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Hydrogeology • Mineral Resources Waste Management • Geological Engineering • Mine Hydrology

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July 1, 1986
Contract No. NRC-02-85-008
Fin No. D-1020
Communication No. 67

Mr. Jeff Pohle
Division of Waste Management
Mail Stop 623-SS
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

RE: Detailed FEA Comments

Dear Jeff:
We have enclosed completed copies of the Hydrology Detailed Comment Resolution Forms for the NTS, BWIP, Deaf Smith, Davis Canyon, and Richton dome sites. Please call if you have any questions concerning these comments.

Sincerely,

Gerry

Gerry Winter

GW:sl

enclosures

WM-RES
WM Record File
D1020
W&A

WM Project 10, 11, 16
Docket No. ____
PDR ✓
LPDR ✓ (B, N, S)

Distribution:
JPohle

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3165

See D1020 7/1/86
J. Pohle: comments for sites

1. MAJOR COMMENT FOR NNWSI FEA

1.1 Travel Time Calculations

The NRC agrees with DOE that evidence does not support a finding that the site is disqualified under the condition that the groundwater travel time is less than 1000 years (960.4-2-1) but there are numerous uncertainties in travel time calculations which have not been addressed satisfactorily.

1.2 Development of the Conceptual Model

The conceptual model for water movement from the potential repository to the water table consists of vertically downward flow under unsaturated conditions. For the purpose of travel time estimates, water movement from the disturbed zone to the water table is assumed by the DOE to occur under steady-state conditions with a gradient of one.

Travel time values are critically dependent on the assumed magnitude of flux used in the calculations. In the draft EA, DOE used the geometric mean saturated hydraulic conductivity of 1 mm/year as the upper bound for flux for travel time calculations through the unsaturated zone. This value was criticized by NRC as being poorly supported. In the final EA (FEA), this upper bound has been reduced to 0.5 mm/year; a value supported by Wilson (1985). Wilson uses two sources of information to arrive at this number: 1) data from insitu level of saturation values combined with capillary pressure-saturation data from Peters and others (1984); these data result in calculated flux values in the Topopah Spring unit that vary from 10^{-7} to 0.5 mm/year; 2) data from an empirical method of estimating the ratio recharge/precipitation in arid regimes.

The first of these methods appears to be reasonable, but the NRC is not able to verify the 0.5 mm/year as an upper bound because of data not yet received. The second method is highly questionable because values of the ratio recharge/precipitation from other areas presented by Wilson vary from 0.019 to 0.35 for precipitation in the range of that measured at Yucca Mountain. The value of this ratio used by Wilson was 0.003 based on the Macey-Eakin method. Using the value of 0.003 results in a recharge of 0.45 mm/year while a value of 0.01 results in a recharge of 1.5 mm/year.

The NRC feels that the uncertainty in the values of flux must be considered in the analysis of travel time.

1.1.1 Matrix Versus Fracture Flow in Topopah Spring Unit

If the value of flux is less than the matrix saturated conductivity in the Topopah Springs unit it is assumed that flow does not occur in the fractures, thereby producing a large (>40,000 year) travel time. The NRC agrees with this analysis; however, it must be recognized that the wide variation in saturated hydraulic conductivity values reported by Peters and others (1984) (0.03 to 14.2 mm/year) indicates that there may be significant zones in the Topopah Springs unit in which the matrix saturated hydraulic conductivity is less than 0.5 mm/year. If such values occur throughout the entire thickness of the unit, fracture flow could occur at flux values less than 0.5 mm/year, thereby producing travel times <1000 years in certain areas of the Topopah Springs unit. A detailed discussion of the statistical analysis of the actual distribution of hydraulic conductivity is included subsequently herein.

In summary, the importance of the comparison between matrix saturated hydraulic conductivity and flux value in the Topopah Springs unit cannot be overemphasized because complete matrix flow provides a travel time estimate of greater than 40,000 years whereas complete fracture flow provides a travel time estimate of less than 100 years. Therefore, the spatial variability of saturated hydraulic conductivity and the uncertainty in the assumed value of flux must be accounted for correctly in the analysis.

1.3 Development of the Deterministic Mathematical Model

The analysis of travel time through the unsaturated zone at NNWSI was conducted by applying a standard equation to evaluate the velocity of water movement through unsaturated porous media. The equation is as follows:

$$v = (q/ne)(q/Ks)^{-1/\varepsilon}$$

where:

v = velocity
q = flux
ne = effective porosity
Ks = saturated matrix hydraulic conductivity
ε = an empirical constant that describes a pore-size distribution index

The validity of this equation for the purpose for which it is used in the FEA is accepted by the scientific community.

The DOE lists several major assumptions that were incorporated into their analysis of travel time for NNWSI. These assumptions are:

1. The unsaturated zone flux is vertical and uniformly distributed in time and space (i.e., a vertical hydraulic gradient of one).

2. The effective hydraulic conductivity through the matrix of any given rock volume adjusts by changes in saturation so that the effective conductivity exactly equal the flux.

3. At certain conditions of saturation, water probably does not move rapidly through fractures until flux approaches the saturated matrix hydraulic conductivity.

In addition to these major assumptions, the DOE assumes that flux through the Topopah Spring member is constant (steady-state flow) and that 0.5 mm/yr is the upper bound of the flux. The DOE assumes further that the 0.5 mm/yr flux is a conservative upper bound.

Of the assumptions listed above, the assumption of a constant flux of 0.5 mm/yr is most critical to the prediction of travel time. The significance of this assumption is illustrated by the fact that the mean saturated matrix hydraulic conductivity of the Topopah Spring member is given as 0.7 mm/year in Table 6-18 of the FEA. The 0.7 mm/yr value indicates that a significant number of measurements of saturated matrix hydraulic conductivity in the Topopah Spring member are less than 0.7 mm/yr and potentially are less than 0.5 mm/yr.

Fracture flow is initiated wherever the flux exceeds the saturated matrix hydraulic conductivity of the hydrogeologic units. This fact is important because fracture flow produces calculated travel times that are significantly lower than travel time through the matrix.

DOE assumes an effective porosity of 0.0001 for all fractures in the calculation of travel time. This value for effective fracture porosity was derived from information provided by Sinnock and others (1984). Sinnock and others (1984) estimated effective fracture porosity from the following relationship:

$$b = (12\ ps)^{0.333} \times 10^{6}$$

where:

s = distance between fractures in meters obtained by one divided by fracture density

p = permeability in m^2 or 3.2×10^{-18} times conductivity in mm/yr (Freeze and Cherry, 1979)

b = aperture in microns

The calculated effective porosity equals the fracture density times the fracture aperture in microns times 10^{-6}.

This estimate of effective fracture porosity assumes that all fractures participate in flow, where permeability equals 3.2×10^{-18} times flux in mm/yr. The assumption that all fractures convey flow equally may not be conservative, especially for flow in the unsaturated zone.

The evaluation of travel time from the disturbed zone to the water table for NNWSI requires calculating the velocity of water movement through each of the hydrogeologic units that exist beneath the proposed repository. These units include:

1. The undisturbed portion or the Topopah Springs welded unit
2. The Calico Hills vitric unit
3. The Calico Hills zeolitic unit
4. The Prow Pass welded unit
5. The Prow Pass non-welded unit
6. The Bullfrog welded unit
7. The Bullfrog non-welded unit.

The velocity of water movement through each hydrogeologic unit was calculated by solving the velocity equation for values of the measured hydrogeologic parameters for each unit. Total travel time was estimated by calculating the travel time through individual units and summing these travel times for all of the units that exist between the disturbed zone and the water table.

1.4 Deterministic Model with Stochastic Analysis

1.4.1 Input Parameters

The DOE made an effort to assess uncertainties in some of the hydrogeologic properties that control predicted groundwater travel times. A deterministic mathematical model was used in an iterative calculational procedure to produce a distribution of predicted travel times. Assumed or estimated variabilities (distributions) in some of the necessary hydrogeologic parameters were input into the model.

Input hydrogeologic parameters for the predicted groundwater travel time analyses were divided into two general categories: 1) those properties that were assumed to be constant; and 2) those properties that were assumed to be random variables. Inputs to the groundwater velocity calculations for matrix flow included the flux, the vertical hydraulic gradient, an empirical constant, the thicknesses of geologic units, the saturated matrix hydraulic conductivity, and the effective porosity of the rock matrix. The first four parameters were considered constants (discussed previously), whereas the latter two terms were input into the model as random variables. Probability distributions were estimated for the random variables by using subjective judgement and the results of tests on core specimens obtained from pertinent hydrogeologic units (Table 6-18, p. 6-155). However, the specific types of input distributions used to characterize the random variable are not listed in the FEA. This information may be contained in a supporting document cited in the FEA as Sinnock and others (1984), which has not been received by the NRC to date (June 20, 1986). With no other information available, the NRC must assume that the saturated hydraulic conductivity of the rock matrix was considered in the analysis to be lognormally distributed and that the effective porosity of the matrix was considered to be distributed in some type of symmetrical fashion (probably as a normal or uniform distribution). The NRC cannot evaluate these assumptions or considerations without listings of testing results and without written documentation to support the parameter means and standard deviations reported in Table 6-18.

