivity unit with a relatively small thickness would not necessarily dominate the equivalent conductivity.

C-12 In Table C-2, the air conductivity of the drift backfill is not provided for Analysis Nos. 4, 5 and 6. The conclusions based on these analyses would appear to be valid only if the air conductivity of the drift backfill was similar to or equal to that of the shaft backfill.

D-3 Section D.2.1 (Hydraulic Conductivity of Cohesionless Backfill Materials) — The constant C_1 (Hazen Equation in the middle of the page) is set to 100 in units of 1/(cm-sec). However, the reference (Terzaghi and Peck, 1967, p. 50) from which the equation is taken states that C_1 varies from 100 to 150.

F-12 Figure F-10 gives a design chart for shaft fill. This chart assumes a host rock hydraulic conductivity of 10^{-2} cm/sec. It is not clear what effect would result if other possible hydraulic conductivities for the host rock are considered. It should also be noted that the design chart is intended to be used to select fill material for shafts above the repository horizon. It would seem logical to use different fill above and below the repository horizon because of the different purposes served by the fill. For shaft fill above the repository, a general design goal is the reduction of air and water flow. For shaft fill below the repository horizon, the general goal is to increase water flow.

Recommendations

This report, fully appropriately, integrates input from several disciplines. It would be desirable, therefore, to have a review performed by several disciplines as well—specifically, the following.

Radionuclide Release From Emplacement Waste — The fundamental driving performance requirements that underlie all sealing performance goals are the necessary water inflow limitations or restrictions. These, in turn, are based on radionuclide releases associated with certain water flow rates. It is recommended, therefore, that Section 3.1 (and Appendix B) of the report be reviewed by a radionuclide release rate specialist.

Although less prominent with respect to ultimate sealing performance requirements, gaseous radionuclide releases do play a role. It is recommended, therefore, that Section 3.2 of the report be reviewed by someone qualified to evaluate the validity and completeness of the reported gaseous release analyses.

If such radionuclide release rate reviews confirm that the conclusions presented in this report are conservative, it would provide considerable confidence in the fundamental seal performance requirements and design objectives established later in the report. If such reviews find significant deficiencies or uncertainties in the radionuclide release rates utilized in the report, it would impact all subsequent hydrological analyses and, ultimately, seal design objectives.

Note that it would be relatively easy to meet the sealing performance requirements as determined here on the basis of the maximum acceptable water inflow consistent with the maximum allowed radionuclide release rates. It is essential, therefore, that reasonable confidence must exist that the presented radionuclide release rate calculations are indeed conservative. Otherwise, the risk exists that sealing requirements may be underestimated. The document implicitly appears to recognize this risk, if only because of the extensive and rigorous further sealing development program it proposes.

Hydrology — Acceptable radionuclide release rates define acceptable water flow to waste packages. Hydrological analysis is the basic tool used to identify sealing requirements that follow from the required water flow restrictions. As such, fully appropriately, hydrology discussions pervade the report. It would be desirable that the entire report be reviewed from a hydrological point of view. As a minimum, however, a hydrological review should be requested, in order of priority, of Chapter 4, Appendix A, Chapter 5, Appendix C, Chapter 6, Appendix F, Chapters 7 and 8, and Appendices D, G, H, and I.

Some specific topics for which it would be helpful to have a hydrological evaluation are as follows:

(1) estimates of water inflow into repository shafts (Section 4.1);

(2) water flow into the underground facility (Section 4.2);

(3) an assessment of shafts and boreholes as preferential pathways (Section 5.2); and

(4) performance goals and design requirements for borehole seals (Section 6.7.3).

An independent hydrological review to ascertain the validity of the conclusions drawn in these sections, even recognizing the present uncertainty about most details, would be of considerable benefit to the seal reviewers. It would provide them confidence that seal design objectives are valid.

<u>Air Flow Out of the Repository</u>

It is recommended that Appendix C be reviewed by a mine ventilation specialist. In light of the almost complete absence of detailed descriptions of the analyses, input data, underlying assumptions, etc., it may be preferable to have an independent air flow analysis performed.

<u>Iterative Sealing Review</u> — If the radionuclide release rate review and the hydrology review confirm, at least in broad lines, the conclusions derived in SAND84-1895, then these can be accepted as the basis of the review with respect to sealing design, materials selection, etc.—always subject, of course, to re-evaluation on the basis of data acquired in the future.

Conversely, if either the radionuclide release rate review, or the hydrology review, or both, were to identify serious deficiencies, it could fundamentally alter sealing design, performance requirements, etc. and, presumably, such implications would need to be identified in the SCP Consultation Draft review, or during future DOE-NRC interactions.

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