ENCLOSURE 3

SUMMARY MEETING NOTES OF NRC BWIP HYDROLOGY REVIEW TEAM MEETING NOVEMBER 6-7, 1986

Introduction

The NRC BWIP Hydrology Review Team was met on November 6-7, 1986, to prepare for the upcoming BWIP Hydrology Data Review (December 2-5, 1986), to discuss the strategy for hydrologic testing described in NRC's BWIP Site Technical Position 1.1, and to discuss a review of "Groundwater Travel Time Analysis for the Reference Repository Location at the Hanford Site" (SD-BWI-TI-303) prepared by Nuclear Waste Consultants, Inc. (NWC). These notes summarize the results of the meeting.

Data Review

The Hydrology team proposed review teams for the upcoming BWIP Hydrology Data Review as follows:

A. Monitoring Installations

Lead: Mike Galloway, Terra Therma Inc. (for NWC)
Members: Roy Williams, Williams and Associates (W&A)
Fred Marinelli, Terra Therma Inc. (for NWC)
Michael Weber, NRC

B. Geologic Information (Related to Hydrogeologic Models)

Lead: Roy Williams
Members: Paul Davis, Sandia National Laboratory (SNL)
Mark Logsdon, NWC
Michael Weber, NRC
Harold LeFevere, NRC

C. Hydraulic Head Data

Lead: Gerry Winter, W&A
Members: Paul Davis, SNL
Mike Galloway, Terra Therma (for NWC)
Adrian Brown, NWC
Neil Coleman, NRC
Dale Ralston, W&A
Harold LeFevere, NRC

D. Hydrogeologic Laboratory Testing Data (if available)

Lead: Adrian Brown, NWC
Members: Neil Coleman, NRC
Michael Weber, NRC
Gerry Winter, W&A

E. Hydraulic Testing Data

Lead: Dale Ralston, W&A
Members: Paul Davis, SNL
Fred Marinelli, Terra Therma (for NWC)
Adrian Brown, NWC
Harold LeFevere, NRC
Michael Weber, NRC

F. Hydrochemistry Data

Lead: Mark Logsdon, NWC
Member: Neil Coleman, NRC

STP 1.1

The group concluded that STP 1.1 still provides a viable strategy for hydrologic testing at the Hanford site, although it could be supplemented to provide for characterization of effective porosity and resolution of other significant aspects of site hydrogeology. The strategy is compatible with both deterministic and deterministic-stochastic approaches to predict groundwater travel times.

NWC's REVIEW OF SD-BWI-TI-303

The group discussed the review performed by NWC of the document entitled "Groundwater Travel Time Analysis for the Reference Repository Location at the Hanford Site" (BWI-SD-TI-303). Adrian Brown summarized NWC's review and the technical details of NWC's calculations of pre-waste emplacement groundwater

travel times for the Hanford site. The discussion resulted in the following positions:

NWC (as stated in NWC's review of June 13, 1986)

It is unlikely that the Hanford site meets the 1000-year pre-emplacement groundwater travel time criterion based on an analysis using existing information.

NRC Staff

Available information is insufficient to determine whether the Hanford site meets the 1000-year pre-emplacement groundwater travel time criterion.

The NRC staff position is endorsed by Williams and Associates and Paul Davis of the Sandia National Laboratory. NRC staff will request that NWC respond to comments made about the NWC analysis as directed by the NRC staff. NWC's response will identify the assumptions upon which their analysis is based, the suporting data, and a discussion of the uncertainties associated with the groundwater travel time calculations.

Approvals

For Nuclear Waste Consultants, Inc.: Mark J. Logsdon, Project Manager 86/11/07

For Williams and Associates, Inc.: Roy E. Williams 86/11/07

For the NRC staff: Tilak R. Verma 86/11/07

ENCLOSURE 4

NOV 25 1986

Mr. Mark J. Logsdon, Project Manager
Nuclear Waste Consultants
8341 So. Sangre de Cristo Road
Suite 6
Littleton, Colorado 80127

RE: BWIP

Dear Mr. Logsdon:

After detailed examination of your review of "Groundwater Travel Time Analysis for the Reference Repository Location at the Hanford Site" (SD-BWI-TI-303) and our subsequent meeting with you on November 7, 1986, the NRC staff disagrees with your position that the pre-waste emplacement groundwater travel time at the Hanford site probably does not meet the 1000-year groundwater travel time criterion based on your analysis using existing information. As summarized in the enclosed memorandum to Paul Hildenbrand dated October 28, 1986 (Enclosure I), and discussed in the November 7 meeting (see Enclosure II), the NRC staff considers that current uncertainties are too large to assign high levels of confidence to any estimates of groundwater travel time at the Hanford site. The staff's conclusion recognizes the large amount of uncertainty associated with the hydrogeologic data base, conceptual groundwater flow models, and groundwater travel time analyses for the Hanford site.

As agreed in the November 7 meeting, please provide the NRC with (1) a detailed description of the assumptions you made in your calculation of groundwater travel times for the Hanford site, (2) an assessment of the uncertainties associated with your calculated groundwater travel times, and (3) an evaluation of the sufficiency of the data base used for calculating groundwater travel times in SD-BWI-TI-303 and your analysis. I request that you respond to me in writing on or before December 19, 1986. This effort should require no more than one staff week of effort. If you conclude that additional effort is necessary to respond to this request, please contact me immediately to discuss this matter further.

The action taken by this letter is considered to be within the scope of the current contract NRC-02-85-009. This letter does not authorize changes to the

NOV 25 1986

cost or delivery of contracted services or products. Please contact me immediately if you believe this letter would result in changes to cost or delivery of contracted products.

Sincerely,

Jeffrey A. Pohle, Project Officer
Geotechnical Branch
Divison of Waste Management

Enclosures:
As Stated

cc: Mary Little, ACB

ENCLOSURE 5

NUCLEAR WASTE CONSULTANTS INC.
8341 So. Sangre de Cristo Rd., Suite 14
Littleton, Colorado 8012?
(303) 9?3-?49?

January 15, 1987

009/2.3/NWC.002
RS-NMS-85-009
Communication No. 129

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 B (RS-NMS-85-009)

Re: **NWC Re-Review of Clifton's BWIP GWTT Analysis**

Dear Mr. Pohle:

This cover letter transmits to the NRC staff Nuclear Waste Consultant's (NWC) Re-Review of "Groundwater Travel Time Analysis for the Refernce Repository Location at the Hanford Site", by Peter Clifton (SD-BWI-TI-303). The original copy of the review is being transmitted to the NRC Project Officer by Federal Express; the additional required copies will be transmitted by regular mail.

The initial NWC review of Clifton's paper was submitted on June 13, 1986 as NWC Comunication No. 65, in response to written direction from the NRC Project Officer (Letter from J. Pohle (NRC) to M. Logsdon (NWC), dated May 5, 1986). The conclusions of the original NWC review were considered by the NRC staff, and their response is contained in an internal staff memorandum dated October 28, 1986 (Memorandum from M. Weber and N. Coleman (WMGT) to P. Hildenbrand (WMRP), dated October 28, 1986). The Weber/Coleman memorandum states that "... 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." As a result of this memorandum, on November 7, 1986, management of the Division of Waste Management (DWM) requested that Mr. Adrian Brown, President and Technical Director of NWC, make a presentation explaining the findings of the original review. Mr. Brown made his presentation in the DWM offices, Willste Building, Silver Spring, Maryland, on November 8, 1986.

