U.S NUCLEAR REGULATORY COMMISSION
DIVISION OF WASTE MANAGEMENT

REVIEW OF GROUNDWATER FLOW MODELING OF ALTERNATIVE REPOSITORY CONCEPTS (SD-BWI-TA-015)

TECHNICAL ASSISTANCE IN HYDROGEOLOGY
PROJECT B - ANALYSIS
RS-NMS-85-009

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1.0 INTRODUCTORY INFORMATION

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DOCUMENT: "GROUNDWATER FLOW MODELING OF ALTERNATIVE REPOSITORY CONCEPTS", by S.A. Estey and R.C. Arnett, Basalt Waste Isolation Project, Rockwell Hanford Operations. Copy dated 6/14/85. Document number SD-BWI-TA-015.

REVIEWER: Adrian Brown, Nuclear Waste Consultants.

COMPLETED: October 30, 1986

APPROVED:

2.0 SUMMARY OF DOCUMENT AND REVIEW CONCLUSIONS

2.1 SUMMARY OF DOCUMENT

The purpose of this document appears to be to evaluate which of a number of repository layouts provides optimal protection of groundwater against flow of radionuclides to the environment via a pathway which involves the shaft system (which connects the repository to the ground surface).

The analysis does not specifically state an objective but says on Page 5 that the report contains "a performance assessment analysis (of) the relative performance of alternative repository layouts. The performance criterion was groundwater flow-split between the repository seal and site subsystems."

The approach taken in the report was to analyse the heat driven groundwater flow from the repository system. The heat driven component was added to the "natural" groundwater head gradients, vertically upward and a mild head gradient to the east. Values of parameters used in the repository were the standard parametric values that have been used in many performance assessments by BWIP, together with some new values needed for the analysis:

- horizonal hydraulic gradient............. 5×10^{-4} to east
- vertical hydraulic gradient.............. 10^{-3} upward
- vertical hydraulic conductivities of basalt
    - dense interiors................ 10^{-11} meters/second
    - flow tops...................... 10^{-7} meters/second
    - damaged dense interior......... 10^{-8} meters/second
    - stress induced zone............ 10^{-10} meters/second

- vertical hydraulic conductivities of shaft materials
  - shaft seals - dense interior... $6x10^{-10}$ meters/second
  - shaft seals - flow tops........ $3x10^{-6}$ meters/second

Layer geometry was essentially as an average of holes in and near the reference repository location.

The temperatures assumed in the analysis were assumed to be equal to the estimated temperature distribution around the repository at approximately 300 years after closure. This temperature was computed using a modification of the MAGNUM-3D code, and was held constant throughout the analysis. This selection is explained in the report as follows: "Selection of repository temperatures 300 years after closure as internal boundary conditions for this steady state analysis was estimated to be a good approximation of the peak temperature around the shafts above the repository on the basis of the PORFLO simulations. This approach was felt to maximize the thermal buoyancy effects and hence would be conservative in terms of transport up the shaft." The thermally driven flow system was analyzed using a computer code called MAGNUM-3D. It is the understanding of the reviewer that this code has not been benchmarked nor has documentation been presented for it which would allow its benchmarking by others at this time.

The conclusion of the report is that essentially none of the flow that leaving the repository proceeds up the shaft system. In none of the analyses performed was any pathway found that went from the repository through any part of the shaft system into the environment. Secondly there was no difference in the results in terms of the performance criterion selected to distinguish between any of the shaft layouts with respect to the repository.

2.2 SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM

The significance to the waste management program of this piece of analysis should be that it will assist in rational optimization of the design of the repository. There has always been considerable concern within the NRC about the ability to seal shafts, and avoiding having the shafts become principal pathways for contaminant migration out of an otherwise excellent repository system. This concern is articulated in 10 CFR 60.134 - Design of seals for shafts and boreholes, in which section (a) states that "Seals for shafts and boreholes shall be designed so that following permanent closure they do not become pathways that compromise the geologic repository's ability to meet the performance objectives (f)or the period following permanent closure."

2.3 REVIEW CONCLUSIONS

It is the reviewer's opinion that this is an essentially unusable document. The analysis evaluated the amount of flow that would go differentially through a set of shafts whose permeability was similar to the rock from which they were excavated. The differences in permeability between the shafts and the repository host rocks were less significant in terms of perturbation of the flow system than the presence of the shaft barrier pillar. Because there will be no waste emplaced in the shaft pillar, the shafts will be located in a somewhat lower temperature rock than that which is above the repository. The resulting reduced thermal drive for flow up the shafts is a greater effect than the somewhat enhanced permeability resulting from the backfill. The inevitability of this result could have been easily identified by simple Darcy Flow analysis, given the parameters that were used.

The analysis may indicate how Rockwell plans to undertake performance analyses of repository performance using the tools that they have been developing for some years. However, in the absence of benchmarking and in the absence of worthwhile tests of this technology, it is difficult to make any comment on the effectiveness of this approach.