An error (or at least a misunderstanding) is present in Table 6-18 regarding the saturated hydraulic conductivity of the rock matrix. The equation given in Table 6-18 calculates the median value of this hydrogeologic parameter, not its mean value. The observation leads to the conclusion that the reported values of mean saturated hydraulic conductivity of the matrix actually are median values of saturated hydraulic conductivity of the rock matrix. In addition, the calculation formula for standard deviation is incorrect for a lognormally distributed random variable. As a result, the NRC cannot be certain whether the intended or proper distribution of saturated hydraulic conductivity of the rock matrix was input into the computer model analysis of predicted travel times.

In the case of fracture flow, a constant value of 0.0001 was assumed for the effective porosity of the rocks (p. 6-157). This estimate was derived from information provided by Sinnock and others (1984) for saturated groundwater flow. The NRC must conclude that purely subjective judgement was used by the DOE in the determination of the applicability of this value for fracture flow in the unsaturated zone. Intercorrelations (covariances) between hydrogeologic properties were not studied, evaluated, or used in the analysis of predicted groundwater travel time. The spatial correlation of individual properties is ignored in the analysis as well. Sufficient data necessary for these more complicated studies may not exist; however, the DOE should have made an effort to describe, at least subjectively, the probable intercorrelations and spatial correlations among the hydrogeologic parameters. By so doing, the potential effects of these correlations and intercorrelations on travel time predictions could have been evaluated.

1.4.2 Computational Procedures

The computational procedures used by DOE to generate a frequency distribution for predicted groundwater travel times can incorporate only the estimated uncertainties in those parameters that are input into the model as random variables. The uncertainties in those parameters that are treated as constants, the uncertainty about the defensibility of the conceptual model, the uncertainty about the validity of the boundary conditions, and the uncertainty about some of the assumptions used in the mathematical flow model are not accommodated in the uncertainty analysis. One critical aspect of the predicted travel time computations is the assumed threshold condition for the transition from matrix flow to fracture flow. The analysis assumed that fracture flow is initiated when flux exceeds 95 percent of the saturated hydraulic conductivity of the rock matrix. But no rationale for this assumption is provided in the FEA. Although the NRC is concerned about the justification for the use of this 95 percent value, it is even more concerned that no sensitivity calculations were conducted (or at least none were reported) that would reveal the extent of the influence of this percentage on the distribution of predicted travel times. Conceivably, this percentage could have been treated as a random variable in order to provide an analysis of uncertainty in the identification of the transition point from matrix flow to fracture flow. This transition point must be identified in the analysis in order to account for the occurrence of fracture flow at moisture contents that are less than 100 percent saturation.

Without access to the supporting document cited in the FEA as Sinnock and others (1986), the NRC is unable to evaluate whether the number of simulation iterations was sufficient to provide statistically stable results. The FEA itself does not address this issue specifically. For computer model 1, each of the 963 discretized stratigraphic columns was simulated and analyzed 10 times to provide an output frequency distribution of 9,630 predicted groundwater travel times. For computer model 2, each column was simulated 100 times. The NRC cannot determine whether either of these total number of iterations (simulation passes) is sufficient to "...provide a representation of the variations in travel time due to the variation in hydraulic parameters..." as stated by DOE (p. 6-157).

The simulation of spatially independent realizations of saturated hydraulic conductivity (or of effective porosity) for each 10 ft. element incorporated in computer model 1 facilitates representations of unrealistic in-situ hydrogeologic conditions. This is true unless it can be demonstrated that model element size is significantly larger than the spatial range of influence of the simulated parameter (saturated hydraulic conductivity or effective porosity). Such a demonstration is not possible without a spatial analysis of the pertinent hydrogeologic parameters. Calculations based on a model element size of 10 ft. may provide results that are no more realistic than those provided by a model with elements of any other size.

1.4.3 Interpretation and Verification of Results

The maximum, minimum and mean values of predicted travel times as presented on p. 6-157 are the result of only one computer model run; each value will differ for additional runs. If a sufficient number of iterations (passes) is conducted for each run (see previous discussion), then this difference will be insignificant. However, the DOE has not demonstrated this to be the case. The FEA does not state clearly that the reported values of maximum, minimum, and mean predicted travel times are for one simulation run and that they vary (perhaps considerably) from one simulation pass to the next. The reported values are not conclusive and they may not be representative of the expected maximum, minimum, and mean predicted travel times.

The DOE has reached questionable conclusions in their comparison of results obtained from method 1 and method 2 (Fig. 6-9, p. 163). The difference in predicted travel time distributions is due to the effects of size in modeling elements, not due to a difference in physical reality. The NRC disagrees with the statement "...that as more physical realism is introduced into the travel-time mode, the range of travel times is likely to be compressed..." (p. 6-162). In fact, the variance of simulated travel times for 10 ft. model elements is less than that for elements comparable in size to the units of interest for at least one obvious reason. As model elements with independent hydrogeologic properties become smaller, the overall predicted travel time through a given geologic unit becomes more uniform (i.e., as the size of the elements approaches zero, the travel time approaches a constant). Results of the computer model are highly sensitive to flux. The results are particularly sensitive to the manner in which flux is compared to randomly sampled saturated hydraulic conductivity values in order to differentiate fracture flow from matrix flow. If the flux is assumed to be 0.70 mm/yr rather than 0.5 mm/yr, then half of the model elements in the Topopah Spring welded unit are expected to experience fracture flow (the reader should recall that the median saturated hydraulic conductivity in this unit is 0.70 mm/yr). Consequently, overall predicted travel times can be decreased considerably by a very slight increase in flux.

In conclusion, the computer simulation procedure presented by DOE for estimating travel time distributions does not provide results that quantify appropriately the uncertainties in hydrogeologic parameters. In addition, the computer simulation procedure does not consider uncertainties in the conceptual model or in the very critical input parameter known as flux.

1.5 References Cited

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Prentice-Hall, Inc., Englewood Cliffs, NJ.

Peters, R.R., and others, 1984, Fracture and Matrix Hydrologic Characteristics of Tuffaceous Materials from Yucca Mountain, Nye County, Nevada: Sandia National Laboratories, Albuquerque, NM, SAND84-1471.

Sinnock, Scott, Lin, Y.T., and Brannen, J.P., 1984, Preliminary Bounds on the Expected Postclosure Performance of the Yucca Mountain Repository Site, Southern Nevada: Sandia National Laboratories, Albuquerque, NM, SAND84-1492.

Sinnock, Scott, Lin, Y.T., and Tierney, M.S., 1986, Preliminary Estimates of Groundwater Travel Time and Radionuclide Transport at the Yucca Mountain Repository Site: Sandia National Laboratories, Albuquerque, NM, SAND85-2701

Wilson, W.W., 1985, Letter from W.W. Wilson (USGS) to D.L. Vieth (DOE/NVO), December 24, 1985; regarding unsaturated zone flux.

1. MAJOR COMMENT FOR BWIP FEA

1.1 Groundwater Travel Time Calculations

The NRC's major comment #1 on the BWIP draft EA questioned the overall methodology for estimating groundwater travel times. Review of the final EA (FEA) has led the staff to conclude that significant concerns remain about the reliability and representativeness of: 1) The conceptual model, 2) the hydrogeologic parameter data base and the treatment of these data in combination deterministic-stochastic models, 3) model formulations and calculational procedures, and 4) interpretations of model results. The FEA states that a final conclusion on the disqualifying condition for pre-waste-emplacement groundwater travel time is not possible at this time. It also states that the travel time "has a likelihood of exceeding 1000 years." The NRC staff considers that this statement may or may not be correct and that it is poorly supported.

Five sources of concern were identified in NRC major comment #1 on the BWIP draft EA. These sources of concern were: 1) the applicability of previously published travel time estimates, 2) the reliability and representativeness of the data base for transmissivity, hydraulic gradient, and effective thickness, 3) the treatment of these data in deterministic and stochastic models, 4) the treatment of numerical model geometry, and 5) the definition of the orientations and lengths of flow paths from the disturbed zone to the accessible environment. Only item (1) on this list has been resolved in the FEA. The FEA simply noted that no reliance was placed on the previously published travel time estimates. The NRC staff believes that items #2, 3, 4, and 5 remain unresolved. In addition, new material presented in the FEA raises additional questions.

1.2 Conceptual Model

The NRC staff believes the conceptual model of the BWIP site retains considerable uncertainty. Application of porous media concepts to describe flow in flow tops and interiors continues to be a poorly supported assumption in the FEA. The characteristics of the system's hydrogeologic boundaries are still uncertain. Flow direction is still in question, both horizontally and vertically. Hydraulic responses to the construction of borehole DC-23 (not presented in the FEA) suggest that large scale heterogeneities that cut across layers may be present in the RRL area.

1.3 Development of the Deterministic Mathematical Model

Details of the model developed and used in the FEA are not presented in the FEA or in the supporting document (Clifton, 1986). The NRC staff believes it is similar to that presented in the draft EA and supporting documents (Clifton, 1984; Clifton and others, 1984). The FEA models do not represent tentatively identified physical boundaries at the BWIP site (Rattlesnake Ridge, Columbia River...). Model elements of unknown size that have constant hydraulic properties apparently are used in the FEA models. The impact of this assumption on the calculated travel times is unknown.