The attached report has been prepared at the request of the NRC Staff (Letter from J. Pohle (NRC) to M. Logsdon (NWC), dated November 25, 1986), and constitutes NWC's written response to the criticisms set out in the NRC's internal memorandum. The present report reevaluates the finding of the original NWC review that "...there is a low probability that GWTT will exceed 1,000 years..." at the Hanford site. In particular, the re-review addresses the NRC Staff's direction that (1) assumptions made in the NWC evaluation be documented and their impact on the result be evaluated; (2) an assessment be made of the uncertainties associated with the NWC-computed groundwater travel time; and (3) an evaluation be made of the sufficiency of the database used for calculating groundwater travel times in both the NWC and Rockwell reports.

Because of the sensitivity of the NRC concerns, NWC designated the re-review as an NWC QA-Level 1 report, per the terms of our project-specific quality assurance plan. The document has received detailed review by five reviewers (including complete, independent assessment of all mathematics by two different reviewers from two different organizations) and has also received additional peer review of the body of the text by key members of all three subcontractor organizations.

Nuclear Waste Consultants considers that the attached report responds fully to the written direction of the NRC Project Officer and that, in addition, it responds fully the criticisms raised in the NRC internal memorandum. Based on the very extensive reevaluation, NWC restates the conclusion of its review of "Groundwater Travel Time Analysis for the Refernce Repository Location at the Hanford Site", by Peter Clifton (SD-BWI-TI-303) as follows:

> Based on the review results, the reviewers consider that there is a significant likelihood that the BWIP site will fail the 1,000-year travel time rule as currently interpreted in the NRC's draft technical position. This is directly contradictory to the Rockwell evaluation.

If you have any questions concerning this letter or the attached report, please contact me immediately.

Respectfully submitted,
NUCLEAR WASTE CONSULTANTS, INC.

Mark J. Logsdon

Mark J. Logsdon, Project Manager

Att: Re-Review of Clifton's Groundwater Travel Time Evaluation

cc: US NRC - Director, NMSS (ATTN: PSB)
DWM (ATTN: Division Director) - 2
Mary Little, Contract Administrator
WMGT (ATTN: Branch Chief)

L. Davis, WWL
J. Minier, DBS
M. Galloway, TTI

ENCLOSURE 6

REPORT TO

NUCLEAR REGULATORY COMMISSION

ON

RE-REVIEW OF CLIFTON'S GROUNDWATER TRAVEL TIME EVALUATION

Prepared by

Adrian Brown, Nuclear Waste Consultants

Report 1074/86/2

January 13, 1987

8702200418 44 pp.

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1.0 INTRODUCTION

In April, 1986, Rockwell Hanford Operations released a report entitled "Groundwater Travel Time Analysis for the Reference Repository Location at the Hanford Site", authored by P.M. Clifton (Clifton, 1986). This document was the fifth in a series of reports setting out the evaluation of groundwater travel time for the Hanford site. Such an analysis allows evaluation of 10 CFR 960.4-2-1 (d), which requires that "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 pathway of likely and significant radionuclide travel." The document was used as support for the following finding in the Final Environmental Assessment (FEA): "...there is a high likelihood (i.e., a probability of at least 0.97) of pre-waste emplacement ground-water travel time to the accessible environment exceeding 1,000 years." (DOE, 1986, p. 6-100). Based on this finding, the DOE concluded that "The evidence does not support a finding that the reference repository location is disqualified (Level 1)." (DOE, 1986, p. 2-80).

At the request of the NRC made by letter dated May 5, 1986, Nuclear Waste Consultants reviewed the Clifton report as part of support for the review of the FEA. This review, performed by Adrian Brown (NWC) and Catherine Kraeger-Rovey (Terra Therma Inc), was presented to the NRC under a covering letter dated June 13, 1986. The text of this original report is presented as

Appendix A to this report. The NWC review disagreed with the Clifton conclusions and concluded instead that there was a relatively low probability that the GWTT along the fastest path of likely radionuclide travel would exceed 1000 years.

The conclusions of the review were considered by the NRC staff, and their response is contained in a memorandum dated October 28, 1986, which stated that "..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." (memorandum by M. Weber and N. Coleman dated October 28, 1986 - copy in Appendix B). As a result of this memorandum, on November 7, 1986 a presentation was requested of Mr. Brown to explain the findings of NWC. This presentation was made in Silver Spring on November 8, 1986.

This report has been prepared at the request of the NRC staff (letter J. Pohle to M. Logsdon dated November 25, 1986 - copy in Appendix B), and constitutes the requested response to the criticisms set out in the above internal memorandum. The present report re-evaluates the finding of Nuclear Waste Consultants review of the Clifton paper that "...there is a low probability that GWTT will exceed 1,000 years..." at the Hanford site (NWC, 1986). In particular, it was requested that (1) any assumptions made in the NWC evaluation be documented, and their impact on the result be evaluated; (2) that an assessment be made of the uncertainties associated with the NWC computed groundwater travel time, and (3) an evaluation be made of the

sufficiency of the database used for calculating groundwater travel times in both the NWC and the Rockwell report.

2.0 APPROACH

The approach to this additional evaluation is to revisit those matters that are called into question by the Weber/Coleman memorandum. These criticisms of the NWC review are stated as follows:

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."

2. "[The analysis] does not consider representative values of hydrogeologic parameters along flow paths and realistic conceptual models of the groundwater flow system."

The re-review will conclude by addressing the statement in the NRC memorandum 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."

It should be noted that there appears to be no disagreement that the Clifton analysis overestimates the GWTT, and the ability of the Hanford site to meet the regulatory requirement. The matter at issue is whether the supportable GWTT is so much lower than the Clifton value that failure of the regulatory requirement was likely. Accordingly this re-review will not repeat the evaluation of the Clifton analysis, except to the extent necessary to

re-evaluate the NWC analysis. The original review is included for reference as Appendix A.

3.0 SUMMARY OF FINDINGS

The re-review text is relatively long, as it is intended to be exhaustive. This summary of the key aspects of the BWIP GWTT evaluation are presented here, so that the reader may be aware in advance of where the presentation is leading.

3.1 CONCLUSIONS OF ORIGINAL REPORT

The analysis performed by Clifton concluded that the pre-emplacement GWTT for the Hanford site is in the order of 50,000 years, with a 97% chance that it will exceed 1,000 years, and would therefore have a high probability of passing the DOE siting requirement (10 CFR 960.4-2-1(b)(1)). Based on this finding, the DOE concluded that the site should not be disqualified.

3.2 CONCLUSIONS OF ORIGINAL NWC REVIEW

In order to check the reasonableness of this conclusion, NWC performed a simple check analysis and concluded that the pre-emplacement GWTT for the fastest path at Hanford was likely to be less than 1,000 years, and would therefore have a significant probability of failing the NRC regulatory requirement (10 CFR 60.113) and the DOE siting requirement

(10 CFR 960.4-2-1(b)(1)). Based on this result, the DOE finding was questioned.

3.3 THE RE-REVIEW

The re-review concentrates on the confidence issue. How confidently can conclusions be drawn using a performance measure (in this case GWTT) which is presently very uncertain? The re-review looks at the sources and magnitude of the uncertainty in the derived quantity (the GWTT), and of the uncertainty in the regulatory measure (the probability that the GWTT along the fastest path will exceed 1,000 years). In reading this analysis it is important to distinguish between these two uncertainties: only the latter is of importance in the context of 10 CFR 60 and 10 CFR 960.

