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MEMORANDUM FOR: Robert J. Wright
Repository Projects Branch
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THRU: Myron Fliegel, Section Leader
Hydrology Section
Geotechnical Branch
Division of Waste Management

FROM: Matthew Gordon
Hydrology Section
Geotechnical Branch
Division of Waste Management

SUBJECT: LEONHART, ET AL., (1984): "ANALYSIS AND INTERPRETATION OF A RECIRCULATING TRACER EXPERIMENT PERFORMED ON A BASALT FLOW TOP"

The subject document was received by NRC in November of 1984 as an enclosure to a letter from Olson (DOE/BWIP) to Wright (NRC/WMRP). The document is a pre-copy of a Rockwell document (RHO-BW-SA-300P), a final copy of which has not been received by NRC to date. The document describes a dual-well recirculating tracer test and its analysis. The analysis yields a value of flow top effective thickness (effective porosity times interval thickness) and dispersivity. These parameters, especially effective thickness, are critical for hydrogeologic performance assessment.

Enclosed please find a review of the subject document. The main conclusions of the review are that 1) the document is responsive to concerns about a precursor document (Gelhar et al. 1982); 2) certain aspects of the described test warrant further examination, e.g., the small magnitude and irregularity of drawdown/buildup; 3) additional documentation of the lag time analysis and discussion of potential dispersion in the boreholes would have been helpful in the document; 4) the low effective thickness measured can be explained based on a consideration of fracture flow; 5) the representativeness of this effective thickness value for larger scales than the scale of the test, and the validity of the equivalent porous-medium continuum assumption at the scales of testing and modeling, are important questions which warrant additional research; and

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6) BWIP is clearly a leader in advancing the state of the field practice.

I recommend that this review be transmitted to BWIP and other interested parties, subsequent to peer review as appropriate.

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Enclosure:
As stated

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WMGT DOCUMENT REVIEW:

"Analysis and Interpretation of a Recirculating Tracer Experiment Performed on a Deep Basalt Flow Top," by L. Leonhart, R. Jackson, D. Graham, L. Gelhar, G. Thompson, B. Kanehiro, and C. Wilson, 1984

Review by Matthew Gordon, Hydrology Section, WMGT

1. INTRODUCTION AND GENERAL COMMENTS

The subject document was received by NRC in November of 1984 as an enclosure to a letter from Olson (DOE/BWIP) to Wright (NRC/WMRP). The document is a pre-copy of a Rockwell document (RHO-BW-SA-300P), a final copy of which has not been received by NRC to date. The document describes a dual-well recirculating tracer test performed at the Hanford site, and its analysis. The analysis yields a value of flow top effective thickness (effective porosity times interval thickness) and dispersivity.

The test analysis utilizes the same methodology employed in a previous document Gelhar (1982). The Gelhar (1982) document has been reviewed previously by NRC (Gordon and Coleman (1984)). NRC's review of the Gelhar (1982) document did not question the analytical methodology, but noted deficiencies in the test documentation, and questioned whether adherence to the analytical assumptions of Gelhar (1982) was maintained during the test, which was performed several years earlier (1978) by Science Applications Inc. (SAI).

The new document (Leonhart et al. (1984)) evidences a large measure of responsiveness to NRC's concerns regarding the previous document (Gelhar (1982)). The documentation is superior: the assumptions and limitations of the test are clearly presented. The analysis appears sound, and a discussion of the test results and its implications is well-presented. The test itself was run under better-controlled conditions, which more closely adhere to Gelhar and Collins (1971) analytical approach. The analysis appears to have been successful in terms of producing an excellent type curve match (Figure 8 of the report). The superiority of the Gelhar and Collins (1971) type curve approach to tracer test analysis to the simpler and more common two-point analysis is clear. BWIP, in its application of the Gelhar and Collins (1971) method, is leading the state of the field practice into the state of the art, for which they deserve commendation.

A few questions and comments regarding the test and test documentation have been identified during the review of this document. These questions and comments are discussed below, followed by a discussion of the test result and its implications.

2. COMMENTS REGARDING TEST AND TEST DOCUMENTATION

One puzzling aspect of the documented tests is the the observed development of a head buildup at DC-8 of only two feet (0.61 m) during the test, while the drawdown at DC-7 reached a magnitude of 77 feet (23.5 m). Leonhart et al. note that, "theoretically, a mirror-image symmetry should develop between the cones of impression and depression at the recharge and discharge wells under conditions of ideal homogeneity and isotropy within the flow top, and equivalent well efficiencies [apparently meaning wellbore damage or improvement (c.f. Earlougher, 1977) in this context] and under conditions of equal flow" (p. 28). Leonhart et al. reason that lateral heterogeneities in the vicinity of the two boreholes, e.g., a local pinch-out of a more highly transmissive horizon within the flow top may be responsible for the observed asymmetry.