1.4 Deterministic Model with Stochastic Analysis

1.4.1 Sources and Distributions of Parameters

Questions about the transmissivity data base raised in the review of the draft EA remain unresolved in the FEA. These questions are: 1) the validity of using an ensemble of point source (small scale) transmissivity measurements from various flow tops at a number of sites both within and outside the RRL to represent the Cohassett flow top; 2) the validity of assuming that transmissivity values would be log-normally distributed for the Cohassett flow top based upon data from other flow tops; and 3) the representativeness of single hole test results for application in large scale modeling. In addition, the uncertainty associated with selection of a single transmissivity value to represent test results for an individual interval has not been considered. The transmissivity input data used in the FEA are the same as those used in the draft EA.

The NRC staff continues to question the spatial correlation ranges used for transmissivity distributions input to the numerical models. Field data are not available upon which to calculate or infer correlation range values. In addition, a cross-correlation between transmissivity and effective thickness was not used in the draft EA or FEA models. This parameter interdependence, if known and input into the models, undoubtably would produce different outputs (cumulative frequency distributions) of simulated travel time.

Effective thickness is input into models presented in the FEA as a uniform distribution in the range of 10^{-3} to 10^{-1} meters. This range is the same as the range used in model #3 of the draft EA. DOE did not defend satisfactorily why a range was used that does not symmetrically bracket the only available field value ($2x10^{-3}$ meters).

Horizontal gradient was input into draft EA models as either constant (10^{-3}) or uniformly distributed (10^{-4} to 10^{-3}). The horizontal gradient is held at $2x10^{-4}$ for models presented in the FEA. The basis for the gradient used in the FEA is the difference in heads measured in boreholes DC-22 and DC-15.

This assumed flow direction is contrary to that measured using data from boreholes DC-19, 20, and 22, although the magnitude of the gradient is the same. DOE noted that head data from borehole DC-12 should be ignored in gradient calculations even though it lies between boreholes DC-22 and DC-15 because borehole DC-12 is not located within the Cold Creek syncline. DOE did not respond adequately to this NRC comment on the draft EA.

Vertical gradient was not an input parameter in the models presented in the draft EA but it is used for models 2 through 5 of the FEA. An upward gradient of 10^{-3} is used in models 2 through 5. The NRC staff notes that non-steady state water level conditions create considerable uncertainty in the estimation of vertical gradient. Also, the vertical gradient direction reversal noted in borehole DC-19 creates uncertainty with respect to the gradient value used as input.

Vertical hydraulic conductivity was not an input in the models presented in the draft EA but it is used in models 2 through 5 of the FEA. A log-normal distribution with median values of 5×10^{-13}, 1.5×10^{-12}, and 1.5×10^{-11} meters per second dependent upon ratios of vertical to horizontal hydraulic conductivity of 1, 3 and 30 was assumed for the models. The NRC staff believes that the numbers used are not conservative because the highest measured horizontal hydraulic conductivity value within a flow interior (10^{-10} meters per second) is not used at least as an upper bound. The values used also are considerably lower than those suggested by MacNish and Barker (1976) (10^{-8} meters per second) based on regional modeling studies. The staff also questions the validity of using a limited number of horizontal transmissivity values derived from small scale single hole tests as a basis to estimate vertical hydraulic conductivity over a large region. The FEA notes that chemical data suggest considerable mixing of water from deep horizons, which adds to the uncertainty about the validity of low vertical hydraulic conductivity values.

Flow interior effective porosity was not an input to the models presented in the draft EA but is an input in models 2 through 5 in the FEA. This input parameter is assumed to be log-normally distributed with a medium of 10^{-4}. The NRC believes that there is no support basis for this number; it could be much smaller or it could be larger.

Layer thickness for the analysis of vertical flow is another input parameter to the FEA models that was not used in the draft EA models. Mean values of layer thicknesses are used in the models. NRC staff questions why the values used to calculate the means are not presented. Uncertainty is introduced by not providing input data or statistical parameters on input data (i.e., range as well as mean).

1.4.2 Computational Procedures

The NRC staff believes that the model boundary conditions used with input hydraulic parameters in the FEA models will not produce the hydraulic head distribution observed at the site. The models used in the FEA do not consistently provide concurrence with observed site conditions. For example, transmissivity values used at any element in the FEA models are not constrained by measured values. The NRC staff questions the validity of using vertical flow in the Cohassett flow interior in calculating ground water travel times. The disturbed zone may extend to the flow top and alter its properties.

The FEA and the primary supporting document (Clifton, 1986) do not present detailed information with respect to formulation and operation of the majority of the five models used to predict ground water travel times. Details are not given on boundary conditions (both horizontal and vertical), number and size of model elements, number of calculated realizations, and modeling procedure and logic. No indication is given that the models were checked for sensitivity to number of realizations and to input parameter characteristics. The absence of this supporting information creates considerable uncertainty with respect to utilization of model output distributions of travel time. The NRC staff believes that this is a major problem with the FEA. Considerably more information on computational procedures was presented in the draft EA and its supporting documents; some of the comments presented herein are based on our understanding of the models formulated for the draft EA (Clifton and others, 1984). Detailed comments on each of the five models presented in the FEA are presented in the following paragraphs.

Model #1: The results from model #1 presented in the FEA are most comparable to model results presented in the draft EA. In addition to the problems associated with the lack of documentation noted in the opening paragraph, model #1 suffers from a lack of explanation of the relationships of scale between field testing, model elements and spatial correlation range for transmissivity. The NRC staff believes that this is a major source of uncertainty in the model results. Clifton and others (1984) addressed this problem to a limited extent in support of the models used in the draft EA. Clifton (1986) does not address this topic in support of the FEA.

Information is not given with respect to the generation of the transmissivity field(s) or the assumed spatial covariance of log transmissivity. Sampling and assignment of effective thickness values in the model is unexplained. The computer sampling of transmissivity and effective thickness arrays may not guarantee a consistent treatment of thickness (used to determine hydraulic conductivity and effective porosity).

Model #2: Model #2 simply provides a mechanism to account for vertical flow within the dense interior portion of the Cohassett flow above the repository. The NRC staff questions whether the disturbed zone will extend to the flow top thereby enhancing flow through this region. Justification for the 10-meter interval used in the model is sparse. No information is given on the number of realizations used for the results presented in the FEA or the sensitivity of the model to this number.

Model #3: Model #3 is a combination of models #1 and #2. All of the comments noted above for models #1 and #2 apply to model #3. In addition, the linkage of models #1 and #2 may not satisfy questions of conservation of mass concerning flow from the flow interior into the flow top.

Model #4: Model #4 permits both horizontal flow within the flow top of the Cohassett flow and upward flow through the overlying flow interior and into the next flow top. Questions presented above pertaining to model #1 are pertinent to model #4. Details concerning the number of overlying flow interiors and flow tops considered in the model and the upper boundary of the model are not given. The NRC staff recognizes a major inconsistency in the procedure described by Clifton (1986) for differentiating between horizontal and vertical flow pathways. Details concerning calculation and comparison of vertical residence time and horizontal travel time in the flow top are not presented. The procedure described by Clifton (1986) apparently does not account for directional flow in the flow top other than at an angle of 45 degrees or horizontal (i.e., a vertical flow path through the flow top to the overlying flow interior may not be possible in the model). Questions of conservation of mass between the flow top and overlying flow interior are not addressed. Relationships between hydraulic parameters and flow tops and interiors overlying the Cohassett flow are not described (i.e., are the transmissivity fields the same for each flow top in the vertical sequence).

Model #5: Model #5 is a combination of models #2 and #4; all of the comments noted for these two models are pertinent to model #5.

1.4.3 Interpretation of Model Results

The results of both the draft and FEAs for the BWIP site are graphs of cumulative frequency results from model simulations versus ground water travel time. The graphs show smooth lines that vary from a cumulative frequency of zero to a cumulative frequency of one. However, the FEA labels the Y axis on these graphs as probability rather than cumulative frequency. The NRC staff believes that labeling the Y axis on the model output graphs as probability is incorrect. In reality, these graphs are cumulative frequency plots of simulated groundwater travel times that consider only the assumed uncertainty in input parameters and not the uncertainties in the conceptual and mathematical flow models. Also, the graphs are smoothed curves that have been fitted to discrete values that are not presented. Raw discrete values, or an associated discrete cumulative frequency graph, must be presented in order to evaluate the degree of fit of the cumulative frequency distribution curves.

1.5 References Cited

Clifton, P.M., 1984, Groundwater Travel Time Uncertainty Analysis-Sensitivity of Results to Model Geometry, and Correlations and Cross Correlations Among Input Parameters: Rockwell Hanford Operations, SD-BW-TI-256.

Clifton, P.M., 1986, Groundwater Travel Time Analysis for the Reference Repository Location at the Hanford Site: Rockwell Hanford Operations, SD-BWI-TI-303.

Clifton, P.M., Arnett, R.C., and Kline, N.W., 1984, Preliminary Uncertainty Analysis of Pre-Waste-Emplacement Groundwater Travel Times for a Proposed Repository in Basalt: Rockwell Hanford Operations, SD-BWI-TA-013.

MacNish, R.D., and Barker, R.A., 1976, Digital Simulation of a Basalt Aquifer System, Walla Walla River Basin, Washington and Oregon: State of Washington Dept. of Ecology, Water-Supply Bulletin 44.