The key findings of the re-review include the following:

1. The main non-parametric uncertainty in the analysis is the identification or selection of the "fastest path" of groundwater travel. The Clifton analysis considers only flow in the Grande Ronde basalts. This is considered to have the potential to greatly overestimate the GWTT, as overlying flow tops are considerably more permeable than those in the Grande Ronde. In order to err (where necessary) on the side of giving the DOE the benefit of the doubt, the NWC analysis made the same simplification. However it is

considered that the _fastest path_ would in all likelihood involve the higher permeability flows of the Wanapum formation.

2. The main parametric uncertainty in the analysis is the selection of a value of porosity. GWTT is proportional to porosity, so that the larger the porosity, the longer the GWTT. There is only one reported direct test of porosity of the Columbia River Basalts on site, and it produced a value of about 0.016%. If flow is confined to the Grande Ronde Formation, it is computed that the site would pass the NRC regulatory standard if the effective porosity along the flow path could be shown to be greater than 0.07%. If the fastest path enters the Wanapum Formation, the required porosity to meet the regulatory standard would be even greater than 0.07%. For additional testing to demonstrate that the effective porosity is greater than 0.07%, more than 90% of the future test values would need to exceed the present test value, and more than 50% of the test values would need to produce a large scale porosity in excess 0.07%. Based on what is known of porosity in fractured rock media, this is considered to be an unlikely outcome of testing. Accordingly it is considered unlikely that the actual "fastest path" will meet the proposed regulatory test.

Based on the re-review, NWC re-states the review conclusion as follows:

"Based on the review results, the reviewers consider that there is a significant likelihood that the BWIP site will fail the 1000 year travel time

rule as currently interpreted in the NRC's draft technical position. This is directly contradictory to the Rockwell evaluation."

4.0 RE-EVALUATION OF FINDINGS OF NWC REVIEW

4.1 METHODS OF ACCOMMODATING UNCERTAINTY IN GWTT COMPUTATIONS

4.1.1 The "Conservative" method of accommodating uncertainty

There are a number of ways of taking uncertainty into account in an evaluation. The traditional way is to select a conservative (or "the" conservative) value of each of the important parameters in the analysis, and to compute a conservative result for the derived quantity, in this case GWTT. However the determination of what is "conservative" can be difficult. This is because the definition of "conservative" depends on what hypothesis is being tested.

In the Clifton report, the hypothesis being tested was that there was a high probability that the GWTT exceeded 1,000 years. For this purpose, "conservative" assumptions are those that tend to underestimate the GWTT; if this underestimate of GWTT produces a positive result for the hypothesis, then presumably so would the "actual" answer, because it would be even higher. This is the approach that the Clifton report claims to use where there is uncertainty about a parameter that is not included explicitly in the statistical portion of the analysis.

For the purposes of the original NWC review, the hypothesis being tested was that there was a significant probability that the GWTT would be less than

1,000 years. This is fundamentally different from the Clifton hypothesis. For the NWC hypothesis, a "conservative" assumption is one which tends to overestimate the GWTT; if this overestimate of GWTT is significantly likely not to exceed 1,000 years, then presumably the "actual" GWTT is even less likely to meet the standard. This is therefore the approach to conservative or bounding estimation that is used in the original review, and in this re-assessment.

4.1.2 The "Statistical" method of accommodating uncertainty

The issue of what is "conservative" is avoided if it is possible to determine the nature of the variability and the uncertainty associated with each of the important components of a derived quantity. For the purposes of this document, this approach will be described as the "statistical" approach. In the statistical approach the entire population of information on each relevant component is incorporated in the analysis, and the uncertainty in the components is then reflected in the calculated uncertainty of the derived quantity. The use of this approach is standard in reliability engineering, and application in the earth sciences has been set out in detail in two books by Harr (1977, 1987).

The population of information that is available on a particular component of the analysis can be described in statistical terms, using as many moments of the distribution of the information that are desired. Using these descriptive statistical parameters, the corresponding parameters of the computed quantity

(in this case the GWTT) can be calculated. In this way an estimate of the uncertainty in the computed quantity can be made by carrying the component uncertainty through the computation. If desired, the uncertainty in the statistical parameters can also be derived, and the uncertainty in the estimate of uncertainty can also be computed (however it is usually small compared to the uncertainty in the computed quantity).

4.1.3 Approaches used in computation of GWTT

Both the Clifton and the NWC analyses use a mixture of the "conservative" approach and the "statistical" approach: both use the "statistical" approach for the inclusion of parametric variability and uncertainty into the analyses, and both use the "conservative" approach for the inclusion in the analysis of uncertainty about flow paths and conceptual models.

4.2 PROPER ACCOUNTING FOR UNCERTAINTIES IN PARAMETERS AND ANALYSES

The initial Weber and Coleman criticism of the review is that it "does not properly account for large uncertainties associated with the hydrogeologic database and groundwater travel time analyses for the Hanford site" (emphasis added). It is presumed that the term "properly" is here used in an analytical sense.

The handling of uncertainty in the review document is rigorous, as set out on page 23 of the review. In that section the uncertainty in the GWTT result is

shown to be directly related to the variability of the parameters which are used to compute the GWTT. Note that the accuracy of the relationship presented (for uncorrelated components):

Variance of the log of GWTT

= Sum of the variances of the logs of the components

is derived directly from the definitions of the first and second moments of any sample, and is not generally dependent on the form of the distributions of the logs of the components. This formula is supported in Appendix C. It is also shown in Appendix C by similar theoretical considerations that the variance of the log of the GWTT is greater if any of the components are positively correlated with each other, so if the uncorrelated components are used, this will produce (for the NWC analysis) a conservative (lower) degree of variance than would result from assumptions of correlation.

It is significant that the application of this simple approach does indeed produce values of variance for the GWTT that are close to those derived from the Clifton numerical analyses (Appendix D). That these two radically different approaches produce essentially the same estimate of variability in the result is considered to be generally supportive of both, and indicative that the method of computing variance in GWTT does not introduce significant uncertainty into the evaluation of regulatory compliance.

4.3 CONSIDERATION OF CONCEPTUAL MODELS

The "conservative" approach is taken to accommodate uncertainties in the conceptualization of the fastest pre-emplacement flow path. As noted above, the conservatism appropriate to the NWC analysis is that which produces an upper bound estimate of GWTT (i.e. GWTT essentially equal to or greater than the actual value), as we were testing the hypothesis that the site would have a significant probability of failing the GWTT performance standard.

The NWC conceptualization of the flow paths analyzed includes the following elements:

1. flow takes place in the Grande Ronde Basalt;
2. flow is mainly in the flow tops;
3. flow in the vicinity of the RRL may be in any direction; and
4. the flow path is highly heterogeneous with respect to flow parameters.

These four simplifications were made to allow a simple check of the Clifton analysis. Accordingly they are not considered to be assumptions, in the sense that there is any implication that they involve an act of faith. However the reviewers consider that an analysis performed using these simplifications will be conservative (i.e. will produce longer GWTTs) when compared to a more detailed and exact evaluation which does not make these simplifications, for

the reasons set out below. If it can be shown that the simplifications do indeed lead to an overestimation of GWTT, and if the GWTT computed using these simplifications is not likely to exceed 1,000 years, then refinements (for example by obtaining more precise parameters, by better definition of actual flow paths, or by performing more accurate analyses) will simply more strongly confirm this conclusion.

The degree of conservatism or lack of conservatism that each introduces into the final evaluation is considered below.

