KALE/87/2/18 2

Mr. Stephen H. Kale, Associate Director
Office of Geologic Repositories
U.S. Department of Energy
Washington, DC 20585

Dear Mr. Kale:

Enclosed for your information are several documents related to a recent NRC contractor (Nuclear Waste Consultants (NWC)) review of a DOE contractor report entitled "Groundwater Travel Time Analysis for the Reference Repository Location at the Hanford Site". The enclosed documents highlight some of the hydrologic concerns which need to be discussed along with other items during the April hydrologic testing meeting so that the DOE can take these items into consideration when completing their test plans.

Both the NRC staff review and that of NWC question the DOE's conclusion in the final Environmental Assessment (EA) that the groundwater travel time at the Hanford site will be well in excess of the 1000 year requirement. They differ significantly, however, in the degree to which they question the DOE's conclusion. Based upon NWC's analysis and the NRC staff's analysis and interpretations of the uncertainties existing at this time, the staff concluded that one could only state that travel times may be significantly closer to 1000 years than the DOE has stated. The NRC staff also concluded that with the existing limited data base, it is premature to place a significant amount of credibility on any current estimate of groundwater travel time until additional data has been collected. The above conclusions are reflected in the staff's final EA comment. NWC, based upon their assumptions, analysis, and interpretation of the uncertainty, concluded that there is a significant likelihood that the site will fail the 1000 year groundwater travel time criterion.

The NRC recognizes that questions concerning groundwater travel time at the Hanford site can only be resolved by collecting additional data and using it appropriately in models, and that this is the purpose of hydrologic testing during site characterization. The NRC staff and contractors all agree that additional site characterization work is necessary and desirable. Additional hydrologic testing should be performed as soon as possible upon consultation with the NRC and prior to commencement of shaft sinking so that all data that could be affected by shaft construction is available for analysis. The NRC and DOE have previously agreed upon a testing strategy for the Hanford site which has been documented in the NRC's Technical Position 1.1. Modification of this general testing strategy should include proven and accepted procedures for determining other hydrologic parameters that are crucial to determining groundwater travel time (such as effective porosity). Such a testing program, if performed appropriately, should yield data that would allow better estimations of pre-emplacement groundwater travel time at the Hanford site as well as the data needed to begin addressing questions related to post waste emplacement groundwater flow and radionuclide transport.

Because of the need to conduct hydrologic testing before shaft construction and disturbance of the hydrologic system, a primary objective of the April 1987 BWIP Hydrology meeting should be for the NRC and DOE, together with the participation of the representatives from the affected states and Indian tribes, to discuss and reach agreement on the hydrologic testing program and strategy that will be necessary to resolve the types of concerns raised in the enclosed documents as well as other related concerns identified to date, so that testing can proceed with minimal programmatic impact.

Should you have any questions please contact me at FTS 427-4069 or John Linehan of my staff at FTS 427-4177.

Sincerely,

Original Signed by
MICHAEL J. BELL

for Robert E. Browning, Director
Division of Waste Management
Office of Nuclear Material Safety
and Safeguards

Enclosures:
1. Review of SD-BWI-TI-303, "Groundwater Travel Time Analysis for the Reference Repository Location at the Hanford Site" by Nuclear Waste Consultants
2. Memo fm Weber & Coleman (NRC) to Hildenbrand (NRC) dtd 10/28/86
3. Summary Meeting Note of NRC BWIP Hydrology Meeting with contractors 11/6-7/86
4. Ltr fm Pohle (NRC) to Logsdon (NWC) requesting clarification & justification of positions taken in the 6/86 document review
5. Ltr fm Logsdon (NWC) to Pohle (NRC), transmitting re-review of Clifton's groundwater travel time analysis
6. Re-review of Clifton's Groundwater Travel Time Evaluation by Adrian Brown (NWC) and transmitted to NRC under cover of letter described in (5) above

cc: See attached sheet

cc: J. Knight, DOE/HQ
J. Antonnen, DOE/RL
T. Husseman, State of Washington
B. Dixon, State of Oregon
R. Jim, Yakima Indian Nation
W. Burke, Umatilla Indian Nation
R. Half-Moon, Nez Perce Tribe

KALE/87/2/18

OFFICIAL CONCURRENCE AND DISTRIBUTION RECORD

LETTER TO: S. Kale

FROM: R. Browning

SUBJECT: CONTRACTOR REVIEW OF GWTT

DATE: MAR 1987

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ENCLOSURE 1

NUCLEAR WASTE CONSULTANTS INC.
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June 13, 1986

009/2.3/REV.004
RS-NMS-85-009
Communication No. 65

U.S. Nuclear Regulatory Commission
Division of Waste Management
Geotechnical Branch
MS 623-SS
Washington, DC 20555

Attention: Mr. Jeff Pohle, Project Officer
Technical Assistance in Hydrogeology - Project 8 (RS-NMS-85-009)

Re: Review of "Groundwater Travel Time Analysis for the Reference Repository Location at the Hanford Site", SD-BWI-TI-303