1. MAJOR COMMENT FOR DEAF SMITH FEA

1.1 Groundwater Travel Time Calculations

Guideline on Geohydrology 10 CFR 960.4-2-1 (d)
Guideline on Geohydrology 10 CFR 960.4-2-1 (b)(1)

The NRC staff's major comment on the draft EA for the Deaf Smith site stated a general concern that many of the assumptions and approaches used in the groundwater travel time analysis were not conservative and did not incorporate appropriate uncertainties. The draft EA used mean values for the hydrogeologic parameters (permeability and porosity) for estimating travel times. Mean values do not reflect spatial variation or heterogeneity relative to the distribution of hydrogeologic data within hydrostratigraphic units. The NRC major comment stated that the groundwater travel time analyses should "accurately convey the uncertainty associated with its conclusions on the pre-waste-emplacement groundwater travel time favorable condition."

The final EA (FEA) states that "The travel times are based on conservative assumptions, and statistical methods are employed to deal with parameter uncertainty. The probability of travel times being less than 1,000 years in the expected porous flow model is 0.005 (based on 1,000 trials)" (FEA, p. 6-97).

The NRC staff considers that despite the claimed "conservative assumptions" many of the "realizations" that comprise the predicted groundwater travel time distributions are not realistic (Andrews and others, 1985). Consequently, the output distribution of simulated travel times cannot convey uncertainties in the validity of values of hydrogeologic parameters appropriately nor do they constitute predictions of probability of groundwater travel time. It is incorrect to view the simulated cumulative frequency distributions of predicted travel time as cumulative probability functions because uncertainties in all the pertinent input hydrogeologic parameters, uncertainties in the conceptual model, and uncertainties about the mathematical flow model have not been considered nor incorporated into the travel time analysis. Additional detail on this statement is presented below.

1.2 Conceptual Model(s)

The travel time analysis presented in the FEA addresses only a portion of the uncertainties that are inherent in the hydrogeologic variables that control the flow of groundwater. Uncertainties associated with the conceptual model(s) are not fully accommodated in the stochastic analyses. The porous media equivalent conceptual model used in the FEA does not permit the simulation of travel times for all the defensible conceptual models that can be developed based on available data.

1.2.1 Flow in Fractured Media vs. Flow in Porous Media

Groundwater flow in fractured media, which commonly occurs in carbonate rocks, is simulated using an equivalent porous medium analytical model. An equivalent porous medium analytical or numerical model assumes that at some scale of examination (10-100 meters), the fracture flow response is integrated over space and that the medium hydraulic property can be represented by some "bulk" equivalent hydraulic conductivity. Single-hole tests, such as drill stem tests or slug tests, measure an integration of the hydraulic response of (a) the matrix, plus (b) those fractures which happen to be present in that small (1-5 meter) zone of influence. This hydraulic response will be significantly different than the truly integrated response of a large-scale, multiple-well pump test. Therefore, it is unrealistic to use PTRACK, which assumes equivalent porous medium mathematics, with data from single-hole tests that are not representative of equivalent porous medium properties. Fracture characteristics and fracture zone hydraulic properties have not been quantified at the scale of the model.

1.2.2 Hydrogeologic Framework

The hydrogeologic framework for Deaf Smith County is based on a layered sequence of evaporites and a combination of clastic and dolomitic or limestone hydrostratigraphic units. The existing data base supports this portion of the conceptual model. Salt is assumed to be isotropic (horizontal hydraulic conductivity equals vertical hydraulic conductivity). For all other hydrostratigraphic units the horizontal hydraulic conductivity is assumed to be equal to ten times the vertical hydraulic conductivity. The data base does not support these ratios of vertical to horizontal hydraulic conductivity; no ratios are supported because the DOE has not measured vertical hydraulic conductivity in the vicinity of the site or in the Palo Duro Basin. Neither the horizontal nor the vertical hydraulic conductivity has been measured for the evaporite strata in the Palo Duro Basin.

Lateral hydrogeologic boundaries for the conceptual model are based upon the definition of the accessible environment. Physical hydrogeologic boundaries are not prescribed in the PTRACK model.

1.3 Development of the Deterministic Mathematical Model

The formulation of the PTRACK model and its inherent assumptions create uncertainties in the outcome of the travel time simulations. Only some of the uncertainties are addressed by this model. The model is formulated based upon Darcy's law. The vertical velocity is calculated using a form of Darcy's law stated as follows:

$$v_{jz} = \frac{K_{jz}\, I_{jz}}{n_j}$$

where v_{jz} = vertical seepage velocity in layer j,
K_{jz} = vertical hydraulic conductivity in layer j,
I_{jz} = vertical gradient in layer j, and
n_j = porosity in layer j (Thompson et al., November 1985, p. 13)

The document states that horizontal velocity is calculated similarly.

Thompson et al. (November 1985, p. 16-18) list several assumptions and limitations of the PTRACK model. These assumptions are pertinent to the discussion presented subsequently. Thompson et al. state:

"1. It is assumed that the geologic system and the ground-water flow system under consideration can be reasonably well represented by a series of horizontal layers each having uniform thickness.

2. The code formulation implicitly assumes that the relevant hydrogeologic properties which control the travel path and travel time for a given realization (i.e., permeability, porosity, TDS, viscosity, and horizontal and vertical gradient) are homogeneous within each layer...

3. The horizontal and vertical hydraulic gradients are constant within each layer.

4. Fluid velocities are computed from hydraulic gradients and conductivity and porosity values...

5. The vertical permeability is determined by multiplying the sample value for the horizontal permeability by a fixed anisotropy factor which may vary from layer to layer.

6. The density is assumed to vary as a function of the total dissolved solid (TDS) of each layer, which may also be sampled from a distribution of values...

7. Flow is assumed to be horizontal, with no vertical component in the uppermost or lowermost layers of the system. If a particle enters

these layers it is assumed to continue horizontally the remaining distance to the accessible environment.

8. It is assumed that the ground-water flow system is in steady state and that Darcian flow is applicable in all geologic units.

9. In any given geologic setting it is possible that certain units may be fractured. If the matrix permeability of these fractured rocks is sufficiently low, it is probable that the bulk of the ground-water flow will occur through the fractures. Given that the fracture porosity may be significantly lower than the matrix porosity, the interstitial velocities in a fractured rock mass may be considerably higher (leading to lower travel times) than in a porous media...

10. Once a particle enters a fracture zone at a given distance from the particle drop location, the particle is assumed to stay in the fracture zone the remaining distance to the exit boundary, regardless of the orientation of the fracture zone with respect to the direction of the regional hydraulic gradient...

11. Fracture length is not accounted for in the present formulation...

12. While one might consider any number of observed pressures or heads in defining vertical hydraulic gradients across intervening strata, the present version of PTRACK has been designed to treat at most three observed values at differing depths...

13. PTRACK is designed to address the impact of data uncertainty rather than the impact of conceptual model uncertainties...

14. The thicknesses and elevations of the individual lithologic layers used in the PTRACK would normally be based on the geologic log of the nearest hydrogeologic borehole to the site of interest...This implies that the travel times are representative of the condition at the nearest borehole and that this borehole represents the expected conditions at the site itself..."

1.3.1 Boundary Conditions

Uncertainties regarding the vertical discretization of layers that control vertical and horizontal velocity during modeling and therefore dominate the travel time analyses have been addressed by using 19 layers in the PTRACK model. These layers were designated based on lithologies determined from J. Friemel #1 well data. The uppermost layer corresponds to the Dockum Group. The lowermost layer corresponds to the Wichita and Wolfcamp Series. Andrews et al. (November 1985, p. 13) state that "Not every lithology represented on the detailed geologic profile is delineated by a discrete layer in the model." The model has lumped those "units which are considered to have relatively low horizontal permeability and to model as discrete layers units which are considered to have a relatively high horizontal permeability." The model does not take credit for travel time occurring within the host salt (Lower San Andres Unit 4).

1.3.2 Model Framework

Uncertainty inherent in the deterministic mathematical model framework exists because the test data that are available are not representative of the same scale that is used in the PTRACK model to predict groundwater travel times. The scale of the available field test data is several orders of magnitude smaller than the scale of the hydrostratigraphic units (layers) in the deterministic mathematical model. The stochastic analysis neglects to consider the significance of the impact of the scale differences.

1.3.2.1 Vertical Gradient

Vertical gradients are calculated based on the calculation of environmental heads (Lusczynski, 1961). Thompson et al. (November 1985, p. 12) state that the calculation of environmental head requires a pressure or head measurement, the elevation of that measurement point, and the elevations and total dissolved solids content for any layers of different fluid density that may occur above the measurement point. Uncertainties exist because of potential inaccuracies incurred when calculating environmental heads based on pressure readings, total dissolved solids content, and in situ temperature.

1.4 Deterministic Model with Stochastic Analysis

Considerable uncertainty exists in several areas of the deterministic/stochastic analysis of simulated travel times. Uncertainty exists because of the sources for data used to create input for the model analysis. Uncertainty also exists relative to the selected input distributions that are assigned to the hydrogeologic properties (input parameters). A simplistic treatment of spatial correlation of input parameters is questionable which in turn raises additional questions about the uncertainties in the model output. The computational procedure constitutes an additional concern regarding uncertainties in model output. Therefore, multiple sources of uncertainty cause the validity of the output of the predicted travel time analysis to be questionable.

1.4.1 Sources and Distributions of Input Parameters

The well nearest the proposed site (J. Friemel #1) to the site from which the lithology was defined for the hydrostratigraphic units in the model is located several miles south of the site. Differences may exist in the geology and lithology between the J. Friemel well site and the proposed location for the repository. Consequently, uncertainties exist in the basic hydrogeologic framework of the model.