The finding which is made in this report and which has been carried forward and used in subsequent design activities is that less than 1% of the flow from the repository would go up the shafts. This reviewer considers this to be an entirely unsupported assertion and certainly not a result which can be considered to be derived from this analysis. The reasons for this statement are as follows.

1. The analysis as performed makes an assumption about the vertical hydraulic conductivity of the dense interiors which produces an essentially impermeable mass of rock in which the repository is located. Therefore, there is essentially no flow into the repository and there can therefore be little if any flow out of the repository up any sign of weakness.

2. The lack of contrast between the permeability of the shaft backfill materials and the intact local rock essentially means that the analysis performed is of an equivalent homogeneous material. This is unlikely to produce startling results with respect to the impact of the shafts on the rock. The permeabilities assumed for the shaft in tunnel backfills appear to this reviewer to be unreasonably low given that these shaft shields must be placed by hand in circumstances which are probably, in retreat, not conducive to laboratory-level precision in material placement.

3. The selection of the 300 year thermal period appears to the reviewer to be both too simple and unnecessarily restrictive given the great capability of the technology which was available. If one is to do an analysis which is in other respects as complex as the analysis presented, it seems unreasonable to restrict the principal driving energy mechanism to a single value, and it is extremely unclear that

this will indeed produce the conservative result which is claimed in the report.

2.4 RECOMMENDATIONS

Based on this review the following recommendations are made:

1. The evaluation should be broadened to include the effects of partial or total shaft seal failure, to allow assessment of the relative protection that different shaft pillar configurations provide under this scenario.

2. The analyses should be broadened to include times other than 300 years.

3. The conclusion that the design of the shaft pillar arrangement is not significantly influenced by containment considerations should be withdrawn until such a time that this can be supported.

3.0 DETAILED REVIEW (PROBLEMS, DEFICIENCIES AND LIMITATIONS)

3.1 VALIDITY OF REPORT CONCLUSIONS

As noted above, the principal problem associated with this report is that the hydraulic conductivities selected for the flow components in the analysis are not significantly different. The predictable conclusion is that there is no differential flow into the shafts, and that therefore the selection of shaft location and layout is not affected by containment considerations. The reviewer considers that this is probably an incorrect conclusion.

The shaft locations should presumably be selected to achieve at least three things:

1. Reasonably convenient access to the repository

2. Stability of the shafts under expected subsidence/uplift resulting from repository development and use.

3. Isolation from the repository so that the sealed shafts do not provide a significant differential pathway to the environment.

While in a conventional mine the first two factors are paramount, in a repository the second and third would appear to have primacy.

In order to assess which shaft arrangement provides the best protection against releases of radionuclides to the environment, it would appear to this reviewer to be more appropriate to determine the extent to which the shaft backfill could fail and the repository still meet the EPA standard. In this way, the contrast between the expected hydraulic conductivity of the backfill material and the hydraulic conductivity needed for compliance would give an easily understood measure of the degree of safety of the seal system, and also a ready measure of the relative protection provided by different shaft arrangements. This was not done in the analysis presented.

Alternatively it would have been more useful to evaluate a range of permeabilities for the backfill and shaft systems. This range could go from the numbers assumed (essentially the laboratory permeabilities of the backfill materials) through to total failure of the seal systems. In this way it would have been possible to identify the extent to which the failure of the seals systems would in fact imperil the performance of the repository. Such an evaluation was at least attempted by Golder Associates in an earlier report to the NRC and indicates the kind of analysis from which useful conclusions can be drawn.

Accordingly, a more useful question to address in this analysis would have been as follows: "At what average shaft and tunnel seal permeability do the shafts and tunnels become a significant conduit for flow to the accessible environment under the thermal loadings posed by the repository wastes themselves?". Analysis of this question would probably have required the tools which were used and would have provided valuable guidance in design in terms of the quality of barrier represented by the shaft pillar and the shaft seal materials.

3.2 HEADS

There appears to be some lack of clarity over the way in which head is used in this particular report. Plots of alleged head do not make it clear whether the head is a cold water head, a head at ambient density, or a head modified in some other way to attempt to show the energy field which will be operating in the analysis. Because the flow and the flux depends on the driving force, it is very important that the potential term be explicitly and correctly presented.

3.3 DIFFICULTY OF REVIEWING COMPUTER GENERATED RESULTS

In the absence of information about MAGNUM 3-D, it is particularly difficult to review the credibility of the analyses. In fact from the point of view of a reviewer, this report cannot be reviewed as to accuracy and reasonableness, as one is obliged to take on trust both the results of the computer runs and the interpretation presented in the report.

In particular, the reviewer is unable to make any assessment about flow systems, flow quantities, or flow split simply by looking at the head contours provided. This is because in a varying temperature environment the flow system is not an energy-conservative system and, therefore, simply looking at hydraulically related parameters is not enough of the picture to be able to make an assessment about what is in fact happening in the flow system.

3.4 THERMAL ANALYSIS

One portion of the report which is of utility as far as the NRC's review team is concerned is the thermal analysis. This shows interesting patterns of thermal distribution around a three dimensional repository, and clearly indicates that at least at 300 years, the thermal regime is far from isotropic, particularly with respect to the shaft pillars when compared to the materials immediately above the repository. This may be useful in future simple analyses of flow through the system, and is worthy of inclusion in an evaluation of the degree of protection that a shaft pillar provides to the repository.