Dear Mr. Pohle:

Please find attached the Nuclear Waste Consultants/Terra Therma Inc. (NWC/TTI) document review of "Groundwater Travel Time Analysis for the Reference Repository Location at the Hanford Site", SD-BWI-TI-303, by P.M. Clifton. The review, prepared by Dr. Catherine Kraeger-Rovey and Mr. Adrian Brown, was performed under Subtask 2.3 of the current contract. The review has received a technical and management review by Mark Logsdon of Nuclear Waste Consultants. This document review has taken longer to prepare than we had originally anticipated, but in light of the sensitivity of the issues associated with this matter and the high likelihood that the Clifton document has been used to support findings in the Final Environmental Assessment for BWIP, Nuclear Waste Consultants determined that it was better to take the extra time needed to complete a comprehensive and quality-assured review than to hurry the product.

The review, as most NWC/TTI reviews, is quite extensive and very detailed. NWC/TTI reach two important conclusions about the subject document:

1. The use of stochastic analyses is appropriate and probably the only technically sound method available to deal with the variability and uncertainty in the hydrogeology of the site.

2. However, the results obtained in the Clifton computations of GWTT are incorrect. NWC/TTI computations (presented in full in the review) show that there is a low probability that GWTT will exceed 1,000 years (between 20% and 50%) and a much lower probability that GWTT will exceed 10,000 years (between 2% and 7%). The differences between the DOE result and the review result stem mainly from differences in the interpretation of porosity, both with respect to the "best estimate" value and the nature of the parameter's distribution around the estimate.

~~8607110301~~ 3/pp.

If you have any questions about this review, please do not hesitate to contact me or Mr. Adrian Brown.

Respectfully submitted,
NUCLEAR WASTE CONSULTANTS

Mark J. Logsdon

Mark J. Logsdon, Project Manager

cc: US NRC - Director, NMSS (ATTN PSB)
DWM (ATTN Division Director)
Mary Little, Contract Administrator
WMGT (ATTN Branch Chief)

L. Davis, WWL
R. Knowlton, DBS

bc: M. Galloway, TTI

1.0 INTRODUCTION

TITLE: "Groundwater Travel Time Analysis for the Reference Repository Location at the Hanford Site", SD-BWI-TI-303

AUTHOR: P.M. Clifton

DATE: January, 1986

REVIEWERS: Dr. Catherine Kraeger-Rovey (Terra Therma) and Adrian Brown (NWC)

DATE: June 11, 1986

SCOPE: General review of concepts and methods, with emphasis on logic, assumptions and limitations. Specific review with respect to input data and computations. Reviewed in the context of support for decision-making in the EA process.

KEYWORDS: Pre-emplacement Groundwater Travel Time; Hanford Site; Stochastics; Probabilities; Porous Media; Fluid Flow; Conceptual Models; Computer; Model

Date Approved:

2.0 SUMMARY OF DOCUMENT AND REVIEW CONCLUSIONS

2.1 SUMMARY OF DOCUMENT

The document under review attempts to evaluate the current best estimate of the pre-emplacement groundwater travel time (GWTT) at Hanford, as is required to evaluate whether the site complies with the requirements of 10 CFR 60.113:

> "The geologic repository shall be located so that pre-waste-emplacement groundwater travel time along the fastest path of likely radionuclide travel from the disturbed zone (around the repository) to the accessible environment shall be at least 1,000 years or such other travel time as may be approved or specified by the Commission."

and with 10 CFR 960:

> "A site shall be disqualified if the pre-waste-emplacement groundwater travel time from the disturbed zone to the accessible environment is expected to be less than 1,000 years along any path of likely and significant radionuclide travel."

In addition, 10 CFR 960 includes a favorable condition (which if present is considered to enhance confidence in the ability of the site to contain and isolate nuclear waste), which is that the GWTT is greater than 10,000 years (10 CFR 960.4-2-1).

The document presents the results of a computation of the GWTT that takes into account a variety of pathways and the variability of the input data that must be used for the computation. It utilizes a series of five models to predict ranges of pre-waste-emplacement groundwater travel times for the proposed repository beneath the Hanford Site. The models account for different concepts and interpretations about the deep basalt groundwater flow regime.

The simplest of these five models considers two-dimensional, horizontal flow in the basalt flow top overlying the repository. Complexity is added to this model by superimposing vertical flow, first through the repository horizon, then through the overlying sequence of flow interiors and interflows, to the ground surface. The models are briefly described as follows:

- Model 1 is limited to a consideration of two-dimensional, horizontal flow in the basalt flow top overlying the dense interior of the emplacement horizon. Neither vertical flow, nor flow in any other layer is considered. Groundwater travel times are calculated between a point in the flow top immediately above the downgradient edge of the repository and the accessible environment, assumed five kilometers laterally distant from the repository edge. A potentially non-conservative assumption is that the disturbed zone is limited to the emplacement horizon. If the disturbed zone is larger, the flow path to the accessible environment may be shorter, resulting in shorter travel times.