1.4.1.1 Lateral Boundaries

Uncertainties exist regarding the lateral boundaries for the model. Physical hydrogeologic boundaries are not prescribed in the PTRACK model. As noted under the previous heading entitled Conceptual Model, lateral boundaries are based upon the definition of the accessible environment. The hydrogeologic effects associated with real or perceived boundary conditions cannot be simulated with PTRACK in the configuration used by Andrews et al. (November 1985).

1.4.1.2 Vertical Gradient

The validity and representativeness of the vertical hydraulic gradients is questionable because only three point source values from one well (J. Friemel #1) are used in the PTRACK model. The use of three point source values to derive vertical hydraulic gradients limits the possible conceptual models that can be accommodated by the PTRACK model. Data used as input to Latin Hypercube Sampling (LHS) are derived from the J. Friemel #1 well. Pressure data from the Queen/Grayburg, Lower San Andres Unit 4 dolomite, and the Wolfcamp series of rocks were assumed to represent the mean pressures in normal distributions of pressures within those units. Pressure values are assumed to be distributed normally (Andrews et al., November 1985, p. 17). Most simulations used head values derived from the Dockum Group instead of the Queen/Grayburg; this procedure increased the vertical distance particles could move during simulations. Hydraulic head data necessary to assign vertical gradients are questionable because of the effect of variable fluid density on head measurements (see previous discussion regarding assignment of vertical gradient in section on development of deterministic model).

1.4.1.3 Horizontal Gradient

Horizontal gradients are based on near-site data and deterministic model output. A triangular distribution of gradients was assigned for the Lower and Upper San Andres salt and interbeds; a second triangular distribution was assigned for all layers except the Lower and Upper San Andres salt and interbeds. Uncertainties exist regarding the representativeness of the interpreted gradients (see subsequent discussion on spatial correlation).

1.4.1.4 Hydrogeologic Parameters

Uncertainties exist in the data bases for hydraulic conductivity and effective porosity. These hydrogeologic properties are quantified for the stochastic analyses by the inclusion of values for similar rock types from textbooks and by inferring values based on measurements in other sedimentary basins (Andrews et al., November 1985, p. 18-26). Little confidence can be placed on the assigned probability distributions of the input hydrogeologic parameters because of the nature of the data bases. The shapes of the distributions must be hypothesized in several cases because of limited data bases. Very simplistic relationships are inferred in other cases. Log normal distributions for hydraulic conductivity are assumed for numerous layers in the model. These distributions are hypothesized in several instances, using non-site data as supporting evidence (Andrews et al., November 1985, p. 18-23).

Porosity values are based on resistivity log interpretation or "textbook" ranges (Andrews et al., November 1985, p. 23). Porosity is hypothesized to be distributed normally for the purposes of the PTRACK model. Uncertainties exist with respect to the values of effective porosity used in the model because effective porosity has not been measured in the Palo Duro Basin.

1.4.2 Spatial Correlation

Spatial correlation of inputs to the deterministic model with stochastic analysis creates an additional aspect of uncertainty. Uncertainty exists in the potentiometric surface because of the uncertainty associated with kriged analyses of potentiometric data. Harper and Furr (1986) evaluated the potentiometric data in the "Wolfcamp aquifer of the Palo Duro Basin." The geostatistical analysis of the potentiometric data revealed an error standard deviation of 148 feet in the potentiometric data. This large standard deviation implies that more than one hydrostratigraphic unit may exist in the hydrostratigraphic unit now being called the "Wolfcamp aquifer." Continuity requires that only head data within a single hydrostratigraphic unit (aquifer or aquitard) be compared by Kriging. Unreasonable results (large errors) result from combining head data from different hydrostratigraphic units.

Andrews et al. (November 1985, p. 69) addressed the spatial correlation of interbed permeability. They attempted to investigate the spatial correlation of the permeability of the interbeds over distances at the scale of the Palo Duro Basin. They state that the wide range of permeabilities observed in the Lower San Andres interbeds may indicate that the permeability is not well correlated. The spatial correlation study conducted by Andrews et al. fails in its attempt to investigate the spatial correlation of the Lower San Andres Unit 4 dolomite. The approach used by Andrews et al. was simplistic in that it used a definition of correlation range that seems inappropriate to assess spatial correlation effects. Consequently, the analysis provided inconclusive results.

1.4.3 Computational Procedures

The computational procedures (PTRACK) use Darcy's law in the deterministic portion of the stochastic analysis. Latin Hypercube Sampling (LHS) was used to sample from distributions and provide vectors of values for PTRACK. Probability distributions can be assigned to

- head or pressure values at A, B, and C,
- the horizontal hydraulic gradient for each unit,
- the total dissolved solids for each unit,
- the horizontal permeability of each unit,
- the porosity of each unit,
- the porosity scaling factor for fractured rock, and
- the shortest distance to the fracture zone (Andrews et al November 1985, p. 19).

Unfortunately, PTRACK does not necessarily conserve mass (a basic law of aquifer hydraulics); Andrews et al. (November 1985, p. 10) agree that PTRACK does not necessarily conserve mass. Uncertainty ensues because of the absence of conservation of mass in the deterministic portion of the model. Therefore, a given set of parameters may result in a flow regime that cannot exist physically. Uncertainties result from this shortcoming because unrealistic combinations of input parameters can occur in the deterministic model. The ability of PTRACK to evaluate alternate conceptual models is thereby restricted.

1.4.4 Interpretation of Results

The DOE states in the FEA that in spite of the above problems, the travel times are conservative. The NRC staff believes that a more appropriate treatment of scale, for example, may produce a cumulative frequency distribution of predicted travel times that is shaped differently than those presented in the FEA. This distribution of predicted travel times could even be bimodal or multimodal which would influence significantly the estimates of the mean, standard deviation, and median parameters, as well as probability estimates of travel time. In spite of these problems the cumulative frequency distributions of predicted travel times are presented (incorrectly) as probability distributions. The distributions presented, in fact, are cumulative frequency distributions of simulated travel times. The travel times are not a reflection of a sample from a true population of travel times as is required of a probability density function. These distributions have not been validated by applying statistical sensitivity and stability studies of the simulation models and their results. As noted by Andrews et al. (November 1985, p. 10) the simulation results should be compared to output from independent, defensible deterministic models in order to evaluate their validity.

On the basis of this rationale the staff concludes that the predicted travel time distributions presented by the DOE may not be realistic, because the predicted travel times cannot incorporate all of the uncertainties that are inherent in any hydrogeologic analysis.

1.5 References Cited

Andrews, R.W., Kelley, V.A., McNeish, J.A., LaVenue, A.M., and Campbell, J.E., November 1985, Travel Path/Travel Time Uncertainties at Salt Sites Proposed for High Level Waste Repositories: Prepared by Intera Technologies, Inc. for Office of Nuclear Waste Isolation, ONWI/E512-02900/TR-36.

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Lusczynski, N.J., 1961, Head and Flow of Ground Water of Variable Density: Journal of Geophysical Research, vol. 66, no. 12, p. 4247-4256.

Thompson, B.M., Campbell, J.E., and Longsine, D.E., November 1985, PTRACK A Particle Tracking Program for Evaluating Travel Path/Travel Time Uncertainties: Prepared by Intera Technologies, Inc. for Office of Nuclear Waste Isolation, ONWI/E512-02900/CD-27.

1. MAJOR COMMENT FOR DAVIS CANYON FEA

1.1 Groundwater Travel Time Calculations

Guidelines on Geohydrology 10 CFR 960.4-2-1 (d)
Guidelines on Geohydrology 10 CFR 960.4-2-1 (b) (1)

The NRC staff major comment on the draft EA for the Davis Canyon site stated a general concern that many of the assumptions and approaches used in the groundwater travel time analysis were not conservative and did not incorporate appropriate uncertainties. The draft EA used mean values for the hydrogeologic parameters (permeability and porosity) for estimating travel times. Mean values do not reflect spatial variation or heterogeneity relative to the distribution of hydrogeologic data within hydrostratigraphic units. The NRC major comment stated that the groundwater travel time analyses should "accurately convey the uncertainty associated with its conclusion on the pre-waste-emplacement groundwater travel time favorable condition.

The final EA (FEA) shows great improvement over the draft EA with respect to representing accurately the uncertainties associated with the groundwater travel time calculations. The DOE has made a distinct effort to correct the previous lack of recognition of uncertainties as well as to incorporate uncertainties quantitatively in the groundwater travel time calculation. For the Davis Canyon site, a simulated groundwater travel time distribution is presented which is based on conservative assumptions. The simulation employs stochastic methods to quantify the uncertainties that are known to exist for field data and to quantify the uncertainties likely to exist for assumed parameter ranges where no field data are available. The simulation uses a hypothesized hydrogeologic framework (deterministic model) to generate 1,000 realizations (runs) of groundwater travel times where for each run, values for the system parameters are chosen randomly from a range of values for each parameter. The DOE concludes that "The probability of not meeting the 1,000 year travel time criteria, assuming porous flow, is less than 0.003."

