FLOW OF GROUNDWATER AND TRANSPORT OF CONTAMINANTS THROUGH SATURATED FRACTURED GEOLOGIC MEDIA FROM HIGH-LEVEL RADIOACTIVE WASTE

QUARTERLY REPORT
JULY-SEPTEMBER 1986

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NRC Project Manager
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INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) is committed to providing pre-licensing guidance to the Department of Energy (DOE) in technical areas related to hydrogeology and to evaluating the technical content of DOE's documents leading to licensing decisions about high-level radioactive waste (HLW) disposal. To this end, the NRC staff will need to prepare specific staff technical positions related to acceptable methods and techniques for characterizing and assessing saturated fractured geologic media. The objective of the contract work described herein is to provide the NRC with research products which may support and/or confirm the basis for such technical positions and to provide a capability sufficient for evaluating DOE documents related to groundwater flow and transport in saturated rocks in which HLW disposal is being considered.

The contract work is comprised of seven study components (Tasks 1 through 7) and an annual seminar (Task 8). According to the final project proposal, the tasks and their projected durations are as follows:

Task 1: Relationship of field-scale measurements of hydrologic and transport parameters to length scales used in modeling (October 1985 to March 1988)

Task 2: Characterization of potentially important discrete hydraulic features (October 1985 to May 1987)

Task 3: Comparison of continuum models versus discrete-fracture models (November 1985 to September 1987)

Task 4: Effective porosity (February 1986 to December 1987)

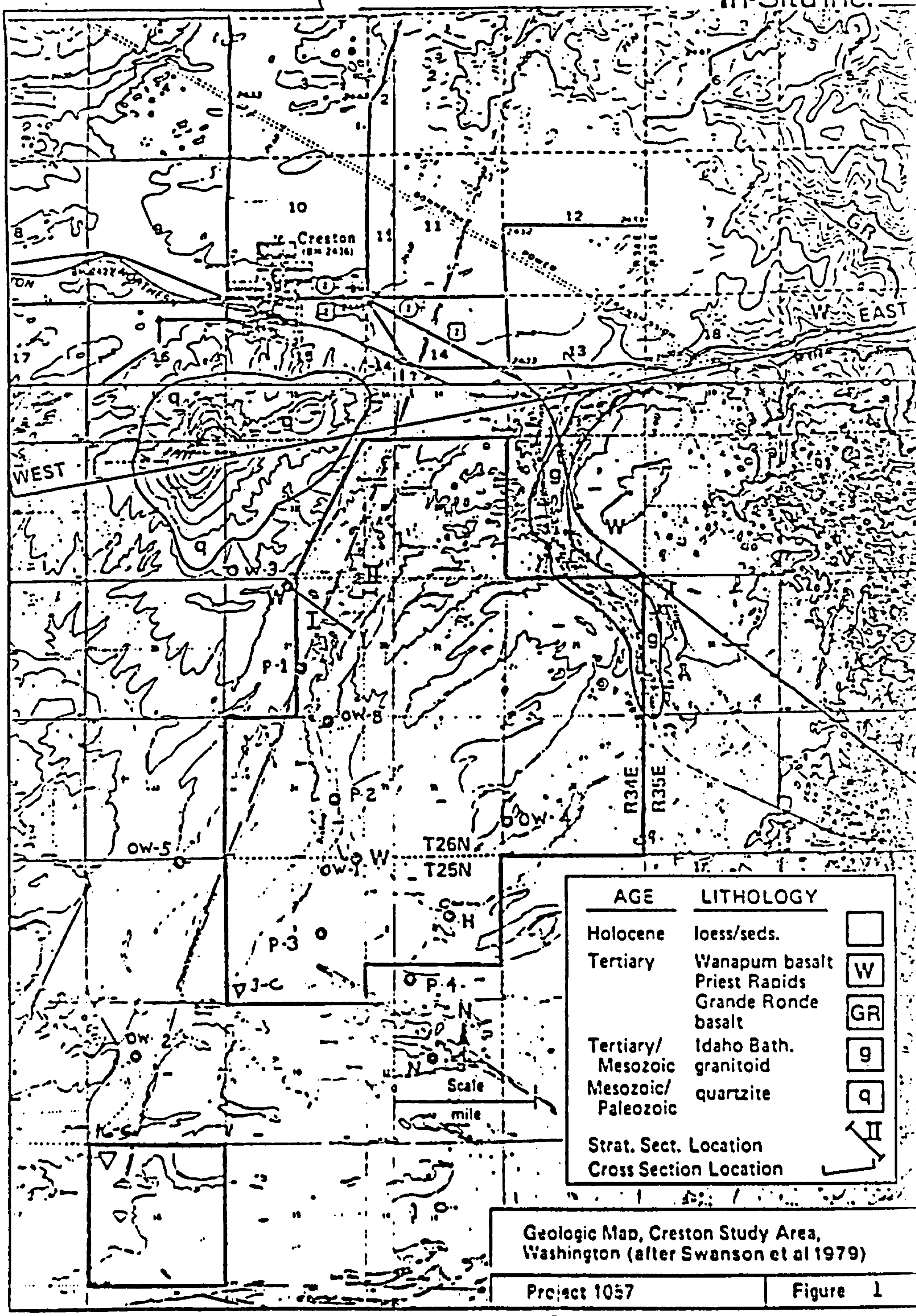
Task 5: Testing theories for spatial projections of dispersivity (August 1986 to December 1987)

Task 6: Matrix diffusion (May 1987 to March 1988)

Task 7: Model calibration based on groundwater dating and hydraulic-parameter estimation based on the use of environmental tracers (October 1986 to July 1988)

Task 8: Annual seminars (July 1986 to September 1988)

During this quarter's reporting period, little or no work has been completed on Tasks 6 through 8. Work activities performed on Tasks 1 through 5 are noted in this progress report, as is work scheduled for the next quarter. Also, proposed work on Tasks 7 and 8 will be addressed. An updated study reference listing is provided in Appendix A. A generalized map of the Creston study area in Washington is given in Figure 1 for referencing certain field activities discussed in this report.