Travel times predicted in this model ranged over eight orders of magnitude. Spatial variability and uncertainty contribute to this broad range. However, the significant portion of the range of results is not as broad, considering the regulatory criteria for pre-emplacement travel times. Clifton calculates that the probability of exceedance of 10,000-year travel times is greater than 99 percent for all variations of parameter uncertainty and spatial variability considered in the model.

- Model 2 considers one-dimensional, vertically upward flow in the uppermost section of the dense interior of the emplacement horizon beneath the flow top. Groundwater travel times to the accessible environment are not calculated in this model; instead its purpose is to demonstrate the increment of groundwater travel that can be attributed to movement through an undisturbed section of the emplacement horizon. The travel distance is arbitrarily set at 10 meters with no basis. It is implicitly assumed that the disturbed zone will not extend upward from the repository to within 10 meters of the flow top. Should the disturbed zone extend further, Model 2 results would be non-conservative.

The results of this model predict an additional increment of groundwater travel time due to consideration of vertical movement in the dense flow interior immediately above the repository horizon. The variation in predicted groundwater travel times of about 1.5

orders of magnitude is due primarily to the variation in assumed values of hydraulic conductivity anisotropy ratio. The greatest anisotropy ratio (30) corresponds to the lowest range of travel times, in which the median is 2,200 years. However, the range of travel times considered by Clifton does include values in the tens and hundreds of years that may be of concern, depending on the results from Model 1, for travel time to the accessible environment.

- Model 3 is a combination of Models 1 and 2; its purpose is to demonstrate the magnitude of increased travel time estimates that can be achieved by accounting for the increment of flow in the emplacement horizon dense interior.

  In the discussions of Model 3, the author indicates that the model results are very sensitive to both the log-transmissivity range (Model 1, for horizontal movement through the flow top) and the hydraulic conductivity anisotropy ratio (Model 2, for vertical movement through the flow interior of the repository horizon). As has been discussed previously, these input parameter value ranges are relatively uncertain; given the high degree of sensitivity, those uncertainties transmit directly to the model results. For Model 3, the uncertainties of Models 1 and 2 are compounded, and, therefore, the results of this model are especially uncertain.

- Model 4 accounts for horizontal and vertical flows in a sequence of basalt flow tops and dense interiors above the emplacement horizon.

The flow regime is two-dimensional and horizontal in the flow tops, and one-dimensional and vertical in the flow interiors. Three variations are developed, with three different anisotropy ratios for the flow interiors, to account for uncertainties as to vertical hydraulic conductivity values. The pathlines for determining groundwater travel time begin at the base of the flow top overlying the dense interior of the emplacement horizon.

Model 4 adds to Model 1 a consideration of upward, vertical movement through the sequence of basalt flow tops and dense interiors above the repository horizon. Runs of Model 4 were made with a range of vertical hydraulic conductivity anisotropy ratios from 1 to 30 and a range of flow top transmissivity correlation ranges from zero to 5 kilometers.

- Model 5 is similar to Model 4; the principal difference is that the flow path for Model 5 begins in the dense interior of the emplacement horizon, for the purpose of demonstrating the additional travel time accountable to movement through the flow interior above the repository. Model 5 differs from Model 4 in that it includes consideration of travel time vertically through the dense flow interior of the repository horizon.

Other assumptions made in modeling travel times through the layered sequence of basalt flows and dense interiors in Models 4 and 5 include uniform vertical hydraulic conductivity and thickness within each layer, and horizontal groundwater flow within the flow tops determined with the algorithm described in Model 1. The Monte Carlo version of PORFLO, PORMC-SF is used to determine groundwater travel times. This code solves the steady-state groundwater flow equation for a velocity field, which is then used to trace particle paths and determine total travel time of each particle. The logic and procedures in Models 4 and 5 are considered adequate and appropriate.

To accomodate data uncertainties for some of the hydrologic parameters, probabilistic functions replace single values as input data to the models. Input data for the models were developed from existing data, and where data were lacking, from judgement. Sensitivity analyses were conducted with each model to determine effects of variations in the assumed data on predicted travel times and, for the more complex models, flowpaths.

For all but one of the five models, the computer code used is PORMC-SF. The current version of this code solves the steady-state, two-dimensional groundwater flow equation. Results of the groundwater travel time models are presented in the form of probability distributions, instead of single values. These probability distributions are developed by accounting for uncertainties in some of the model inputs, including lack of information and spatial variability.

Using the data selected by Rockwell, the evaluation results in the conclusion that there is a very high probability that the GWTT is greater than 1,000 years (97% or greater), and a high probability that the GWTT is greater than 10,000 years (73% or greater).

2.2 SUMMARY OF REVIEW COMMENTS

The results of this review are that the approach used for the computations is in general appropriate, to the extent that it can be understood using the material presented in the report. Stochastic approaches to analysis will, in the opinion of the reviewers, always be needed for analyses of performance of high level waste repositories, for the following reasons:

1. At all stages of the licensing process, the data that are available will always have a high level of variability and uncertainty, which will require a need to understand the uncertainty of the results of analyses.