The NRC staff considers that despite the "conservative assumptions", many of the realizations that comprise the predicted ground water travel time distributions are not realistic (Andrews et al., 1985). The simulations that are unrealistic are a consequence of uncertainties that the model is not designed to incorporate. These uncertainties pertain to the validity of the conceptual model used in the model, to the model itself and to the validity of input hydrogeologic parameters. Consequently, the model output distributions of predicted travel times simply cannot convey uncertainties in hydrogeologic parameters appropriately nor do the output distributions constitute valid predictions of probability of groundwater travel time. It is incorrect to use the simulated cumulative frequency distributions of predicted travel time as cumulative probability functions when uncertainties in all pertinent input parameters, in the conceptual model, and in the mathematical flow model have not been considered nor incorporated into the predicted travel time analysis.

The NRC concludes that the DOE has represented incorrectly the simulated output distribution of their stochastic analysis when it is viewed as the probability density function of groundwater travel times at the Davis Canyon Site. Despite the fact that the DOE incorporated conservative assumptions in the model the simulated output distribution is conservative only if the assumptions cause the distribution to be sufficiently broad to include all the groundwater travel time predictions that will be possible when the site has been characterized completely. Furthermore, the NRC concludes that it is unlikely that the mean or median of the output distribution of predicted travel times (which depends upon some unrealistic combinations of input parameters) constitutes the groundwater travel time that ultimately will be determined as "most likely" when the site has been well-characterized. In summary, the NRC concludes that the DOE has completed a useful study of the potential variability in groundwater travel time predictions using PTRACK. However given the limited knowledge about the hydrogeology at the site, the output distribution of that study is not the expected probability density function of groundwater travel times at the Davis Canyon site. The range of travel times generated is defensible for purposes of the FEA, which is to assess whether or not the favorable condition and the disqualifying condition for groundwater travel time may be met. Existing data are inadequate for a more substantial demonstration. Therefore, the DOE should not and does not need to represent the simulated output distribution as the expected probability function of predicted travel time; to do so is technically incorrect.

The remainder of this comment constitutes the rational for stating that it is incorrect to equate the simulated cumulative frequency distribution of predicted travel time with the expected probability function of predicted travel time. This explanation is organized in terms of a) choice of conceptual model, b) data inputs to a deterministic model that is prerequisite to the stochastic process, and c) use of a stochastic procedure to assess data uncertainties. This explanation is preceded by a correction of the DOE's interpretation of the letter documenting the NRC staff's licensing position (Browning, 1985).

<u>Correction of DOE Interpretation of NRC Letter (Browning, 1985)</u>

This space provided for NRC correction of DOE interpretation.

1.2 Conceptual Model(s)

The travel time analysis presented in the FEA addresses only a portion of the uncertainties that are inherent in the hydrogeologic variables that control the flow of groundwater. Uncertainties associated with the conceptual model(s) are not fully accommodated in the stochastic analyses. The porous media equivalent conceptual model used in the FEA does not permit the simulation of travel times for all the defensible conceptual models that can be developed based on available data.

1.2.1 Flow in Fractured Media vs. Flow in Porous Media

Groundwater flow in fractured media, which commonly occurs in carbonate rocks, is simulated using an equivalent porous medium analytical model. An equivalent porous medium analytical or numerical model assumes that at some scale of examination (10-100 meters), the fracture flow response is integrated over space and that the medium hydraulic property can be represented by some "bulk" equivalent hydraulic conductivity. Single-hole tests, such as drill stem tests or slug tests, measure an integration of the hydraulic response of a) the matrix, plus b) those fractures which happen to be present in that small (1-5 meter) zone of influence. This hydraulic response will be significantly different than the truly integrated response of a large-scale, multiple-well pump test. Therefore, it is unrealistic to use PTRACK, which assumes equivalent porous medium mathematics, with data from single-hole tests that are not representative of equivalent porous medium properties. Fracture characteristics and fracture zone hydraulic properties have not been quantified at the scale of the model.

1.2.2 Hydrogeologic Framework

The hydrogeologic framework for the Davis Canyon site is based on a layered sequence of evaporites and a combination of clastic and dolomitic or limestone hydrostratigraphic units. The existing data base supports this portion of the conceptual model. Salt is assumed to be isotropic (horizontal hydraulic conductivity equals vertical hydraulic conductivity). For all other hydrostratigraphic units the horizontal hydraulic conductivity is assumed to be equal to ten times the vertical hydraulic conductivity. The data base does not support these ratios of vertical to horizontal hydraulic conductivity. The DOE has not measured vertical hydraulic conductivity in the field at borehole GD-1. Vertical hydraulic conductivity tests performed in the lab on core from GD-1 show K_V/K_H ratios from 10:1 to 1:10. Only the Leadville Limestone showed laboratory K_V/K_H ratios of 1:10 consistently.

Lateral hydrogeologic boundaries for the conceptual model are based upon the definition of the accessible environment. Physical hydrogeologic boundaries are not prescribed in the PTRACK model.

1.3 Development of the Deterministic Mathematical Model

The formulation of the PTRACK model and its inherent assumptions create uncertainties in the outcome of the travel time simulations. Only some of the uncertainties are addressed by this model. The model is formulated based upon Darcy's law. The vertical velocity is calculated using a form of Darcy's law stated as follows:

$$v_{jz} = \frac{K_{jz}\, I_{jz}}{n_j}$$

where v_{jz} = vertical seepage velocity in layer j,
K_{jz} = vertical hydraulic conductivity in layer j,
I_{jz} = vertical gradient in layer j, and
n_j = porosity in layer j (Thompson et al., November 1985, p. 13)

The document states that horizontal velocity is calculated similarly.

Thompson et al. (November 1985, p. 16-18) list several assumptions and limitations of the PTRACK model. These assumptions are pertinent to the discussion presented subsequently. Thompson et al. state:

"1. It is assumed that the geologic system and the ground-water flow system under consideration can be reasonably well represented by a series of horizontal layers each having uniform thickness.

2. The code formulation implicitly assumes that the relevant hydrogeologic properties which control the travel path and travel time for a given realization (i.e., permeability, porosity, TDS, viscosity, and horizontal and vertical gradient) are homogeneous within each layer...

3. The horizontal and vertical hydraulic gradients are constant within each layer.

4. Fluid velocities are computed from hydraulic gradients and conductivity and porosity values...

5. The vertical permeability is determined by multiplying the sample value for the horizontal permeability by a fixed anisotropy factor which may vary from layer to layer.

6. The density is assumed to vary as a function of the total dissolved solid (TDS) of each layer, which may also be sampled from a distribution of values...

7. Flow is assumed to be horizontal, with no vertical component in the uppermost or lowermost layers of the system. If a particle enters these layers it is assumed to continue horizontally the remaining distance to the accessible environment.

8. It is assumed that the ground-water flow system is in steady state and that Darcian flow is applicable in all geologic units.

9. In any given geologic setting it is possible that certain units may be fractured. If the matrix permeability of these fractured rocks is sufficiently low, it is probable that the bulk of the ground-water flow will occur through the fractures. Given that the fracture porosity may be significantly lower than the matrix porosity, the interstitial velocities in a fractured rock mass may be considerably higher (leading to lower travel times) than in a porous media...

10. Once a particle enters a fracture zone at a given distance from the particle drop location, the particle is assumed to stay in the fracture zone the remaining distance to the exit boundary, regardless of the orientation of the fracture zone with respect to the direction of the regional hydraulic gradient...

11. Fracture length is not accounted for in the present formulation...

12. While one might consider any number of observed pressures or heads in defining vertical hydraulic gradients across intervening strata, the present version of PTRACK has been designed to treat at most three observed values at differing depths...

13. PTRACK is designed to address the impact of data uncertainty rather than the impact of conceptual model uncertainties...

14. The thicknesses and elevations of the individual lithologic layers used in the PTRACK would normally be based on the geologic log of the nearest hydrogeologic borehole to the site of interest...This implies that the travel times are representative of the condition at the nearest borehole and that this borehole represents the expected conditions at the site itself..."

1.3.1 Boundary Conditions

Uncertainties regarding the vertical discretization of layers that control vertical and horizontal velocity during modeling and therefore dominate the travel time analyses have been addressed by using 21 layers in the PTRACK model. These layers were designated based on lithologies determined from Gibson Dome No. 1 (GD-1) well data. The uppermost layer corresponds to the Elephant Canyon Formation. The lowermost layer corresponds to the Leadville Limestone Formation. Andrews et al. (November 1985, p. 121) state that "not every lithology represented on the detailed geologic profile is delineated by a discrete layer in the model." The model has lumped those "units which are considered to have relatively low horizontal permeability and to model as discrete layers units which are considered to have a relatively high horizontal permeability." The model does not take credit for travel time occurring within the host salt (Paradox Cycle 6 Salt).

1.3.2 Model Framework

In any modeling effort some degree of uncertainty is introduced by the transition from the conceptual model stage to the deterministic mathematical framework. The mathematics will always depend on a set of assumptions which may or may not apply to the physical system being modeled. In the PTRACK simulation many of the recognized assumptions and limitations (Thompson et al., November 1985, p. 16-18) may mean that the entire simulation is somewhat unrealistic. When Andrews et al. (1985) used PTRACK to generate a predicted distribution of travel times, they attempted to compensate for these unrealistic aspects by taking steps to insure or assess conservatism in many of the unrealistic aspects. The FEA stresses this dedication to conservatism, but it neglects to address unrepresentativeness. Specific instances of this omission include mesh (or element) scale, and treatment of vertical gradients, as discussed below.

