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Preliminary Estimates of Groundwater Travel Time at Yucca Mountain*

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by

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This report presents the assumptions, methods, and results of a probabilistic approach to the calculation of groundwater travel times to the water table below Yucca Mountain, Nevada. More detailed information is available in Sinnock et al[1]. Data to support the analyses were abstracted from formal and informal reports generated by the staff of several organizations participating in the Nevada Nuclear Waste Storage Investigations (NNWSI) Project activities; namely, the United States Geological Survey, Los Alamos National Laboratory, Lawrence Livermore National Laboratories, and Sandia National Laboratories.

Because flow in the portion of the unsaturated zone below the proposed repository is probably nearly steady state and vertical, the hydraulic gradient was assumed to equal minus one (-1) in our model. This means that the flow was assumed to be driven vertically downward solely by elevation head along the direction of gravity. On the basis of this assumption, a reasonable approximation of the velocity of water through the unsaturated zone was obtained by dividing the flux by an effective porosity. Flux was assigned

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as a boundary condition. Effective porosities and saturated hydraulic conductivites were derived from experimental measurements. Travel time was determined simply by dividing the distance of flow by the velocity. This was done for each of several stacked calculational elements within each hydrogeologic unit for each of 963 vertical columns (Figure 1).

After a boundary value of flux was assigned, a value of porosity and saturated hydraulic conductivity was randomly sampled for each calculational element from a distribution of values associated with the matrix material of each hydrogeologic unit. If the assigned flux exceeded the sampled saturated hydraulic conductivity for an element, flow velocity was assumed to equal the excess flux divided by a fixed fracture porosity; otherwise the flow velocity was set equal to the flux divided by the sampled matrix porosity corrected for saturation to yield an effective porosity. Travel times for all elements in a column were added to produce a total for each column. The sampling process was repeated in a Monte Carlo fashion to produce a set of travel times for each column with an associated expected value (mean) and standard deviation. Results from the analyses were compiled in the form of histograms, cumulative distributions, and isochron maps of groundwater travel time from the disturbed zone to the water table (Figure 2). The results provided some of the information used to support the NNWSI Environmental Assessment[2] and Site Characterization Plan[3] and indicate that for the upper limit of percolation flux below the repository level at Yucca Mountain (0.5 mm/yr), groundwater travel times have a mean of about 43,000 years and a standard deviation of about 12,000 years; less than 1 percent of the calculated travel times are less than 10,000 years. Therefore, the present model indicates that the Yucca Mountain repository site would comply with regulatory requirements.

However, the following conclusions drawn from the work suggest further refinement of models and augmentation of data that can reduce remaining uncertainties.

1) If the percolating flux is less than average saturated matrix hydraulic conductivity and if matrix suction can draw water from fractures at the same rate as it moves within matrix blocks, then groundwater travel times from the disturbed zone to the water table will exceed 1,000 years with a very high level of probability and are likely to exceed 10,000 years as well, also with a high level of probability. Experimental and field data on the relations between matrix and fracture flow at Yucca Mountain will be paramount in determining whether our current conceptual assumptions and derived travel times are correct.

2) The travel-time distribution appears most sensitive to flux, correlation lengths, and spatial variations of saturated matrix hydraulic conductivity. Less sensitivity is attributed to effective porosity. In most cases, hydrogeologic data are insufficient for performing geostatistical analyses. Collection of sufficient measurements to support good estimates of means, standard deviations, and spatial cross correlations of all hydrogeologic parameters along the flow paths below the proposed repository is strongly recommended. Site-characterization studies should provide sufficient hydrogeologic data for modeling the groundwater travel time based on reliable statistical treatment of site properties.

3) The potential for lateral flow and concentration of flux along fault zones or other conduits needs to be investigated before the distribution of travel times can be confidently interpreted as representing the fastest paths of likely radionuclide travel. Further refinements of the present model will be necessary to account for such potential flux variations in space and will be developed as better conceptual understanding of flow in unsaturated, fractured porous tuff and additional data are acquired for the Yucca Mountain site.

Current work in Sandia's modeling task is addressing the effects of assumptions about the unit hydraulic gradient and vertical one-dimensionality on the potential travel-time distribution. Given the limitations of current computing facilities, it appears that tradeoffs must be made among desires to (1) explicitly account for scale-dependent spatial heterogeneity of material properties and boundary conditions, (2) solve the classical mass-balance, boundary-value flow equations, which are highly nonlinear in unsaturated materials, and (3) provide estimates of the distribution of travel times along all potential flow paths through the geometrically variable unsaturated zone. Future work will focus on developing a suite of single- and multiple-dimension numerical models that incorporate alternative conceptual models (e.g., unit gradient or continuous calculated pressure field). Results of calculations based on this suite of models will be interpreted to provide bounds on, and best estimates of, the potential groundwater travel-time distribution at Yucca Mountain.