2. The regulatory standards are all couched in terms of levels of confidence of the standard being met, rather than of absolute assurance.

However, it is concluded that the results obtained in the actual computation of GWTT are incorrect, and that there is a low probability that the GWTT will exceed 1,000 years (between 20% and 50%), and a lower probability that the GWTT will exceed 10,000 years (between 2% and 7%). The differences in the DOE result and the review result stem mainly from the interpretation of porosity, both with respect to the "best estimate" value, and the nature of its distribution around this estimate.

These reservations and findings have been conveyed to the DOE on at least two previous occasions (NRC, 1983; NRC, 1985), and the failure of Rockwell to either modify the GWTT evaluation on the basis of these comments, or to refute the position of the NRC in the present document suggests to the reviewers that there has been a breakdown in the pre-licensing communication process that is supposed to be occuring at this time. Accordingly, it is the position of the reviewers that the NRC Staff should conszder directing DOE to show cause why the site should not be disqualified, based on any reasonable interpretation of the available information, and the 10 CFR 960 requirement that the Department has set for all repositories.

3.0 SIGNIFICANCE TO THE NRC WASTE MANAGEMENT PROGRAM

Both 10 CFR Part 60 and 10 CFR Part 960 require evaluations of pre-emplacement groundwater travel time. In the case of Part 960, there is a disqualifying condition for site selection associated with likelihood that groundwater travel time is less than 1,000 years. It is anticipated that this document will be used to support DOE contentions in the Final Environmental Assessments that the disqualifying condition is not present at the RRL for the Hanford Site, based on currently available information.

4.0 GENERAL COMMENTS ON REPORT

The reviewers believe that DOE is to be commended for attempting to treat the variability of hydraulic data and the potential uncertainties in the models of groundwater flow in a conceptually sound framework. The NRC has repeatedly demanded that DOE assessments at Hanford take these sources of variability and uncertainty into consideration, and it is well to acknowledge that this paper indicates their intention to do so.

That having been said, it must be stated that this paper fails to adequately or even appropriately assess the likely range of groundwater travel times, for that most common of reasons - the data that are used to implement the approach are not comprehensive, conservative, or even, in some cases, appropriate.

The analysis presented in the report calls to mind an aphorism attributed to one Andrew Lang : "He uses statistics as a drunken man uses lampposts - for support rather than for illumination". The approach presented in the report is complex and difficult to review, and goes a considerable way to diverting attention from the manipulation of the basic data that has been used to produce the claimed "conservative" answers. However, it remains the position of the review team that the currently available field-derived data (as distinct from generally canvassed opinions) indicate a GWTT in the order of 1000 years, with an uncertainty of at least an order of magnitude.

5.0 DETAILED COMMENTS

5.1 ANALYTICAL APPROACH

The general analytical approach of a stochastic analysis seems to the reviewers to be the only realistic possibility for addressing the spatial variability, limited quantities of analytical data, and inherent uncertainties in conceptual models. However, as Clifton acknowledges, there are difficulties in applying the stochastic analyses because of insufficient data to conduct spatial statistical analyses to derive correlation ranges for spatial stochastic processes and problems in assigning convincing ranges and distributions to parameters that are treated as random variables.

NWC/TTI consider that the BWIP analytical approach should be encouraged, but that this application of the stochastic analyses should be rejected on the grounds that the parameter structures that have been used in the analyses have been chosen in a manner that biases the results toward longer travel times. This argument is developed in detail in the sections that follow. In addition, NWC/TTI notes that we do not necessarily concur that the conceptual models used in the Clifton paper realistically describe "likely paths of radionuclide transport", a matter that is dealt with in some detail in Codell (1985). In view of our analyses and conclusions concerning travel-times in light of what we consider to be defensible parametric data, our questions about conceptual models appear to be a second-order concern.

5.2 COMPUTATION OF GWTT

5.2.1 Simple Theoretical Framework

Regardless of the complexities of the method used, the basic formula for the groundwater travel time in a homogeneous medium is:

(1) $t = n\,L\,/\,(k\,i)$

where:
- t = groundwater travel time
- n = effective porosity along path
- L = length of the pathway
- k = hydraulic conductivity of the medium
- i = hydraulic gradient along the pathway.

The complexities that have been introduced in the review report are in part a result of the failure of the entire domain to meet the test of a homogeneous medium. Instead, the total pathway has been subdivided into a series of piecewise-homogeneous pathways, the travel time along the total being the sum of the partial travel times.