4.3.1 Flow takes place in the Grande Ronde Basalt.

There have now been several evaluations of likely flow from the repository to the accessible environment based on existing information developed in the Basalt program at Hanford. These analyses include evaluations performed by Rockwell, Golder Associates, Sandia, Battelle, and the NRC staff. In each of these evaluations, the predominant pre-emplacement groundwater flow pathway has been lateral, generally in the first few flow tops above or below the repository. Relatively few paths have penetrated far into the overlying Wanapum formation, and relatively few paths have moved substantially below the repository horizon. The Clifton analysis makes the simplification that flow remains within the Grande Ronde formation.

Perhaps the most direct evaluation of the likely flow paths that has been performed to date was presented in Appendix D of NUREG-0960 (it should be noted that these computations were for repository location in the Umtanum

flow, well below the present proposed repository host flow - the Cohassett). In this evaluation a wide range of parametric values for flow tops and interiors were selected, using measured head gradients at the site. The result of the analyses was that lateral flow was the dominant pathway for all but a very few paths. Those paths for which the vertical flow component was significant (that penetrated far vertically above the repository horizon) were found to be considerably the fastest paths analysed. The reason for this was found to be that the hydraulic conductivities of the flow tops (in which most of the transit time occurs) happens to increase significantly as one moves upward from the repository horizon, so that the velocity of lateral movement increases in the higher elevation flow tops. This matter is taken up in more detail in Section 4.4.2 of this re-review.

In the NWC evaluation, the simplification that flow remains in the Grande Ronde was conservative as the simplification produces slower groundwater velocities and longer GWTTs than if all possible pathways were considered. As the hypothesis being tested by NWC was that the GWTT has a significant probability of being below 1,000 years, any conservatism requires erring on the side of longer travel times. However in the Clifton case this same simplification is unconservative, because that analysis was attempting to demonstrate that the GWTT was significantly more than 1,000 years, yet a simplification was made that tends to overestimate the GWTT.

This simplification is very conservative with respect to the NWC hypothesis, and very unconservative with respect to Clifton's. Based on the data

presented by Rockwell (Strait and Mercer, 1986, reproduced as Appendix E) and data collected by the NRC at data reviews, the geometric mean of the transmissivity of the flow tops in the lower portion of the Wanapum (the Frenchman Springs Member) is more than 100 times higher than that in the flow tops in the portion of the Grande Ronde adjacent to and above the proposed repository horizon (Appendix F). Thus for those few flow paths that indeed penetrate the Wanapum, the flow times are very short when compared to those in the Grande Ronde flow tops. As the regulatory rule (10 CFR 60) is written in terms of the "fastest path" and the siting guidelines (10 CFR 960) are written in terms of "any pathway", it might be more reasonable when considering the regulatory test to look at pathways that enter the Wanapum as likely being the fastest, and to therefore include them in the analysis. However, in line with Clifton's analysis, this was not done in the review analysis.

4.3.2 Flow is mainly in the flow tops

This simplification is in accord with findings presented in the Clifton report, NUREG-0960, and the NWC review. All show that the time spent in the dense interiors by pre-emplacement water is a small percentage of the time spent in the adjacent flow tops (almost always in the range of 5% to 10%). Accordingly, the NWC simplification was to ignore the GWTT in the flow interiors on the grounds that it is negligible. With respect to the NWC analysis, this presumption is somewhat unconservative, in that ignoring the GWTT in the interiors produces a somewhat lower GWTT than is obtained when it

appear to be a strong lateral gradient in any direction in the vicinity of the RRL, so that the simplification appears to be reasonable. There does, however, appear to be a significant vertically upward gradient in the RRL, which would drive flow upward.

This simplification is consistent with the two simplifications described above, and therefore has no incremental impact on the precision of the computed GWTT when it is made. This is because the above simplifications are equivalent to analysing the lateral travel time in an isotropic, heterogeneous flow system comprised of Grande Ronde flow tops. The gross gradient in the lateral direction in the RRL appears to be less than the gradient in the vertical direction, but the lateral gradient is common to the interiors and the flow tops, while almost all of the vertical gradient occurs in the flow interiors, due to their low hydraulic conductivity (NRC, 1983). Accordingly, in the flow tops, flow is essentially along the unit, rather than upward.

4.3.4 Flow path is highly heterogeneous with respect to flow parameters

The model used by NWC (and Clifton) lumped all transmissivity data obtained in flow tops in the Grande Ronde into one database for use in the analysis. This ensured that the full variability of the parameter was recognized in the analysis. However, it also ensured that the average transmissivity of the flow top would be relatively fixed with respect to the impact of new information, as the sample from which the mean was computed would be larger than that which would be considered if only one flow top were considered.

NWC has tested whether there is a significant difference between the Cohassett Flow top (which Clifton stated would have been used if enough data were available) and the rest of the flow top transmissivity data in the Grande Ronde. Based on the analysis presented in Appendix F, there is not a statistically significant difference in the geometric means of the transmissivities of the Cohassett and the non-Cohassett Grande Ronde flow tops. Therefore it appears statistically reasonable to use the entire dataset.

Finally, it appears reasonable to use the entire dataset because it is not clear which flow top the fastest flow path would actually lie in. What does appear from the available data is that there is great heterogeneity in the point values of transmissivity in any flow top, and that any path of flow will pass through a wide variety of different transmissivity sections. The test described in Appendix F indicates that the Grande Ronde flow tops are not significantly different with respect to this parameter. Accordingly, the use of all the data recognizes the full known variability of this parameter.

4.3.5 Summary of effects of simplifications of conceptual models

In summary, all relevant models were specifically included in the NWC conceptualization. While there can be no question that the actual path that groundwater is taking in the pre-emplacement situation has high uncertainty, this uncertainty is contained within the simplifications (or "assumptions") that have been made with respect to the analysis performed by NWC.

If the analysis performed using these simplifications produces a result which has an acceptable level of regulatory confidence, then the uncertainty associated with the conceptualization used in the analysis is not significant, no matter how large. Further, the simplifications made in the NWC review are consistent with those made by Clifton (whose work was being reviewed), and with the NRC's published analyses in NUREG-0960.

4.4 REPRESENTATIVENESS OF PARAMETERS ALONG FLOW PATHS

4.4.1 Key Parameters

The representativeness of parameters along flow paths is the core question relating to uncertainty, as the parametric variability and uncertainty is indeed large.

The equation for the GWTT along a given pathway is given by:

$$t = \mathrm{SUM}\left(\frac{L\ n}{k\ i}\right)_{\text{all segments}}$$

where:
t = groundwater travel time
L = length of path segment
k = hydraulic conductivity of path segment
n = effective porosity of path segment
i = hydraulic gradient of path segment

Using this relationship, and the conceptualization noted above, the key parametric information needed for the computation of GWTT is that relating to

each of the four parameters involved in the analysis. The extent to which each parameter was selected using representative values was detailed in the original review (pages 16 to 21).

Clearly, as a result of the simplifications made, and justified above, the values of interest were values in the Grande Ronde, values in flow tops, and values near the RRL. When such values were not available, the best information, both testing and theoretical, had to be used. In general, there is adequate information to define a best estimate of the mean, and of the standard error of the mean. However in some cases the standard error of the mean had to be estimated. This estimate is also a "best" estimate, and is itself subject to error. It is possible to also estimate the standard error of the standard error, and carry this uncertainty through the analysis. A trial of this approach indicated that the impact of this error on the estimate of the median of the GWTT, and the standard error of the GWTT, is so small as to be negligable. Accordingly the results of this refinement is not presented here.

The following sections present a discussion of the extent to which the available data can be considered representative of site conditions.