References

1. Sinnock, S., (ed.) Lin, Y. T., and Tierney, M. S., 1986, "Preliminary Estimates of Groundwater Travel Time and Radionuclide Transport at the Yucca Mountain Repository Site", SAND85-2701, Sandia National Laboratories, Albuquerque, NM, 84 p., 4 Appendices.

2. U. S. Department of Energy, 1986, Environmental Assessment: Yucca Mountain Site, Nevada Research and Development Area, Nevada, DOE/RW-0073, U. S. Department of Energy, Office of Civilian Radioactive Waste Management, Washington, DC, 3 volumes.

3. U. S. Department of Energy, Site Characterization Plan: Yucca Mountain Site, Nevada Research and Development Area, Nevada: Consultation Draft, U. S. Department of Energy, Office of Civilian Radioactive Waste Management, Washington, DC, 7 volumes.

Figure Captions for "Preliminary Estimates of Groundwater Travel Time at Yucca Mountain",

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Figure 1. Schematic representation of the conceptual, mathematical, and numerical model of groundwater travel time.

Figure 2. (A) Cumulative distribution and histogram of travel times for all columns and all Monte Carlo iterations and (B) isochron map of expected (mean) travel times for upper bound flux of 0.5 mm/yr.

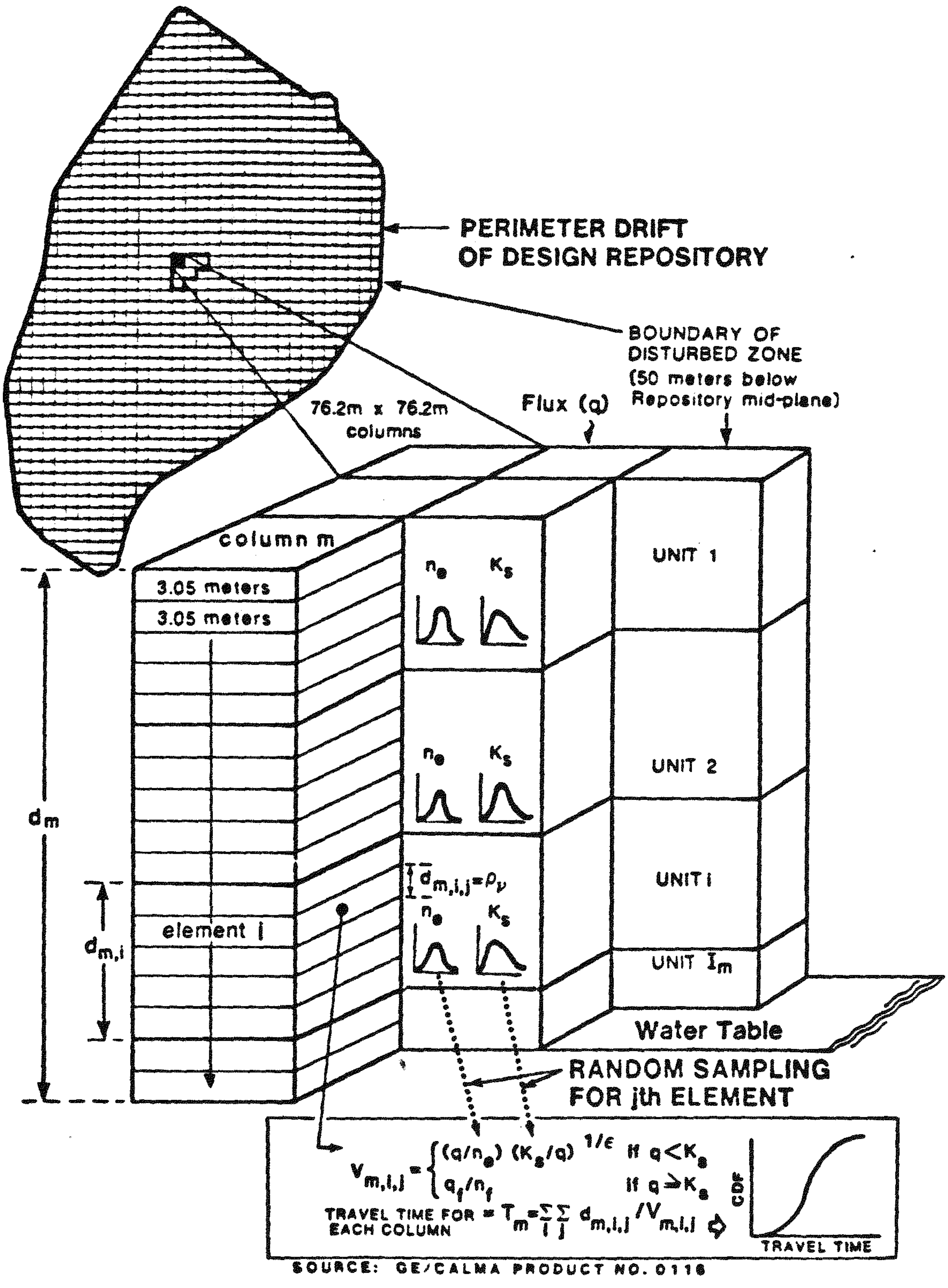
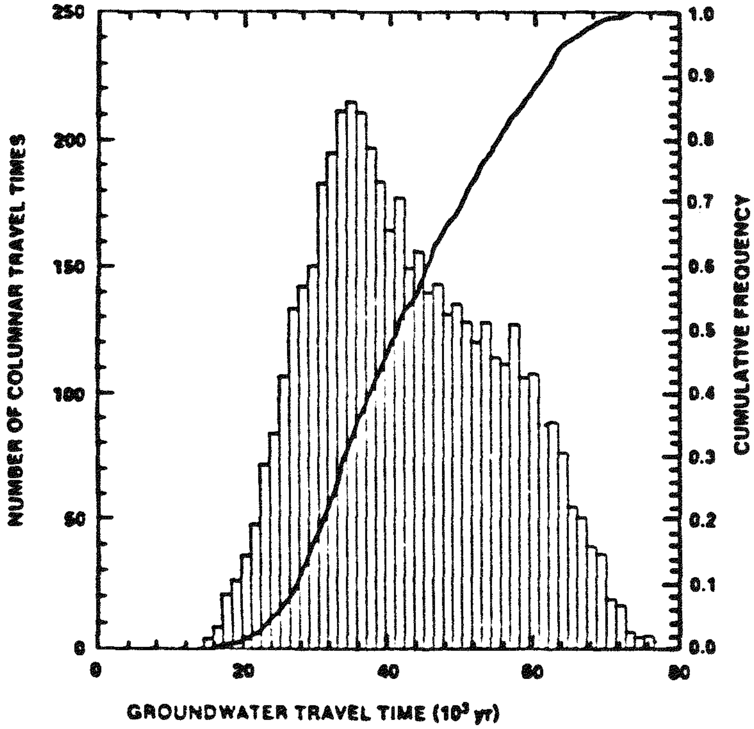
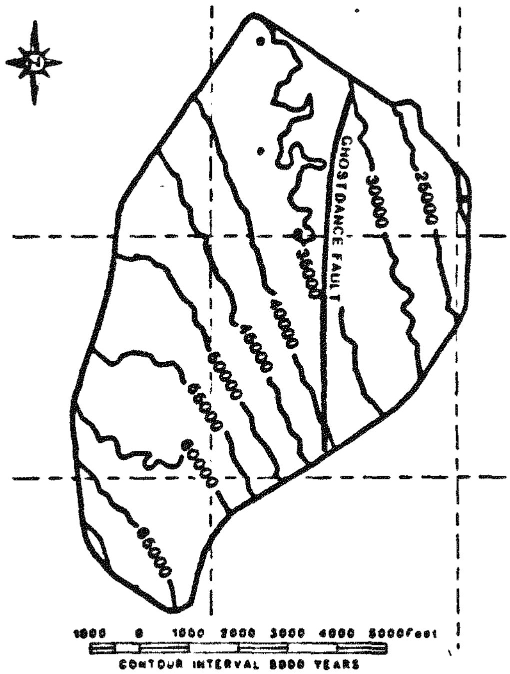