Assuming constant flow rates and an ideal homogeneous isotropic aquifer, the head impression and depression within the <u>aquifer</u>, but not necessarily within the well, would be expected to be symmetrical. The expected head distribution in the aquifer is illustrated in Figure 1, using the aquifer properties of Leonhart et al. (the figure and calculation is based on output from a numerical model, SWIFT, and a contouring post-processor; heads very close to the well are averaged across a larger grid block). However, a difference in the magnitude of drawdown/buildup within the boreholes themselves would in fact be expected due to the differing radii of the two wells: DC-7 being 0.11 m radius, and DC-8 being 0.04 m radius. (We note that inches have been inaccurately converted to centimeters on page 6 of the document.) The inequality in the observed borehole drawdown/buildup is, however, opposite to what would be expected theoretically, i.e., DC-8 (the smaller hole) had less buildup than DC-7 had drawdown. Assuming the value of aquifer transmissivity as noted in Leonhart et al., the expected drawdown in DC-7 would be about 67.3 meters at steady state, while the buildup in DC-8 would theoretically be about 81.5 meters (based on a calculation using equation 8-155 from Bear (1979)) for the 1 gal/min pumping/injection rates). Both of the observed drawdown/buildup magnitudes are less than would be expected theoretically; and the 0.61 m observed buildup at DC-8 is particularly inconsistent with the expected value. This could possibly be due to the aquifer having a higher transmissivity than assumed, with a local low transmissivity zone or wellbore skin near DC-7. Alternatively, a very conductive fracture or other heterogeneity may intercept DC-8 and not DC-7; however, this would seem inconsistent with the reasonably high recovery of tracer (60%) at DC-7. Similarly, a local pinch-out of a more transmissive horizon may also explain the observed drawdown/buildup, as reasoned by Leonhart et al. The presence of a wellbore skin at DC-7 is discounted by Leonhart et al., although no clear justification for doing so is presented in the document. During an attempted pump test at DC-7 prior to the tracer test, "excessive drawdown" (p. 7) was developed at DC-7; this may be consistent with what was observed during the tracer test, and suggests that a skin effect or the presence of lateral heterogeneities are affecting the ground-water flow near DC-7. Another explanation could be that the flow top has a higher transmissivity than assumed, with a less permeable boundary or borehole skin effect near DC-7, causing a higher drawdown at DC-7 than the impression at DC-8. At any rate, given the irregularities in the observed drawdown and buildup, it is surprising that such an excellent fit to the type curve was obtained (Figure 8 of the report).

It is not clear whether steady-flow conditions were attained during the test; on page 11, it is stated that "the drawdown at DC-7 stabilized at about 77 ft and the groundwater mound at DC-8 built up 2 ft". If steady flow conditions were not attained, the test may require reevaluation.

Leonhart et al. note that lag time, i.e., the time that the tracer spent traveling down DC-8 and up DC-7 between injection and detection, is one of the most sensitive parameters in the analysis. The results of the analysis of the lag time are not presented in the report. An analysis of the tracer front, using the method of Muskat (1937) which assumes no dispersivity, would result in a travel time of the non-dispersed front of 139 minutes. The dispersion accounted for by the Gelhar and Collins (1971) solution apparently causes a delay in the arrival of the peak to 178 minutes according to figure 8 of the report. Assuming that the time axis in figure 6 of the report represents the time since the pulse injection, the inferred total lag time is apparently 1242 minutes. Thus, the tracer peak took 178 minutes to travel in the aquifer and spent about 1242 minutes in the boreholes. At the December 1984 BWIP/NRC hydrology meeting in Silver Spring, MD, Dr. Gelhar indicated that, based on his calculations, the dispersion within the boreholes does not adversely affect the dispersivity calculation, since the Taylor-type dispersion in the boreholes is insignificant compared to dispersion in the aquifer. While this appears reasonable, it would have been helpful to have included these calculations in the report, as well as the calculations of lag time, especially given the sensitivity of the analysis to this parameter.

3. DISCUSSION OF TEST RESULT AND ITS IMPLICATIONS

The test yielded a very low value of effective thickness (effective porosity of interval times interval thickness), yielding an effective porosity for the test interval of 1.6×10^{-4}. Assuming the tracer movement in the brecciated flow top to be dominated by movement along the ubiquitous fractures and joints, this value of effective porosity for the "equivalent porous-medium continuum" can be shown to be reasonable. In a fractured medium, where the fractures dominate the flow, the effective porosity of the equivalent continuum may be very small compared to the volumetric fraction of total void space (including the intact matrix block void space). Assuming:

- flow to be dominated by the fractures;
- that the cubic law for flow within fractures is valid in this case;
- the noted interval transmissivity value of .065 m^2/day; and
- the derived effective thickness value of 1.8 x 10^{-3} m,
- the interval thickness value of 11.3 m,

an average fracture aperture of 2.3 x 10^{-5} m with a frequency of 7.1 fractures per meter for the interval can be inferred (see Appendix A). These values are consistent with the ranges of values observed in the field (c.f., Long and WCC, 1984).