4.4.2 Hydraulic Conductivity

The hydraulic conductivity distribution was taken from data used by Clifton, which was taken from Strait and Mercer (1986). A copy of this document is included in Appendix E for reference. It is suggested that this information

was the best data available at the time of the performance of the analysis. Back evaluation of the statistical parameters relating to these data suggested to the reviewers that they were reasonable.

The data used from Strait and Mercer (1986) is by no means all of the information on the hydraulic conductivity of flow tops in the Grande Ronde basalts that have been published by DOE. As part of the database preparation task of contract RS-NMS-85-009, NWC has collected as much of the available data on hydraulic conductivities as can be obtained. While the published quality assurance level of the great majority of the results is relatively low, and while NWC has not yet seen the original data for most of the testing and thus cannot warrant the reasonableness of the results, it is considered that the database, by virtue of its sheer size, does allow some conclusions as to the nature of the hydraulic conductivity of the Grand Ronde flow tops to be made.

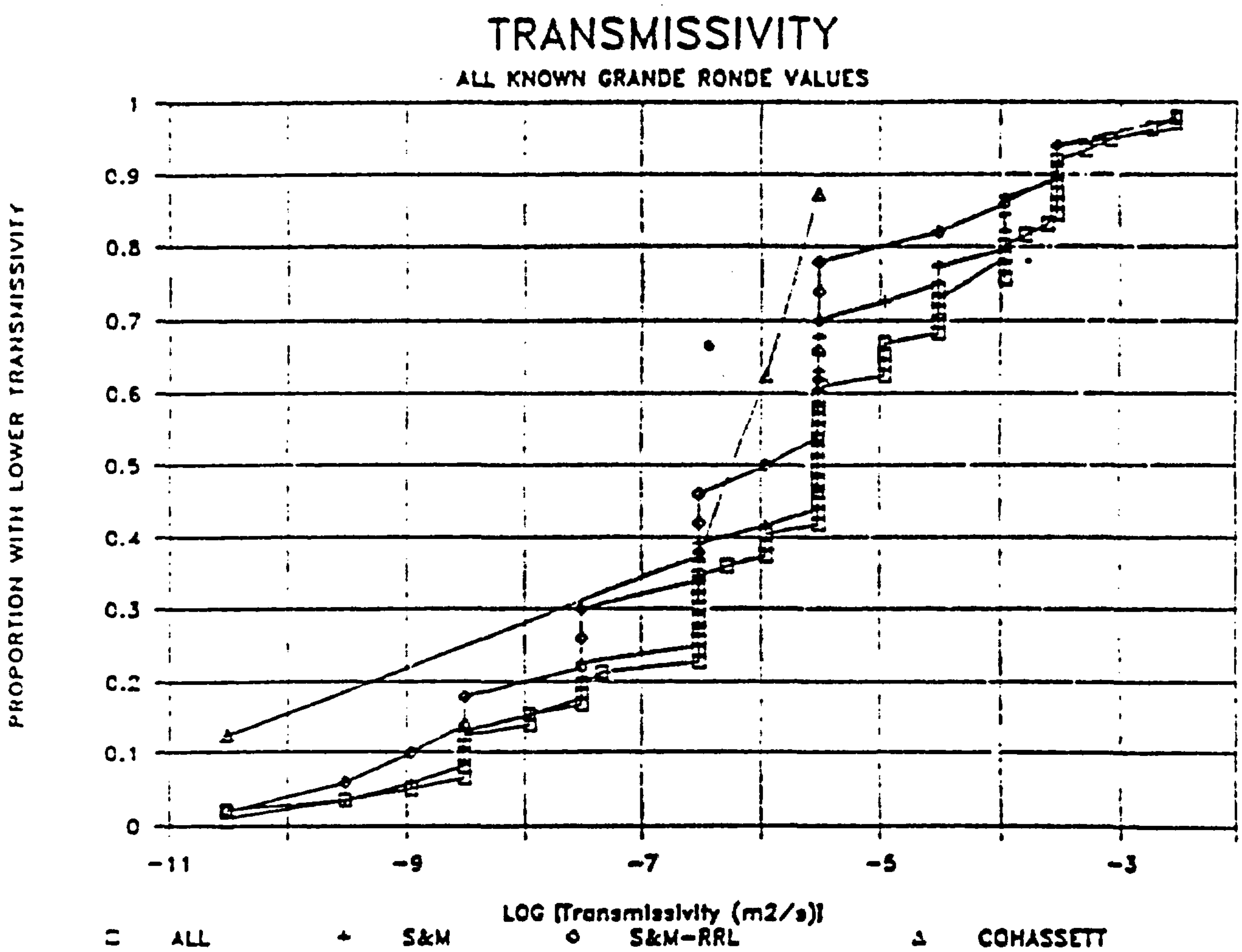
The results collected by NWC are indicated in Table 1. This information has been taken from the NWC database, which is described in (TTI, 1986). Of the 64 different values in the database, 45 (70%) are taken from Strait and Mercer (1986), 28 (44%) are from relatively close to the RRL (i.e. excluding DC-14 and DC-15 as was done by Clifton), and 5 (8%) are from the Cohassett flow top relatively close to the RRL. The relationship between the distributions of the values is of considerable concern. The cumulative distributions (made symmetrical for plotting purposes) are presented in Figure 1. Inspection of these curves indicates that the overall data appears to be approximately

log-normal. Further, the distributions of the overall database, the portion taken from Strait and Mercer (1986), and the portion of the Strait and Mercer (1986) data that are also relatively close to the RRL are all approximately the same distributions. The four values from the Cohassett Flow top, which is the flow top that Clifton wished to use in his analysis, but was prevented by the small number of samples, has a lower geometric mean transmissivity than the other three distributions.