An interesting aspect of the importance of the various parameters arises in the discussion of the vertical transit time which is presented as part of the discussion of the different path models assumed (Page 14). By use of Darcy's Law, it can be simply shown that, for vertical flow through a horizontally layered medium:

(2) $t_i = n_i \cdot L_i / q$

where t_i = time for transit through layer i

n_i = effective porosity of layer i

L_i = thickness of layer i

q = flow through a unit area of layer i

What is interesting is that the transit time is not directly related to the hydraulic conductivity of the layer;. the flow through the layer is controlled by the lowest hydraulic conductivity layer in the pile, in general not the hydraulic conductivity of the layer being considered:

(3) $q = H\ k_e / L$

where q = flow through a unit area of all layers

H = total head loss across system = sum(H_i)

k_e = effective vertical permeability = sum(L_i) / sum(L_i / k_i)

L = total thickness of all layers

Combination of (2) and (3) produces:

(4) $t_i = n_i\ L_i / (i\ k_e)$

where t_i = total transit time over layered system

n_i = effective porosity of layer i

L_i = thickness of layer i

i = gradient = sum(L_i) / sum(H_i)

k_e = effective vertical permeability = sum(L_i) / sum(L_i / k_i)

Finally, it can then be shown that the time for groundwater to transit the entire sequence of layers is, as is stated in the report, given by:

$$(5) \qquad t = \frac{\text{total effective thickness}}{\text{total gradient x effective hydraulic conductivity}}$$

$$t = D_e / (i \ \ k_e)$$

where t = total transit time over layered system

D_e = effective thickness = sum(n_i L_i)

i = gradient = sum(L_i) / sum(H_i)

k_e = effective vertical permeability = sum(L_i) / sum(L_i / k_i)

However, unless the total thickness of the resistive units between the source and sink of the flow system is taken into account, this equation is not particularly useful for the computation of transit time in the present situation.

5.2.2 Parameters

The parameters that are used for the computation of GWTT in the report are discussed below.

5.2.2.1 Horizontal hydraulic conductivity

The geometric mean of the transmissivity of (apparently 13) individual Grande Ronde flow tops is stated to be 0.12 square meters per day (Page 16), with a standard deviation of a factor of 135 (standard deviation of log-transmissivity of 2.13). Clearly this transmissivity is extremely variable.

In addition, the transmissivity in general decreases with depth of the flow tops, for reasons that are not particularly clear. The transmissivity of flow tops in the Saddle Mountains Basalts are greater than those in the Wanapum, which are in turn greater than those in the Grande Ronde (DOE, 1984). Thus to roll the Grande Ronde transmissivities together is not considered particularly wise, although it would hardly make much difference to the results, as they have such a huge range (the 95% confidence range of transmissivity is from 0.000007 to 2200 square meters per day). However it should be noted in passing that if the pathway moved into the Wanapum, then the transmissivities are considerably higher, and the corresponding travel times would be correspondingly higher. In addition, the standard deviation of the mean value is less: for 13 samples, the variation of log mean transmissivity is about 0.6, or a factor of 4.1 either way from the mean.

The distribution of the transmissivity is assumed by Rockwell to be log-normal, which appears reasonable; if it were normal, then the effect of only the top one or two values would be of significance in the evaluation of the mean.

In the above discussion, transmissivity can be transformed to hydraulic conductivity by dividing by the thickness of the aquifer. This is typically in the order of 10 meters. Thus, with little error, the hydraulic conductivity (in meters per second) is found by dividing the transmissivity (in meters squared per day) by 10^6. Accordingly the geometric mean horixontal hydraulic conductivity of the Grande Ronde is about 1.2×10^{-7} meters per second.

5.2.2.2 Vertical Hydraulic Conductivity

The vertical hydraulic conductivity of the dense interiors is the parameter of interest. As stated in the report, a total of 13 tests of the horizontal hydraulic conductivity of the Grande Ronde dense interiors have been conducted. These produce geometric mean permeabilities of 5×10^{-13} meters per second, with a standard deviation of a factor of about 8. This geometric mean presumably does not include the permeability of the vesicular zone. There are some methodological problems associated with the conduct and interpretation of these tests. However it is clear that the measured horizontal hydraulic conductivity of the Grande Ronde flow interiors is in general low.

The transfer of this information to vertical hydraulic conductivity is troublesome. Anisotropy ratios from 1 to 30 have been suggested, and all are credible based on discussions of the nature of jointing and other factors. These would lead to vertical hydraulic conductivities in the order of 10^{-12} meters per second. Based on the data available, it is not possible to ascribe this low hydraulic conductivity to entire layers of dense interior material. First, the mean vertical hydraulic conductivity of the layer is an arithmetic composite of the values obtained. The tests that have been performed in general delete any higher hydraulic conductivities measured on the grounds that there must have been a packer leak. Accordingly, only low values tend to be admitted into the database. Second, there are only 13 tests that form this database. If it is assumed that all 13 were in the RRL, and that the area is 60 square kilometers, then the area covered by each hole is nearly 5 square kilometers, and the data is spread on an average spacing of about 2 kilometers.

The leakage over the area due to (say) a vertical gradient of 10^{-3} (page 24) is computed from Darcy's Law, using the above hydraulic conductivity, to be 6×10^{-8} cubic meters per second (2 cubic meters per year). If, in addition, there were a single geologic "hole" in the sheet, of an area (say) 100 meters square, of average hydraulic conductivity of 10^{-8} meters per second, then the flow through this feature alone would be about twice the leakage of the sheet, using the propc.ed hydraulic conductivity. The probability of any one of 13 tests hitting this feature in any dense interior in the RRL is 0.2%. Accordingly, it is entirely possible that the effective vertical hydraulic conductivity of the formation is considerably higher than the values given.