This test was performed in the McCoy Canyon flow top between boreholes DC-7 and DC-8 which are laterally separated by 55 ft at the test interval. The validity of the calculated effective porosity value at the larger scales of interest for repository performance assessment depends on the degree to which the flow at those scales is dominated by fractures and joints. This will depend in turn on the continuity or "connectedness" of the fracture network on these scales, as explored (in a different context) by Smith and Schwartz (1984). If the fracture network is interrupted on these larger scales by intact rock, the effective porosity will be affected more by the effective porosity of the matrix rock, and could be significantly higher than the effective porosity on the smaller scales at locations dominated by fracture flow. If, on the other hand, groundwater flow at the larger scales is also dominated by fractures, or if the tests are performed within isolated unfractured zones, the large-scale effective porosity could be larger, equal, or smaller than the value measured on the test scale. This scale-dependence of effective porosity is an area of great technical interest which requires more research. It is of significant programmatic interest as well, since the representativeness of this low effective porosity value at larger scales is a key question in assessments of the suitability of the site for a HLW repository. An important related question is whether the medium may validly be assumed to act as an equivalent porous medium at the scale of testing or modeling, or whether the geometry of the individual fractures must be taken into account at these scales.

4. SUMMARY

The most important points of the review above are listed below:

1) The Leonhart et al. (1984) document is responsive to NRC's concerns regarding previous tracer test, test analysis and documentation (Gelhar (1982)).

2) The test result is not unreasonable assuming the flow in the flow top breccia to be dominated by the secondary permeability, i.e., of the fractures and joints, as opposed to the primary permeability, i.e. of the matrix blocks.

3) More research, both generic and site specific, is needed to determine whether the effective porosity value derived at the 55 ft test scale is representative of the effective porosity at larger scales. This is especially important if the fracture network is discontinuous at the larger scales or if the frequency of continuous or connected fracture sets is different at the larger scales. The large-scale testing program planned at BWIP may offer insight into this question. The related assumption that the flow top acts as an equivalent porous-medium continuum also warrants further examination.

4) The irregularity of the observed drawdown/buildup in the boreholes warrants additional examination by BWIP to determine its impact on the tracer test, and on the estimate of the transmissivity of the zone.

5) For completeness, the lag time analysis should have been included in the report, as well as an analysis of dispersion in the borehole.

6) It is not clear whether steady state flow conditions were attained during the test.

7) The test and the analysis by Leonhart et al. (1984) reflects the status of BWIP's hydrology program as a leader in the state of the field practice.

<u>FOLLOW-UP ACTIVITY</u>

This review should be transmitted to BWIP and other interested parties. NRC should obtain the drawdown and recovery data from the DC-7 pump test described in Leonhart et al. NRC should also obtain the drawdown and buildup data that may have been collected during the tracer test, if in fact the flow conditions were not steady during the test.