1.3.2.1 Scale of Model Elements

The DOE considers that their assumption of homogeneous layers with one element for each layer is conservative from a performance assessment perspective because each run of the simulation is based on one set of hydrogeologic data, where each parameter is chosen randomly from the input distribution for that property. They conclude that "using the entire distribution creates a broader time distribution, i.e., an increased probability of very short and very long travel times" (Davis Canyon FEA, p. 6-261, paragraph 2).

An alternative, more realistic, mesh size would generate a significantly different cumulative frequency distribution of predicted travel times if the elements in each layer have lateral dimensions that are comparable to the testing scale, and if the testing scale is large enough to reflect equivalent porous medium properties. The DOE's simulated travel time may be broad enough to be conservative, but it is not defensible to use the mean or median as the most likely value, as is done in the Analysis for the Favorable Condition, 10 CFR 960.4-2-1 (b)(1).

1.3.2.1 Vertical Gradient

Vertical gradients are calculated based on the calculation of environmental heads (Lusczynski, 1961). Thompson et al. (November 1985, p. 12) state that the calculation of environmental head requires a pressure or head measurement, the elevation of that measurement point, and the elevations and total dissolved solids content for any layers of different fluid density that may occur above the measurement point. Uncertainties exist because of potential inaccuracies incurred when calculating environmental heads based on pressure readings.

1.4 Deterministic Model with Stochastic Analysis

Considerable uncertainty exists in several areas of the deterministic/stochastic analysis of simulated travel times. Uncertainty exists because of the sources for data used to create input for the model analysis. Uncertainty also exists relative to the selected input distributions that are assigned to the hydrogeologic properties (input parameters). A simplistic treatment of spatial correlation of input parameters is questionable which in turn raises additional questions about the uncertainties in the model output. The computational procedure constitutes an additional concern regarding uncertainties in model output. Therefore, multiple sources of uncertainty cause some portion of the realizations comprising the predicted travel time distribution to be unrealistic.

1.4.1 Sources and Distributions of Input Parameters

The well nearest the proposed site (Gibson Dome No. 1) to the site from which the lithology was defined for the hydrostratigraphic units in the model is located several miles from the site. Differences may exist in the geology and lithology between the well site and the proposed location for the repository. The DOE source reference (Thompson et al., November 1985, p. 16-18) addresses this matter as an "assumption (or) limitation." The NRC recognizes that the DOE has no site specific data. However the DOE should not present the simulated distribution of groundwater travel times as the expected probability distribution for the Davis Canyon site, given such limitations.

1.4.1.1 Lateral Boundaries

Uncertainties exist regarding the lateral boundaries for the model. Physical hydrogeologic boundaries are not prescribed in the PTRACK model. As noted under the previous heading entitled Conceptual Model, lateral boundaries are based upon the definition of the accessible environment. The hydrogeologic effects associated with real or perceived boundary conditions cannot be simulated with PTRACK in the configuration used by Andrews et al. (November 1985).

1.4.1.2 Vertical Gradient

The validity and representativeness of vertical hydraulic gradients in the model is limited. PTRACK is written so that only three point source values can be used in each run. The use of three point source values to derive vertical hydraulic gradients limits the possible conceptual models that can be accommodated by the PTRACK model. Data used as input to Latin Hypercube Sampling (LHS) are derived from the GD-1 well. The average of the three head measurements taken in the Elephant Canyon Formation at GD-1 was used to define the pressure at the top of the model. The average of the three head measurements taken in the Leadville Limestone Formation at GD-1 was used to define the pressure at the bottom of the model. Pressures from the Ismay or from the Honaker Trail Formation were used as the "midpoint" pressure. If Ismay pressures were used, a local downward gradient was generated. If Honaker Trail data were used, a local upward gradient was generated. Pressure values are assumed to be distributed normally (Andrews et al., November 1985, p. 17). Because of the simplicity of the model, the vertical gradients had little effect upon travel times and flow paths. Hydraulic head data necessary to assign vertical gradients are questionable because of the effect of variable fluid density on head measurements (see previous discussion regarding assignment of vertical gradient in section on development of deterministic model).

1.4.1.3 Horizontal Gradient

Horizontal gradients are based on near-site data and deterministic model output. A triangular distribution of gradients was assigned for each of seven subdivisions of the layers. Uncertainties exist regarding the representativeness of the interpreted gradients (see subsequent discussion on spatial correlation).

1.4.1.4 Hydrogeologic Parameters

Uncertainties exist in the data bases for hydraulic conductivity (stated in units of permeability) and effective porosity. These hydrogeologic properties are quantified for the stochastic analyses on the basis of field and lab tests at well GD-1, values for similar rock types from textbooks and by inferring values based on measurements in other sedimentary basins (Andrews et al., November 1985, p. 126-127). Little confidence can be placed on the assigned probability distributions of the input hydrogeologic parameters because of the nature of the data bases. The shapes of the distributions must be hypothesized in several cases because of limited data bases. Very simplistic relationships are inferred in other cases. Log normal distributions for hydraulic conductivity are assumed for numerous layers in the model. These distributions are hypothesized in several instances, using non-site data as supporting evidence (Andrews et al., November 1985, p. 18-23).

Porosity values are based on geophysical log interpretation from well GW-1 (Thackston et al., 1984). Porosity is hypothesized to be distributed normally for the purposes of the PTRACK model. Uncertainties exist with respect to the values of effective porosity used in the model because effective porosity has not been measured at well GD-1. Andrews et al. recognize this as a limitation (p. 127), but do not assess the potential effect on the output distribution.

1.4.2 Spatial Correlation

Spatial correlation of inputs to the deterministic model with stochastic analysis creates an additional aspect of uncertainty. Andrews et al. (November 1985, p. 69) could not address the spatial correlation of interbed permeability for the Davis Canyon site since only one test well (GD-1) exists in the Paradox Basin.

1.4.3 Computational Procedures

The computational procedures (PTRACK) use Darcy's law in the deterministic portion of the stochastic analysis. Latin Hypercube Sampling (LHS) was used to sample from distributions and provide vectors of values for PTRACK. Probability distributions can be assigned to

- head or pressure values at A, B, and C,
- the horizontal hydraulic gradient for each unit,
- the total dissolved solids for each unit,
- the horizontal permeability of each unit,
- the porosity of each unit,
- the porosity scaling factor for fractured rock, and

the shortest distance to the fracture zone (Andrews et al November 1985, p. 19).

Unfortunately, PTRACK does not necessarily conserve mass (Andrews et al., November 1985, p. 10). Uncertainty ensues because of the absence of conservation of mass (a basic law of aquifer hydraulics) in the deterministic portion of the model. Therefore, a given set of parameters may result in a flow regime that cannot exist physically. Uncertainties result from this shortcoming because unrealistic combinations of input parameters can occur in the deterministic model. The ability of PTRACK to evaluate alternate conceptual models is thereby restricted.

1.4.4 Interpretation of Results

The DOE states in the FEA that in spite of the above problems, the travel times are conservative. The NRC staff believes that a more appropriate treatment of scale, for example, may produce a cumulative frequency distribution of predicted travel times that is shaped differently than those presented in the FEA. This distribution of predicted travel times could even be bimodal or multimodal which would influence significantly the estimates of the mean, standard deviation, and median parameters, as well as probability estimates of travel time. In spite of these problems the cumulative frequency distributions of predicted travel times are presented (incorrectly) as probability distributions. The distributions presented, in fact, are cumulative frequency distributions of simulated travel times. The travel times are not a reflection of a sample from a true population of travel times as is required of a probability density function. These distributions have not been validated by applying statistical sensitivity and stability studies of the simulation models and their results. As noted by Andrews et al. (November 1985, p. 10) the simulation results should be compared to output from independent, defensible deterministic models in order to evaluate their validity.

On the basis of this rationale the staff concludes that the predicted travel time distributions presented by the DOE may not be realistic, because the predicted travel times cannot incorporate all of the uncertainties that are inherent in any hydrogeologic analysis.

1.5 References Cited

Andrews, R.W., Kelley, V.A., McNeish, J.A., LaVenue, A.M., and Campbell, J.E., November 1985, Travel Path/Travel Time Uncertainties at Salt Sites Proposed for High Level Waste Repositories: Prepared by Intera Technologies, Inc. for Office of Nuclear Waste Isolation, ONWI/E512-02900/TR-36.

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1. MAJOR COMMENT FOR RICHTON DOME FEA

1.1 Groundwater Travel Time Calculations

The NRC comments on the groundwater travel time that were presented in the draft EA centered on the uncertainties and assumptions inherent in travel time calculations within the salt host rock and within the surrounding sedimentary strata.

The final EA (FEA) did not address travel time in the sedimentary strata external to the dome. The FEA has defined the accessible environment for Richton Dome as all areas external to the salt dome host rock. Therefore, comments on travel time calculations outside the dome are moot except where such hydrogeologic analyses of the surrounding sedimentary sequence affect travel time calculations within the salt dome.

The analyses of travel time for Richton Dome differ significantly from the analyses of travel time at the bedded salt sites. Analyses at the dome entail the calculations of horizontal groundwater flow within the salt. Travel time analyses do not consider groundwater flow through non-salt strata at the dome unlike the analyses at the bedded salt sites. Data do not exist for the in-situ hydrogeologic properties of salt at Richton Dome.