5.2.2.3 Porosity of Flow Tops

It is in the evaluation of porosity that the main disagreements between the reviewers and the Rockwell team occur. First, there is only one actually measured value of effective porosity for Hanford Basalt. This value is computed by Rockwell to be 1.6×10^{-4}, for a flow top at DC-7/8.

In order to augment this rather limited database, Rockwell convened a panel of experts, which decided on a reasonable range for the porosity of 10^{-2} to 10^{-4}. It is of significance to ask from where this expertise is drawn. There is only the one tracer test that has been performed in Hanford Basalt to date. Core data suggest a great variation of results, with values of total porosity reported as high as 0.2, and as low as zero. The other experience that would have been available to the experts in similar materials is questionable. The average hydraulic conductivity of the flow tops is about 10^{-7} meters per second. It is difficult to perform a reasonable tracer test in materials of this or lower hydraulic conductivity, as the tracer does not move very quickly: in typical test conditions it would take about 3 years for the tracer to move 100 meters. Accordingly, the great majority of porosity information comes from tests in materials that are either of relatively high permeability, or reasonably low porosity, or both. In general, the available data come from granular materials tests. Accordingly, it is suggested that nobody is an "expert" in this particular field.

The distribution of the porosity is of considerable interest. Rockwell claim that it is normally distributed, and cite three references in support of this. At least two, and probably all three, of these references, draw their conclusions from granular materials. In these materials, it is unusual for the effective porosity to fall outside the range of 0.1 to 0.4. The mean of such a population can be computed by assuming a normal distribution, and is about 0.25. Similarly, it can be computed using a log-normal assumption, and is about 0.20. The difference is small, and thus the approach taken would not significantly affect the travel time computation in this case. Contrast this with the situation in the review document. Here the range of the values is from 10^{-3} to 10^{-1}. The corresponding normal mean is 0.05, while the log-normal mean is 0.01, a factor of five lower. As the groundwater travel time is proportional to the porosity, it is considerably unconservative to assume the normal distribution.

In the review document, Rockwell claim a relationship between porosity and hydraulic conductivity (Page 20, second paragraph). If the hydraulic conductivity is log-normally distributed, then it would appear reasonable that the porosity in such situations would also be log-normal. In addition, on Page 24 of the report, Rockwell quotes a paper by Bianchi and Snow (1969) that indicates that fracture apertures in crystalline rock tend to be log normally distributed. If, as seems reasonable, the effective (connected) porosity in the rock is fracture porosity (and the very large variation in hydraulic conductivities suggests that it is), then it is also reasonable to assume that the porosity is log-normally distributed, particularly as it is conservative to do so when computing GWTT.

In summary, it is considered that until more tests are performed, the mean porosity of a basalt flow top should be set at $1.6x10^{-4}$. The mean value assumed by Rockwell ($5x10^{-2}$) is a factor of 316 higher than this measured value. Based on the above considerations, porosity value used by Rockwell is at least a factor of 5 to high, and likely a factor of 300 too high, both of which are unconservative with respect to GWTT.

5.2.2.4 Porosity of Flow Interiors

The porosity of the flow interiors is entirely unknown. It is possible to relate the hydraulic conductivity to the porosity. If the hydraulic conductivity of the flow tops is about 10^5 greater than the conductivity of the interiors, and if one assumes that the transmissivity bears a cubic relationship with porosity (page 20), then the porosity of the flow tops is computed to be 50 times greater than that of the flow interiors. Accordingly, the porosity would compute to be 3.2×10^{-6} for the flow interiors. This is at least reasonably in line with the essentially zero hydraulic conductivity. The Rockwell assumed value was 10^{-5}.

5.2.2.5 Path Length

The path length discussion in the report is considered appropriate, and mimics the discussion in the OSCA (NRC, 1983).

5.2.2.6 Gradient

The gradient discussion in the report is considered to be somewhat too limited. The gradients measured, both horizontal and vertical, are probably influenced by the disposal of water from the 200 West Area ponds. As these are roughly in the center of the triangle described by DC-19, DC-20, and DC-22, which are the primary holes used for gradient evaluation, the value of gradient in the area may be understated. However this is not considered a major source of error in the evaluation: values of $2x10^{-4}$ and $10^{-[illegible]}$ for horizontal and vertical hydraulic gradient seem reasonable for the purpose at hand.

5.2.3 Evaluation

This evaluation is intended to give a rough check of the values presented in the review report. We have not attempted to use the stochastic approach used in the report, for lack of time and resources. We have, however, included a measure of the uncertainty of the results that is a result of the uncertainty of the parameters. In addition, we have tried to indicate where the stochastic approach used by Rockwell would have produced different answers than the simple check approach used here, and the impact on the GWTT that would result from using the Rockwell analytical approach with the parameters that the review team considers to be appropriate.