Table 1 - Transmissivity Data Used in Review

TEST HOLE	GROUP	UNIT	BASALT STRUCTURE	TRANSMISSIVITY (m2/s)
DC-4	GR	COHASSETT	FT	3.00E-07
DC-5	GR	COHASSETT	FT	3.00E-07
DC-6	GR	?	IF	1.30E-05
DC-6	GR	UMTANUM	FT	3.00E-07
DC-6	GR	UMTANUM	FB	1.00E-05
DC-6	GR	?	IF	3.00E-05
DC-6	GR	?	FT	3.30E-06
DC-6	GR	?	IF	3.30E-09
DC-7	GR	?	IF	3.30E-09
DC-12	GR	?	IF	5.07E-07
DC-12	GR	?	FT	3.00E-06
DC-12	GR	ROCKY	FT	3.30E-05
DC-12	GR	ROCKY	IF	3.30E-05
DC-12	GR	?	FT	1.80E-05
DC-12	GR	?	FT	3.30E-03
DC-12	GR	?	FT	3.30E-04
DC-12	GR	?	IF	7.07E-04
DC-12	GR	ROCKY	FT	3.30E-08
DC-12	GR	UMTANUM	FT	1.07E-09
DC-14	GR	?	IF	3.00E-04
DC-14	GR	?	FT	3.07E-07
DC-14	GR	?	FT	3.00E-06
DC-14	GR	?	IF	1.30E-05
DC-14	GR	?	FT	3.30E-09
DC-14	GR	?	FT	3.00E-07
DC-14	GR	UMTANUM	FT	3.30E-05
DC-14	GR	?	FT	3.30E-06
DC-14	GR	?	IF	3.00E-05
DC-15	GR	?	FT	3.30E-06
DC-15	GR	?	FT	3.00E-03
DC-15	GR	?	FT	3.30E-06
DC-15	GR	?	FT	3.00E-04
DC-15	GR	?	FT	1.37E-10
DC-15	GR	?	FT	3.00E-08
DC-15	GR	?	FT	1.07E-06
DC-15	GR	?	FT	1.30E-05
DC-15	GR	?	FT	1.37E-10
DC-15	GR	?	FT	1.08E-08
DC-15	GR	?	FT	3.30E-07
DC-15	GR	?	IF	1.30E-05
DC-16A	GR	?	FT	1.07E-10
DC-16A	GR	?	FT	3.30E-06
DC-16A	GR	COHASSETT	FT	1.30E-06
DC-16A	GR	COHASSETT	FB	3.00E-09
DC-16A	GR	ROCKY	IF	3.30E-07
DC-16A	GR	UMTANUM	FT	3.00E-06
DC-16A	GR	?	FT	3.30E-07
MCGEE	GR	?	FT	3.30E-04
MCGEE	GR	ROCKY	FT	3.30E-04
MCGEE	GR	ROCKY	FB	3.00E-06
MCGEE	GR	COHASSETT	FT	1.61E-04
MCGEE	GR	COHASSETT	FB	1.09E-06
MCGEE	GR	ROCKY	FT	3.33E-06
MCGEE	GR	UMTANUM	FB	1.33E-06
RRL-2	GR	COHASSETT	FT	4.51E-08
RRL-2	GR	COHASSETT	FB	8.30E-04
RRL-2	GR	ROCKY	FT	3.30E-10
RRL-2	GR	UMTANUM	FT	3.16E-04
RRL-2	GR	UMTANUM	FB	3.34E-10
RRL-6	GR	COHASSETT	FT	3.00E-11
RRL-6	GR	COHASSETT	FT	3.30E-11
RRL-6	GR	COHASSETT	FB	3.00E-10
RRL-6	GR	UMTANUM	FT	3.30E-07
RRL-6	GR	UMTANUM	FB	3.44E-09
RRL-14	GR	COHASSETT	FT	3.30E-06
RRL-14	GR	COHASSETT	FB	3.00E-06
RRL-14	GR	UMTANUM	FT	3.30E-06
RRL-14	GR	UMTANUM	FB	[illegible]

Figure 1 - Distributions of Flow Top Transmissivities



In order to evaluate whether the apparent difference between the Cohassett flow top transmissivities and the overall Grande Ronde flow top transmissivities are statistically significant, a non-parametric rank-sum significance test was applied (Hoel, 1966). The procedure used is set out in Appendix F. Based on this test, the difference between the median values of the two distributions is not significant at the 10% level (the statistic indicates that the standard score of the test is $z=-1.05$, and the probability that the differences between the medians of the Cohassett and non-Cohassett flow top transmissivities are due to chance exceed 30%. Note that this test does not require any assumption about the nature of the distribution of the actual transmissivity population. Based on this finding, it is considered statistically acceptable to utilize the data from the entire set of Grande Ronde flow tops, rather than the very limited dataset available from any one flow top.

In addition, early evaluation of the large scale perturbations resulting from drilling indicate that the geometric means of the spot data do indeed give a reasonable estimate of the gross hydraulic conductivity of flow tops in the Grande Ronde.

There is great variability in the spot data used in this evaluation, but relatively little uncertainty in the estimate of the geometric mean of the hydraulic conductivity. The statistics that are determined from the data presented in Table 1 are presented in Table 2.

Table 2 - Statistics of Grande Ronde Flow Top Transmissivities

POPULATION	NO OF Ts	STATISTICS OF LOGARITHMS GEOM MEAN	STD. DEV.	S.E MEAN	MEAN OF TRANSMISSIVITY -95% LIMIT	GEOM MEAN	+95% LIMIT
All Grande Ronde flow tops	64	-.83	1.79	.22	.054	.150	.408
Strait/Mercer GR flow tops	45	-.91	1.88	.28	.033	.122	.451
Strait/Mercer GR FTs less DC14/15	29	-1.21	2.02	.39	.010	.061	.367
S&M GR FTs from Birkett & above	16	-1.00	1.87	.48	.011	.101	.935
S&M Cohassett FTs	5	-2.24	1.78	.89	.00009	.006	.347

The information used by Clifton in the reviewed report included a variety of the above distributions. For the purposes of checking whether the simple method of analysis used in the review produces essentially the same result as the more complex Clifton stochastic analysis, the case illustrated in Figure 5 of the report was analysed. For this case, the transmissivity and hydraulic conductivity data were as set out below:

Statistics: Geometric mean transmissivity = 0.12 sq. m./sec
Assumed flowtop thickness = 10 meters
Mean hydraulic conductivity = 1.2E-07 meters/second

In the course of attempting to reproduce the Clifton transmissivity statistics (which was not in general successful) it became clear that there were some potentially significant differences between the data published and the statistics reported by Clifton. This matter will be taken up separately from

this review. However, for the purposes of generating a GWTT that conforms to the simplifications outlined above, it was considered that the transmissivity data that was obtained in the portion of the Grande Ronde formation that is adjacent to, and above, the proposed repository horizon (the Cohassett flow bottom, the Cohassett flow top, and the Rocky Coulee Flow top) would be most appropriate. The statistics of this group of transmissivities are presented in the second last row of Table 1, and are:

Statistics: Geometric mean transmissivity = 0.101 sq. m./sec
Assumed flowtop thickness = 10 meters
Mean hydraulic conductivity = 1.17E-07 meters/second
S.D.(log hydraulic conductivity) = 1.87
Number of items in sample = 15
S.D.(log mean hydr.conductivity) = 0.483

4.4.3 Gradient

The gradient used in the NWC analysis was assumed to be log-normally distributed, positive, and small. The values were taken by Clifton from early readings at DC-19, 20, and 22. While Clifton assumed no variability in this parameter, NWC assumed that it did vary. The limits on the variability of this parameter at BWIP appear to result more from the inability to to measure slight head differences at great depth in the formation, rather than the actual variability of the measure itself. This parameter does not appear to be a major source of uncertainty with respect to the magnitude of GWTT.