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STEADY STATE FLOW FIELD

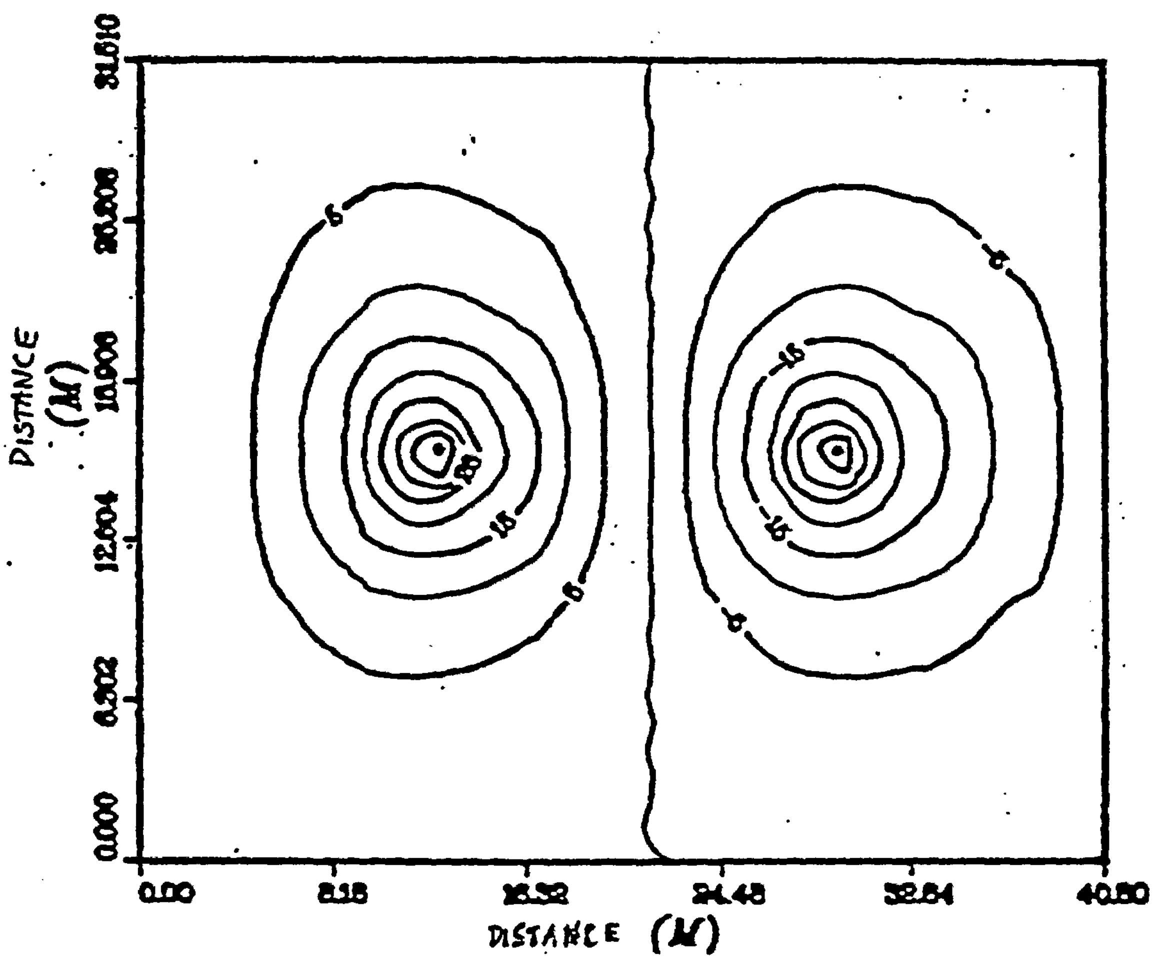

FIGURE 1. CONTOURS OF EQUAL HEAD BUILDUP, IN METERS, FOR HOMOGENEOUS AQUIFER AS DESCRIBED IN TEXT. PUMPING RATE 1 GAL/MIN. NEGATIVE BUILDUP IMPLIES DRAWDOWN. (DC-8 ON LEFT, DC-7 ON RIGHT). THEORETICAL RESULT, FROM NUMERICAL MODEL.

APPENDIX A:

Estimation of Fracture Properties Based on Transmissivity and Effective Thickness Measurements

Assuming prismatic blocks, with flow taking place between parallel fractures and all fractures having equal apertures (2d), the Poiseuille cubic law identifies the transmissivity of each fracture (T_f):

$$T_f = \frac{(2d)^3 \rho g}{12\mu} \qquad (1)$$

where ρ is the fluid density and μ is the fluid viscosity. The total transmissivity of the aquifer is equal to the sum total transmissivity of all the fractures in the interval plus the transmissivity of the matrix. However, the transmissivity of the matrix is generally much lower than the transmissivity of the fractures, and can be neglected for fractured media. The total global interval transmissivity is thus

$$T_g = \frac{(2d)^3 \rho g}{12\mu} \times N \qquad (2)$$

where N = number of fractures in interval
$\quad = B/(2a)$ (3)
where 2a = separation distance between fractures
and B = interval thickness

This global transmissivity applies to the equivalent porous-medium continuum.

The effective porosity within each fracture is, of course, unity. The effective thickness (n_eB) of the interval (i.e., the global effective thickness), which would apply to the equivalent porous-medium continuum, is equal to (c.f., Huyakorn et al., 1983)

$$n_eB = \frac{2d\ B}{2d + 2a} \qquad (4)$$

Since 2d << 2a, n_eB can be approximated as

$$n_eB = B(2d)/(2a) \qquad (5)$$

For the McCoy Canyon flow top, the effective interval thickness (B), global transmissivity (T) and global effective thickness (n_eB) are known (11.3 m, .065

m^2/day and .0018 m respectively). Therefore, equations (2), (3) and (5) are three equations in three unknowns (2d, N, and 2a) and the solution of these equations is:

$$2d = 2.3 \times 10^{-5} \text{ m}$$
$$N = 79.8 \text{ fractures}$$
$$2a = 1.4 \times 10^{-1} \text{ m}$$