In its review of the draft EA the NRC commented that many of the assumptions, approaches, and ranges of values used in the calculation of travel time within the salt stock were not conservative with respect to available data (specifically data on flow paths, hydraulic gradients, permeabilities, and porosities). The NRC stated that potentially shorter flow paths could occur along anomalous zones or through abandoned drill holes. The use of model-generated data sets instead of field data was criticized also. Thus, the NRC concluded that the FEA should "more accurately convey the uncertainty associated with...travel time estimates."

The FEA is greatly improved over the DEA in this respect. DOE has made an effort to correct the previous lack of recognition of the uncertainties that exist in the calculation of travel times. Nevertheless, the concerns that generated NRC comment #3 on the draft EA still exist.

1.2 Conceptual Flow Model

The conceptual hydrogeologic model used in the travel time calculations is shown in Figure 6-21 (p. 6-249). Darcian flow from the repository to the edge of the dome is assumed. The 244-m buffer zone is the shortest path from the repository to the accessible environment. The travel time calculations assume horizontal flow. The conceptual model is discussed also in Andrews and others (November 1985). The conceptual model is simplistic;

uncertainties exist because preferential flow paths may exist within the salt buffer zone in Richton Dome. Potential flow paths (i.e., anomalous zones) may exist that are undetected currently. These vertical to subvertical features are difficult to detect via surface techniques.

The validity of assuming Darcian flow within the salt dome is unknown. The FEA states that no documentation of "groundwater occurrences or movement in the Richton Dome salt stock" (p. 3-99) exists; that Richton Dome "data include extrapolated, direct and indirect estimates" (p. 3-98); that "no data...document the occurrence of anomalous zones in the Richton Dome salt stock" (p. 6-85); and that "no data are available which indicate the potential for movement of groundwater through the Richton Dome salt stock" (p. 6-85).

Thus, few data exist on flow mechanisms in domal salts. Darcian flow, no flow or non laminar flow in fractures may occur in domal salts. The conceptual model assumption is that Darcian flow travel time calculations are conservatively high (p. 6-85, par. 4; p. 6-87, pars. 4 and 6; p. 6-88, par. 3; p. 6-92, par. 1; and p. 6-250, par. 1).

1.3 Development of the Deterministic Mathematical Model

The model is a simple one-dimensional form of Darcy's law. It assumes that flow occurs only through the 244 m (800 foot) buffer zone. Hydraulic gradients within the salt are extracted from regional flow model outputs.

1.4 Deterministic Model with Stochastic Analysis

Uncertainty analysis for this simple flow system was conducted using the PTRACK program which uses Latin hypercube sampling (LHS) to select values of pertinent hydrogeologic parameters stochastically. The equations are:

(1) $t = L/\langle v \rangle$

(2) $\langle v \rangle = -K\ i/\phi_{eff}$

(3) or $t = L\ \phi_{eff}/Ki$

Where t is travel time; L is flow path length; $\langle v \rangle$ is average linear velocity; K is hydraulic conductivity; ϕ_{eff} is effective porosity; and i is the hydraulic gradient. Hydraulic conductivity is related to (intrinsic) permeability by Equation 4:

(4) $K = k\rho_w g/\mu$

where k is (intrinsic) permeability in m^2; ρ_w is fluid density; g is gravitational acceleration; and μ is dynamic viscosity. The underlined parameters (equations 1-4) are hydrogeologic parameters that are input to the model as a distribution.

Uncertainties not covered by model output exist on the sources of input data and the input data distributions. No hydrogeologic data exist for the Richton Dome salt stock. The parameter estimates for travel time calculations were made as follows:

1. L, the length of flow path, is fixed at 244 meters (800 feet) in all analyses (p. 6-245); the source of this input is the repository design (p. 5-6, p. 5-27). The NRC notes that this flow path could be longer or shorter (wherever anomalous or potential disturbed zones are considered). Edge anomalous zones (<200 m) and disturbed zones ($\leq$15m) also may decrease flow path lengths in Richton Dome.

2. k, permeability, is assumed to be distributed log normally within the range of 10^{-2} to 10^{7} millidarcy (md) (p. 6-87) for the input distribution. This range is based upon a selection by INTERA of laboratory and other data which are presented by Baseman (1985, Appendix B). The data reported in Baseman are for tests conducted on salt from sites other than the Richton Dome site. Data presented in this report range from 0 to 6 md, but values greater than 10^{-2} or 10^{-3} md were rejected for Richton Dome because the higher values presumably were measured with confining pressures well below those calculated at the depth of the proposed repository. In addition, stress relaxation near openings or during coring are presumed to have created greater than normal in-situ permeabilities. Nevertheless, references 1, L1, L2, L4, L5, and L7 report intrinsic permeabilities greater than 10^{-2} md. Identical input permeability distributions to the PTRACK model were assumed for all salt sites.

   The permeability distributions apparently are realistic and conservatively high, but no data exist to support this hypothesis.

3. ϕ_{eff}, effective porosity, was estimated from resistivity logs of bedded salt in the Palo Duro Basin. A normal distribution was assumed about a mean of .0097 with a range between .003 and .0164 (Andrews and others, November 1985, p. 201). No site specific data exist for Richton Dome. Salt dome porosities estimated for other Gulf Coast salt domes range from .0001 to .04 weight percent (FEA, p. 6-93). This weight percent translates to a volume percent or porosity between .00026 and 0.104. A maximum volume percentage of 0.26 is estimated (p. 6-93).

   It is not clear that the porosity range used is conservative (low). The lower limit of porosity below which Darcy's law remains valid is unknown. Smaller effective porosities yield shorter travel times. It is conceivable that the effective porosity range could be lower than that which was used in the stochastic analysis. This result occurs because: 1) dome salt water contents (assuming saturation) encompass the range specified in the analysis and; 2) effective porosity must be less than or equal to total porosity.

4. i, hydraulic gradient, was inferred from regional horizontal gradients modeled in the surrounding sediments. Flow in the dome was assumed to be horizontal in the stochastic analysis. Six gradients ranging from .0015 to .0085 were used; the gradients were assumed to be normally distributed. Presumably, the mean of this distribution is .005, but neither the mean nor standard deviation of the distribution are presented in the FEA.

   A horizontal gradient may be a conservative position because modeling results are cited (p. 6-90, par. 2) to indicate downward flux within Richton Dome. The assumption of only a horizontal component of the velocity vector would maximize flow rate. The results cited, however, are not shown in Section 6.4.2.3.5.

   No data exist to imply that the hydraulic gradient (i) distribution is conservative. No reason exists to assume that hydraulic gradients in Richton Dome, if they exist, are horizontal or are not greater in magnitude than those outside the dome.

   No spatial correlations of data are incorporated in the Richton Dome travel time analysis.

   The computational procedure consisted of 1,000 calculations of travel time using Darcy's law (Equations 3 and 4). Values for k, i, and $\emptyset_{eff}$ were sampled from each input probability distribution (Andrews and others, November 1985, p. 201-203). L was fixed at 244 m; g, presumably was set at 9.8 m/sec^2. The parameters μ and ρ_w were considered constant. It can be inferred that μ and ρ_w were representative of NaCl saturated brines at a temperature of about 90°C, although this is not clearly stated in the FEA or Andrews and others. The temperature 90°C (194°F) is the conservatively high value used for evaluating waste package corrosion and thermally induced brine migration (FEA, p. 6-93).

   The model produced a cumulative frequency distribution of simulated travel times that cannot be verified as a probability distribution at this time.

1.4 Interpretation of Results

The FEA is improved over the draft EA in that it recognizes uncertainty in calculating groundwater travel time. On p. 6-246 (par. 2) the FEA states that the "probability of a travel time being less than 1,000 or 10,000 years is less than 0.001." On p. 6-87 (par. 4) the FEA states that the calculations "demonstrate that fluid travel times within salt stocks greatly exceed regulatory requirements."

Uncertainties remain that cannot be addressed with the existing data base. Alternate flow paths may exist that the conceptual model does not accommodate. The validity of the conceptual model cannot be demonstrated at this time.

Neither statement can be verified. The FEA uncertainty analysis is superior to the absence of such analyses in the draft EA. The stochastic analysis is repeatedly stated to be "conservative." In fact, Andrews and others (November 1985, p. 10) list several correlations which would yield perhaps longer travel times, if implemented. Nevertheless, it has been shown that distributions for flow path (L), effective porosity ($\emptyset_{eff}$), and hydraulic gradient (i) may not be conservative. Furthermore, no data exist to demonstrate that the input permeability distribution (k) is valid, conservative or even representative.

The range of possible travel times (ng. 6-19, p. 6-247) and the cumulative frequency distribution (ng. 6-20, p. 6-248) can only be assumed to be representative of actual travel times. They do not represent a true probability distribution. They are, instead, model-generated cumulative frequency distributions based upon simulated (not real) data. The calculated travel times and travel time cumulative frequency distribution may be reasonable or conservative <u>or</u> they may not be reasonable or conservative.

1.5 References Cited

Andrews, R.W., Kelley, V.A., McNeish, J.A., La Venue, A.M., and Campbell, J.E., November 1985, Travel Path/Travel Time Uncertainties at Salt Sites Proposed for High Level Waste Repositories: Prepared by INTERA Technologies, Inc., for Office of Nuclear Waste Isolation, ONWI/E512-02900/TR-36.