Statistics: Geometric mean gradient = 2E-04

S.D.(log mean gradient) = 0.3

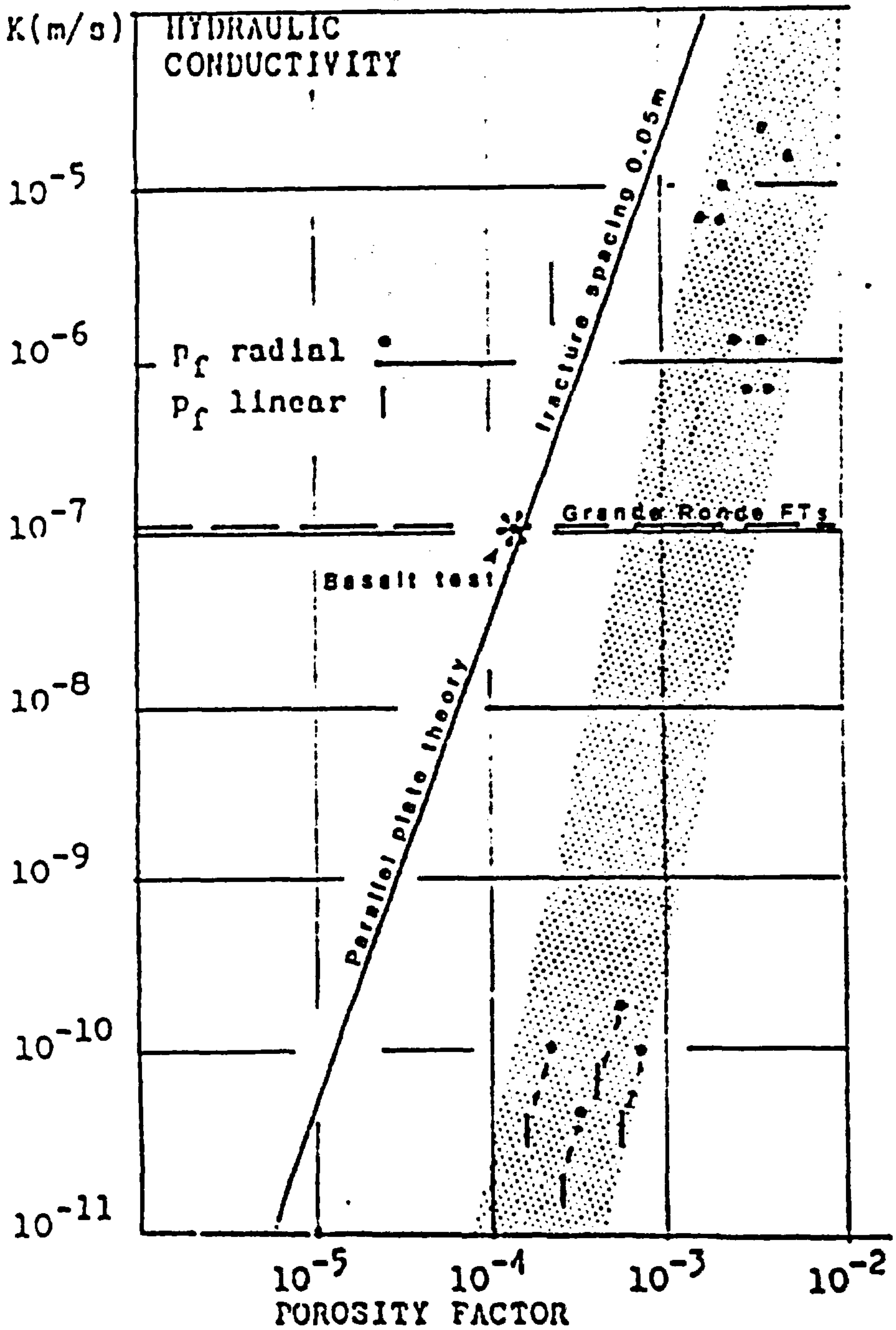
4.4.4 Porosity

The porosity of the Grande Ronde Flow Tops is clearly highly uncertain, as described in the original review (Appendix A, pp. 18-20). One test value is known to exist in all flood basalts, and it is very low by at least granular material standards (0.016%).

The test value is not inconsistent with published estimates and test results of fractured rock porosity. As noted in a recent paper on GWTT (Brotzen, 1986), the effective porosity of fractured granodiorite with an average hydraulic conductivity of 3E-6 meters per second was found to be about 0.3% (9 tests), and the effective porosity of fractured granite with an average hydraulic conductivity of 5E-11 meters per second was found to be 0.03% (4 tests). The geometric mean hydraulic conductivity of the flow tops of interest in basalt at Hanford is 1E-7, which would suggest a porosity value in the order of .1% would appear consistent with these test data. Theoretical considerations (Snow, 1968) based on parallel plate theory give some guidance on expected porosity. For an average hydraulic conductivity of 1E-07, the parallel plate theory porosity would be about 1E-04, about the same as the value reported for the basalt test. These two results are indicated on Figure 2, and are compared with the hydraulic conductivity information obtained for the Grande Ronde Flow tops of interest.

The distribution of the porosity of flow tops is of importance for the evaluation. Clearly not much is known about this, as there are relatively few test results, and only one in basalt. However theoretical considerations can provide some assistance in this matter. Porosity in the basalt flows is expected to be primarily the result of fractures. Bianchi and Snow (1969) indicates that fracture apertures in crystalline rock tend to be log normally distributed. It is therefore considered reasonable to assume that the porosity at depth at Hanford is log-normally distributed.

Figure 2 - Relationship between Porosity and Hydraulic Conductivity



In addition, it has been hypothesized that the porosity and hydraulic conductivity of fractured rock are related (Snow, 1968; Sharp, 1970; Brotzen, 1985). If this is so, then the distributions of these parameters would be expected to be the same. As it is accepted that the distribution of hydraulic conductivity in fractured rock is log normal, it seems reasonable to assume that the distribution of effective porosity is also log normal.

Two panels of DOE experts considered that the range of porosities that would be appropriate for fractured basalt would be from 0.01% to 1%, with normal distribution (Runchal et al, 1984a and 1984b). This was the mean and distribution used by Clifton. Based on this range and distribution, the mean porosity would be expected to be 0.505%, and the standard deviation about .25%. It should be noted that the one test value is, by these parameters, highly unlikely, but not significantly different in likelihood from a negative porosity.

Based on the above discussion, the parameters that characterize the porosity are not clear. Relatively good agreement exists that the size of the range of the distribution of the porosity is about two orders of magnitude, but there is disagreement on the mean porosity, and on the shape of the distribution. A summary of the ranges of statistics that are relevant to this review is given below:

Statistics: Geom mean porosity = 0.00016 (NWC) to 0.005 (Clifton)
S.D.(log mean porosity) = 0.3 (NWC) to 0.15 (Clifton)
Distribution = log-normal (NWC) to normal (Clifton)

Because of this range, porosity is considered a variable in much of this re-review, and the question is asked in the form: "What average porosity would be needed to demonstrate regulatory compliance?".

4.4.5 Summary of Representativeness of Parameters

In summary, NWC considers that the parametric values used in the review of the report were indeed representative, both with respect to including all the available information in the values (i.e. all that data that was used by Clifton, whose paper was being reviewed), and by making reasonable allowances for the uncertainty in the reliability values for the means. Whether these values are a good enough representation of the actual parameters to allow regulatory decision making cannot be determined prima facie: however computations of the probability of regulatory error can be made using the distributions presented, no matter how uncertain. An approach to such computations is presented in the review document, and in Appendix D to this document. Only by consideration of the regulatory decision can the adequacy of the data (for NRC's purposes) be assessed.

4.5 RECONSIDERATION OF NWC'S REVIEW CONCLUSIONS

As noted in the NRC memo, the NRC staff consider that the NWC conclusions are "boldly overstated". This criticism has been evaluated in Appendix D,

primarily by checking whether there is any reason to modify those conclusions made in the original review.

4.5.1 Rectification of computational error in original review

Re-analysis of the GWTT computations upon which the review conclusions were based identified an error in the original computations presented in the NWC review. A transcription error was made in the porosity that was used by Clifton, so that the apparent mean porosity that was transfered into the NWC computations for comparison was 5% rather than the 0.5% value which he actually used. This had the effect of causing the reviewers to mistake the impact that the heterogeneity of the aquifer had on the GWTT, which in turn caused them to over-estimate the extent to which the GWTT appeared to fail the regulatory standard. Quality assurance procedures modifications are presently under study to reduce the probability of a recurrence of this type of error; these efforts will be reported separately.

4.5.2 Re-assessment of GWTT assuming all flow in Grande Ronde

Re-evaluation of the computation, performed in a way that highlights the key uncertain parameter (porosity), indicates that the site would meet the regulatory standard based on NRC's draft guidance on GWTT if:

1. the flow remained entirely within the Grande Ronde flow, and

2. the mean effective porosity of the formation along the path of fastest groundwater travel could be demonstrated to be in excess of about 0.07%.