5.2.3.1 Horizontal GWTT

Using the formula for the horizontal transit time, and the values developed above, the approximate mean transit time in a single layer for groundwater to move 5 kilometers is given by:

(1) $t = n L / (k i)$

where: t = groundwater travel time

n = effective porosity along path = 1.6×10^{-4}

L = length of the pathway = 5000 meters

k = hydraulic conductivity of the medium = 1.2×10^{-7} meters/second

i = hydraulic gradient along the pathway = 2×10^{-4}

Accordingly, the transit time computes to be 1,057 years. An estimate can be made of the standard deviation of the result by assuming that the parameters are independent, and all are log normally distributed. The equation for the transit time can be recast:

(6) $\log(t) = \log(n) + \log(L) - \log(k) - \log(i)$

The standard deviation of a sum is equal to:

$$SD_{\log(t)} = (SUM(SD_{\log(component)}{}^2)^{1/2}$$
$$= (0.5^2 + 0 + 0.615^2 + 0)^{1/2}$$
$$= 0.79$$

Thus the approximate standard deviation of the travel time is a factor of 6.2, and the 95% confidence range of the transit time in the horizontal flow top is 27 years to 40,000 years. Using the above simple approach, there is a 49.6% probability that the 1,000 year travel time will be exceeded, and a 7% probability that the 10,000 year travel time will be exceeded. Based on recent publications by the NRC staff (Codell, 1985), a 15% exceedance of the standard travel time would be the flavor of the limit of the acceptable range. Accordingly, the BWIP site appears to fail the 1,000 year GWTT test.

To check to see the magnitude of the difference between the above simple analysis and the more sophisticated Rockwell analysis, the values used by Rockwell were entered into the equation. This produced results that were 316 times higher, as noted above. The new mean was computed to be 334,000 years, and the standard deviation remains at a factor of 6.2. The probability of exceedance of the 1,000 year limit is 99.9%, and the 10,000 year test is 97%. These are similar to the exceedances that were computed by Rockwell, although the Rockwell mean was lower (about 50,000 years). This would be expected, as the two dimensional analysis performed by Rockwell would allow the water to find the fastest path through the "maze" of high and low hydraulic conductivity zones in the system. In order to compute the result that the use of the reviewers' parameters would have produced in this analytical approach, it seems reasonable to simply factor the GWTT:

$$GWTT_{NWC} = GWTT_{Rockwell} * (50{,}000/334{,}000) = GWTT_{Rockwell} * 0.15$$

Applying this approach, the mean GWTT for the NWC best estimate would fall to about 160 years.

5.2.3.2 Vertical GWTT

The vertical GWTT depends on a knowledge of the entire layered system. However, if it is assumed that the vertical hydraulic conductivity is equal to the value for the dense interior, and that the gradient is all taken up in the low permeability layers, then using (4):

(4) $t_i = n_i L_i / (i\, k_e)$

where t_i = time for transit through layer i

n_i = effective porosity of layer i = 3.2×10^{-6}

L_i = thickness of layer i = 10 meters

k_e = effective vertical permeability

= $\mathrm{sum}(L_i) / \mathrm{sum}(L_i / k_i) = 10^{-12}$ meters/second

i = hydraulic gradient = 10^{-3}

The computed transit time is 100 years for the top of the Cohassett Flow interior.

The standard deviation of a sum is equal to:

$$SD_{\log(t)} = (\mathrm{SUM}(SD_{\log(component)})2)^{1/2}$$
$$= (0.5^2 + 0 + 0.26^2 + 0)^{1/2}$$
$$= 0.56$$

Thus the approximate standard deviation of the travel time is a factor of 3.7, and the 95% confidence range of the transit time in the horizontal flow top is 8 years to 1,350 years. These values are insignificant when compared with the horizontal GWTT values.

5.2.3.3 Total GWTT

The maximum total GWTT can be arrived at by adding the vertical and horizontal GWTT's, providing that one believes that:

1. The portion of the emplacement dense interior for which credit is taken is not within the "disturbed zone".

2. The flow in the generic horizontal layer reasonably represents horizontal flow in any layer above the repository horizon.

3. The flow does not enter the next dense interior.

It is beyond the scope of this review to perform a more detailed analysis than is presented here. However, if one simplistically adds the vertical and horizontal flow in the two layers, the result is a GWTT of about 1,157 years for the best estimate of the average GWTT, and 260 years for the best estimate of the fastest path GWTT. These values appear to be below the 1,000 year regulatory level for the assumptions made.

6.0 SUMMARY AND RECOMMENDATIONS

It is the conclusion of this evaluation that a stochastically based technique appears to be appropriate for the evaluation of GWTT. While the approach used by Rockwell is considered to be theoretically acceptable, it should be pointed out that this is not an endorsement of the conceptual models that were selected by Rockwell, nor is it an endorsement of the results obtained in this particular use of the approach.