PERIMETER DRIFT
OF DESIGN REPOSITORY
BOUNDARY OF
DISTURBED ZONE
(50 meters below
Repository mid-plane)
Flux (q)
76.2m x 76.2m
columns
column m
3.05 meters
3.05 meters
UNIT 1
UNIT 2
UNIT i
UNIT I_m
d_m
$d_{m,i}$
element i
$\bar{d}_{m,i,j} = \rho_\nu$
n_e
K_s
Water Table
RANDOM SAMPLING
FOR jth ELEMENT
$V_{m,i,j} = \begin{cases} (q/n_e)\,(K_s/q)^{1/\epsilon} & \text{if } q < K_s \\ q_f/n_f & \text{if } q \geq K_s \end{cases}$
TRAVEL TIME FOR EACH COLUMN $= T_m = \sum_i \sum_j d_{m,i,j} / V_{m,i,j}$
CDF
TRAVEL TIME
SOURCE: GE/CALMA PRODUCT NO. 0116

Figure 1.


NUMBER OF COLUMNAR TRAVEL TIMES
CUMULATIVE FREQUENCY
GROUNDWATER TRAVEL TIME (10^3 yr)

(A)


GHOSTDANCE FAULT
25000
30000
35000
40000
45000
50000
55000
60000
65000
CONTOUR INTERVAL 5000 YEARS

(B)

Figure 2.

APPENDIX

Information from the Reference Information Base Used in this Report

This report contains no information from the Reference Information Base.

Candidate Information for the Reference Information Base

This report contains no candidate information for the Reference Information Base.

Candidate Information for the Site & Engineering Properties Data Base

This report contains no candidate information for the Site and Engineering Properties Data Base.

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