This value is:

1. exceeded by a factor of eight by Clifton's effective porosity, which explains his confidence that the standard will be met;

2. is about four times greater than the only test value, which explains why NWC considered that the site would appear to be likely to fail based on the present information; and

3. is slightly less than the geometric mean of the Clifton porosity range, which suggests that the site would marginally meet the regulatory standard under the assumptions that Clifton's range is reasonable, and that a log-normal distribution of the effective porosity is also reasonable.

4. is about the same as the expected value for fractured granites of similar hydraulic conductivity.

It seems possible that additional testing of the repository area could indeed result in new data that would result in the mean effective porosity ultimately exceeding 0.07%. In order for the new data to provide that increase from the existing value, 90% or more of the values would have to exceed the present value, and 50% or more would have to exceed 0.07%. Based on what is known of

actual porosities measured in fractured rock media of relatively low hydraulic conductivity, it appears unlikely that such a large change would occur.

4.5.3 Re-assessment of GWTT along fastest path

The proximity of the Cohassett flow to the top of the Grande Ronde formation raises the question as to the GWTT in a hybrid flow path partly in the Grande Ronde, and partly in the Wanapum. As demonstrated in Appendix F, the transmissivity of the lower Wanapum flow tops is statistically significantly greater (about 100 times) than the the transmissivity of the flow tops in the upper Grande Ronde. Accordingly, the lateral groundwater velocity in the Wanapum would be expected to be about 100 times faster than in the Grande Ronde. As a result of this finding, little or no credit will be able to be taken for GWTT in the Wanapum; this is equivalent to locating the accessible environment at the Vantage interbed for GWTT computation purposes.

It would appear that there is almost certain to be some pathways from the repository location to the accessible environment that pass into the Wanapum, as it is only about three flows distant. As the regulatory requirement is couched in terms of GWTT along the fastest path, the presence of the high transmissivity units in the Wanapum would require porosities in the Grande Ronde formation to be considerably higher than the 0.07% cutoff to ensure that the fastest travel time to the top of the Grande Ronde exceeds 1,000 years. Demonstration of effective porosities in the Grande Ronde in the vicinity of the RRL substantially in excess of 0.07% appears unlikely.

4.5.4 Summary of conclusions

In summary, there still appears to the reviewers substantial technical reasons to consider that it is more likely that the site will fail the GWTT performance standard than that it will pass it. It should be borne in mind that the NWC re-evaluation was deliberately intended to err, where simplifications were necessary, towards high GWTT values.

How boldly any conclusion can be drawn about the ability of a site to meet a regulatory condition depends to some extent on the impact of future data on the decision. Based on the above material, we consider that additional data collection will have several effects:

1. Additional information on hydraulic conductivity will reduce the uncertainty in the geometric mean of this parameter, thus somewhat reducing the mean GWTT that would be required for compliance with the regulatory standard (or, put another way, lowering the lower bound of acceptable mean porosity values). Given the current relatively large database of spot values, it does not seem likely that the distribution shape of the individual test values, or the geometric mean value will change significantly.

2. Additional data on gradient will likely not cause a modification in the gradient used in the analysis, or its uncertainty, due to the way that the regulatory guidance is framed.

3. Additional data on porosity has the possibility to substantially change the mean effective porosity, and hence the estimate of GWTT.

Based on these considerations, it would appear that while additional testing has the potential to change the GWTT estimate at Hanford, it appears that only demonstration of a geometric mean effective porosity substantially in excess of 0.07% has the potential to ensure a positive regulatory finding. In the opinion of the NWC reviewers this outcome still does not seem more likely than the failure of the site on the GWTT criterion.

However the revised analysis does cause the NWC reviewers to modify the original conclusion as follows:

"Based on the review results, the reviewers consider that there is a significant likelihood that the BWIP site will fail the 1,000 year groundwater travel time requirement as currently interpreted in the staff's draft technical position. This is directly contradictory to the Rockwell evaluation."

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APPENDIX A - TEXT OF ORIGINAL NWC REVIEW OF CLIFTON'S PAPER

U.S NUCLEAR REGULATORY COMMISSION
OFFICE OF RESOURCE MANAGEMENT

REVIEW OF
GROUNDWATER TRAVEL TIME ANALYSIS FOR THE REFERENCE REPOSITORY LOCATION AT THE HANFORD SITE
SD-BWI-TI-303

JUNE 1986

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

June 13, 1986

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 B (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.

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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, 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 (78% 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.

6.2 COMPUTATION OF GWTT

6.2.1 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) $t_i = n_i L_i / q$

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) $q = H / k_e$

where q = flow through a unit area of all layers

H = total head loss across system = $\mathrm{sum}(H_i)$

k_e = effective vertical permeability = $\mathrm{sum}(L_i) / \mathrm{sum}(L_i / k_i)$

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 = $\mathrm{sum}(L_i) / \mathrm{sum}(H_i)$

k_e = effective vertical permeability = $\mathrm{sum}(L_i) / \mathrm{sum}(L_i / k_i)$

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

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

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 lower. 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 proposed 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 1.6×10^{-4}. The mean value assumed by Rockwell (5×10^{-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 DSCA (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^{-3} 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:

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

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:

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

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 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 BW[illegible]e 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 RWC 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:

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

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 1,250 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 250 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	72%	7%	2%
1,000 years	97%	50%	22%

*Note: "Uncorrected" means 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 Regulatoratory Commission, Office of Nuclear Materials and Safeguards, March.

NRC, 1985. NRC Comments on DOE Draft Environmental Assessment for the Hanford Site, U.S. Nuclear Regulatory Commission, March.

APPENDIX B - CORRESPONDENCE AND DIRECTION FROM NRC

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

NOV 25 1986

DEC 01 1986

Mr. Mark J. Logsdon, Project Manager
Nuclear Waste Consultants
8341 So. Sangre de Cristo Road
Suite 6
Littleton, Colorado 80127

12/8/86
FLC 1074

RE: BWIP

Dear Mr. Logsdon:

After detailed examination of your review of "Groundwater Travel Time Analysis for the Reference Repository Location at the Hanford Site" (SD-BWI-TI-303) and our subsequent meeting with you on November 7, 1986, the NRC staff disagrees with your position that the pre-waste emplacement groundwater travel time at the Hanford site probably does not meet the 1000-year groundwater travel time criterion based on your analysis using existing information. As summarized in the enclosed memorandum to Paul Hildenbrand dated October 28, 1986 (Enclosure I), and discussed in the November 7 meeting (see Enclosure II), the NRC staff considers that current uncertainties are too large to assign high levels of confidence to any estimates of groundwater travel time at the Hanford site. The staff's conclusion recognizes the large amount of uncertainty associated with the hydrogeologic data base, conceptual groundwater flow models, and groundwater travel time analyses for the Hanford site.

As agreed in the November 7 meeting, please provide the NRC with (1) a detailed description of the assumptions you made in your calculation of groundwater travel times for the Hanford site, (2) an assessment of the uncertainties associated with your calculated groundwater travel times, and (3) an evaluation of the sufficiency of the data base used for calculating groundwater travel times in SD-BWI-TI-303 and your analysis. I request that you respond to me in writing on or before December 15, 1986. This effort should require no more than one staff week of effort. If you conclude that additional effort is necessary to respond to this request, please contact me immediately to discuss this matter further.

The action taken by this letter is considered to be within the scope of the current contract NRC-02-85-009. This letter does not authorize changes to the

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cost or delivery of contracted services or products. Please contact me immediately if you believe this letter would result in changes to cost or delivery of contracted products.

Sincerely,

Jeffrey A. Pohle, Project Officer
Geotechnical Branch
Divison of Waste Management

Enclosures:
As Stated

cc: Mary Little, ACB