In fact, the reviewers consider that the results presented by Rockwell very significantly over-estimate the GWTT that a correct use of the available data would produce using the same analytical approach. In order to illustrate the magnitude of the differences, check analyses have been performed by the reviewers, with the following results:

Table 1 - Results of GWTT Evaluations

ORGANIZATION:	ROCKWELL (Review Report)	NUCLEAR WASTE* Uncorrected	Corrected
Groundwater Travel Times:			
Horizontal	50,000 yr	1,057 yr	160 yr
Vertical	30,000 yr	101 yr	101 yr
Total	80,000 yr	1,158 yr	261 yr
Exceedance Probabilities:			
10,000 years	78%	7%	2%
1,000 years	97%	50%	22%

*Note: "Uncorrected" means the mean average GWTT, computed using average parameters for entire flow path segments. "Uncorrected" means the mean shortest GWTT computed, using the fastest path available in each flow path segment.

Based on these results, the reviewers consider that there is a high likelihood that the BWIP site will fail the 1,000 year travel-time rule, based on current data. This is directly contradictory to the Rockwell evaluation.

Accordingly, it is the recommendation of the reviewers that the NRC Staff consider directing DOE to show cause why the RRL at the Hanford Site should not be disqualified, based on reasonable interpretations of the available data and the 10 CFR Part 960 requirement that the Department has set for all its potential repository sites. Alternatively, DOE should consider promptly building their case for a variance from the NRC's 10 CFR Part 60 performance objective for pre-emplacement groundwater travel time and should present that case to the Commission in a timely manner.

7.0 REFERENCES

Codell, 1985. Draft Generic Technical Position on Groundwater Travel Time (GWTT), U.S. Nuclear Regulatory Commission, November.

DOE, 1984. Draft Environmental Assessment Reference Repository Location, Hanford Site, Washington, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, December.

NRC, 1983. Draft Site Characterization Analysis of the Site Characterization Report for the Basalt Waste Isolation Project, NUREG-0960, U.S. Nuclear Regulatory Commission, Office of Nuclear Materials and Safeguards, March.

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ENCLOSURE 2

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

OCT 28 1986

MEMORANDUM FOR: Paul Hildenbrand, BWIP Project Manager
Repository Projects Branch
Division of Waste Management

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

Neil M. Coleman, WMGT
Division of Waste Management

SUBJECT: COMMENT ON NWC'S REVIEW OF "GROUNDWATER TRAVEL TIME ANALYSIS FOR THE REFERENCE REPOSITORY LOCATION AT THE HANFORD SITE," JUNE 13, 1986

In response to an NRC request, Nuclear Waste Consultants Inc. (NWC) reviewed the report entitled "Groundwater Travel Time Analysis for the Reference Repository Location at the Hanford Site," SD-BWI-TI-303 by P. M. Clifton. Clifton's report provided the technical basis for the pre-emplacement groundwater travel times that were stated by DOE in the Hanford Final Environmental Assessment (EA). NWC concluded that the groundwater travel times reported in SD-BWI-TI-303 are incorrect and that there is a low probability (between 20 and 50%) that the travel time at Hanford will exceed 1,000 years (letter from M. Logsdon to J. Pohle dated June 13, 1986, communication no. 65). Based on our review of the comments and SD-BWI-TI-303, we disagree with NWC's assertion that they have sufficient information about the Hanford site to conclude defensibly that the groundwater travel time will probably not exceed 1,000 years.

NWC's analysis is limited by two major aspects: (1) the analysis does not properly account for the large uncertainties associated with the hydrogeologic data base and groundwater travel time analyses for the Hanford site, and (2) it does not consider representative values of hydrogeologic parameters along flow paths and realistic conceptual models of the groundwater flow system. As we discuss in our comment about the groundwater travel time analyses in the Hanford EA, high levels of confidence cannot be assigned to estimates of groundwater travel time at Hanford because of the limited hydrogeologic data base and of concerns about analyses and interpretations presented in the final EA. This conclusion recognizes the large uncertainties presently associated with hydrogeologic conceptual models, testing methods, data analyses, interpolation and extrapolation of parameter values, and application of fracture flow theory at the Hanford site. Thus, it is premature to place any significant amount of credibility in current estimates of groundwater travel time at Hanford, including those prepared by DOE and NWC.

In addition, NWC's independent estimates of groundwater travel time at Hanford are overly conservative because they do not consider a realistic conceptual model of the groundwater flow system and representative values of hydrogeologic parameters (e.g., hydraulic conductivity and effective porosity) along flow paths. These two limitations of NWC's analyses tend to underestimate groundwater travel times.

The staff considers that NWC's review conclusions are boldly overstated given the large uncertainties associated with any current estimates of groundwater travel time at the Hanford site. We recognize that the hydrogeologic system at Hanford is complex and that additional data and analyses are necessary before satisfactory resolution of this issue can be attempted. We will request a response to our comments from NWC. Please contact us if you have any questions about our comments.

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

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Division of Waste Management

Enclosure:
NWC Review of SD-BWI-TI-303