It is particularly unfortunate that the information that is provided in the report on temperature does not indicate a vertical section through the shaft pillar (which is presumably of critical interest in the report), and does not present the thermal regime at other times than 300 years or at other elevations than the repository elevation.

3.5 SIMPLE ASSESSMENT OF EFFECTS OF SHAFTS

In order to check the results of the report, the parametric information summarized in Section 2.1 above was used to estimate the impact one would expect the presence of a somewhat more permeable shaft to have on the integrity of a repository. Consider the following situation:

- a round shaft 3 meters in radius (6 meters in diameter),
- an approximately 0.15 meter thick skin of disturbed rock around the perimeter of the shaft,
- a 2.85 meter thick stress-relieved zone outside the disturbed zone,
- a vertical upward gradient of .001 (as suggested in the report as the situation prior to heat effects), and
- the permeabilities used in the report for the backfill of the shaft, the disturbed zone, and the stress-relieved zone.

One can compute the vertical upward flow which would result from this arrangement using Darcy's Law. The flow in the vicinity of the shaft is approximately as follows:

- via the backfill.................. $2x10^{-11}$ cubic meters per second
- via the disturbed zone........... $3x10^{-11}$ cubic meters per second
- via the stress relieved zone..... $1x10^{-11}$ cubic meters per second

- total flow in shaft vicinity..... $6x10^{-11}$ cubic meters per second

For convenience, an effective vertical permeability of the shaft material which would result if one assumed that all of that flow were in fact conducted within the perimeter of the nominal shaft dimension (3 meters radius) was back calculated . This equivalent hydraulic conductivity was $2x10^{-9}$ meters per second. This permeability is approximately 500 times greater than the equivalent permeability of the dense interiors through which the shaft passes, and might be expected to make a significant difference to the flow system.

To assess the impact that this might have on the flow system, a further calculation was made to evaluate the extent to which the vertical permeability of the entire shaft pillar would be modified by five shafts of identical characteristics to the one computed above. Taking the most conservative layout provided in the report (layout B-2, which has the smallest shaft pillar) and assuming that the vertical permeability in locations other than the shafts is 10^{-11} meters per second, inclusion of the higher permeability shafts raises the effective hydraulic conductivity from 10^{-11} meters per second to $2x10^{-11}$ meters per second - it doubles it.

The results of the analysis in the report suggest that this difference is not significant enough to cause any contaminated flow up the shafts. Examination of the thermal contours that were used in the area of the shaft suggest that the reason for this is that the thermal drive above the repository is greater than the thermal drive in the shaft pillar. This is in part because the thermal generation takes place in the repository panels, and in part because the time selected for the analysis was relatively early in the development of the thermal plume around the repository. However, for this reason, the source of energy for moving water is greater above the repository panels than it is in the shaft pillar. If this thermal drive constitutes more than twice the energy gradient of the repository panels than it does in the pillar panels, then that energy drive would be enough to more than overwhelm the permeability contrast between the shaft pillar and the repository panels.

Finally, it is instructive to evaluate the impact of the permeability of the shafts on the average permeability of the entire repository area. The repository panel area is approximately 20 times greater than the shaft pillar area, based again on the most conservative layout (B-2). As a result, the 100% increase in permeability in the shaft pillar caused by the presence of the back-filled shafts has the effect of producing approximately 5% increase in the average vertical permeability over the entire repository area. Other things being equal, this would suggest that the leakage from the entire repository system, under equal thermal drive conditions over the entire system including the shaft pillar, would increase approximately 5% as a result of the backfilled shafts.

As the vertical permeabilities of all of the units involved in the transport system are poorly known (no better than several orders of magnitude uncertainty), a 5% variation due to shaft backfill would not appear to be a significant variable in performance analyses for the final repository design.

However, the dependence of the flow from the repository on the permeability of the shaft backfill materials is approximately linear. Therefore, if the shaft backfill material were as little as an order of magnitude more permeable than is assumed in this report, the impact of the shaft on the performance of the entire system would be dramatic, constituting more than half to 90% of the total flow capacity vertically through the system. This critically important point is not brought out in the study, as a result of the single selection of vertical permeability in the shaft materials.

As a result of this final finding, the flaw in the report as presented becomes most clear. The permeability of the backfill materials used in the shafts and tunnels would become critical if it were significantly greater than the average of 2×10^{-9} meters per second. This is a relatively low permeability and it is entirely conceivable to the reviewer that the actual permeability of the backfill materials in the shafts and tunnels could be considerably higher. Accordingly, it is the opinion of this reviewer, contrary to the finding of the report, that the location of the shafts as far as possible from the thermal source of the repository is likely to be an important component of the barrier which is represented by the shaft pillar and shaft backfill system. This point is entirely overlooked in the report, and thus the report provides, in the opinion of this reviewer, inappropriate guidance to the repository design team.