Geologic Map, Creston Study Area, Washington (after Swanson et al 1979)

Project 1057 | Figure 1

Existing Well ● Core –

1.0 TASK 1: RELATIONSHIP OF FIELD-SCALE MEASUREMENTS OF HYDROLOGIC AND TRANSPORT PARAMETERS TO LENGTH SCALES USED IN MODELING

The objective of Task 1 is to evaluate methods of assigning effective parameter values to both fluid-flow and contaminant-transport models with respect to model-length scales and field-scale measurements for characterizing a representative elementary volume (REV).

1.1 WORK SCHEDULED FOR JULY-SEPTEMBER 1986

1.1.1 Document preliminary-study assessment of basalt-fracture system. Subsequent evaluation will be completed after core drilling.

1.1.2 Have Mr. Walter Loo review selected project-related technical reports.

1.1.3 Continue literature survey and associated data-base updating.

1.2 WORK PERFORMED DURING JULY-SEPTEMBER 1986

1.2.1 Field Evaluation and Site Work Logistics.--Aerial photographs and photolineament maps were perused for possible expression in the Creston study area (Figure 1). Three lineaments were identified and were located on a study area map. One was eliminated because of its relation to unstructured topographic lineation. Two others were ground-checked, but no observable surface expression was found at the study area.

The City of Cheny water well #5 drill core was briefly examined noting general characterization of basalts as a dominantly fractured media with local porous media and aquicludes represented by a range of clastic sedimentary interbed units.

1.2.2 Mr. Loo's review of selected technical aspects of previous and planned studies was accomplished during August 1986.

1.2.3 Literature references continue to be added to the project listing. The last update (attached) was made on October 20, 1986.

1.3 WORK SCHEDULED FOR OCTOBER-DECEMBER 1986

1.3.1 Further analysis of the basalt-fracture system will entail correlation of geophysical logs by staff of Washington State University and other related field investigations.

1.3.2 Compare the observed fracture frequency in core (drill holes 16-C and 3-C, see Section 2.2.2) to geophysical logs which also may quantify fracture frequency. This may permit geophysical quantification of fracture frequency in non-core boreholes of the proposed pump-test wellfield (see Section 2.3.3).

1.3.3 Analyze drill core from the 16-C and 3-C core holes for fractures which can be characterized for orientation, aperture and length for purposes of the modeling analyses (Task 3).

1.3.4 Review the core from the 16-C and 3-C core holes for significant fractures that reflect deformation of the basalt media and characterize as found by analysis in item 1.3.3.

1.3.5 If the work performed in Sections 1.3.3 and 1.3.4 reveals measurable fracture attitudes in the core, then the merit of paleomagnetic core orientation for the candidate pump-test horizon should be assessed. Based upon identified needs, evaluate contractor proposals for such work and orient critical segments of the core in the test horizon and collect oriented outcrop samples.

1.3.6 Analyze vesicule abundance in core and compare to appropriate geophysical logs which may quantify rock volume occupied by vesicules. Assess if the vesicule interconnection is predictable from the vesicule volume percentage. This may permit geophysical quantification of vesicle interconnection. Test the vesicle for pore fluid content by desiccation or vacuum, if possible.

1.3.7 A letter request has been submitted to Mr. Loo to resolve the apparent discrepancy in the Tera north-south cross-section depiction, based upon the P-series and OW-series wells.

1.3.8 Continue literature survey and associated data-base updating.

2.0 TASK 2: CHARACTERIZATION OF POTENTIALLY IMPORTANT DISCRETE HYDRAULIC FEATURES

The objective of Task 2 is to consider the problems posed by the presence of discrete hydraulic features such as conduits of rapid flow and transport (e.g., fractures, faults, layers, and abandoned boreholes or shafts) and presence of hydraulic features with slow flow and transport (e.g., sealed fractures and faults, layers of very low permeability, and dikes).

2.1 WORK SCHEDULED FOR JULY-SEPTEMBER 1986

2.1.1 Execute a field-reconnaissance survey of the Creston study site prior to selection of core-drilling sites to evaluate surficial features generating photolineaments which may be fracture-related (based upon field evidence). Measure water levels, completion integrity, and transmissivity (based upon slug tests) in existing wells. Assess the extent to which flow tops are geologically characterized as fractured media (based upon core drilling).

2.1.2 Develop a design for a field-coring program. To assist in this design, conduct discussions with several information sources and evaluate existing available core for the Town of Cheney Well #5. It is proposed that diamond core be obtained from two sites in Sections 3 and 16, T 25 N, R 34 E. The core and borehole logs will be used to more accurately characterize the aquifers and to augment the design of pumping and observation wells in the wellfield. If the field reconnaissance (Section 2.1.1) suggests that a lineament fracture feature exists on the study site, then two proposed core holes (eventual observation wells) should be positioned one on either side of this feature. Also, procedures will be reviewed and methods proposed for statistically analyzing fractures.

2.1.3 Prepare and send out contract-bid documents for a field-coring program. Initiate this program by mid-August 1986, if possible.

2.2 WORK PERFORMED DURING JULY-SEPTEMBER 1986

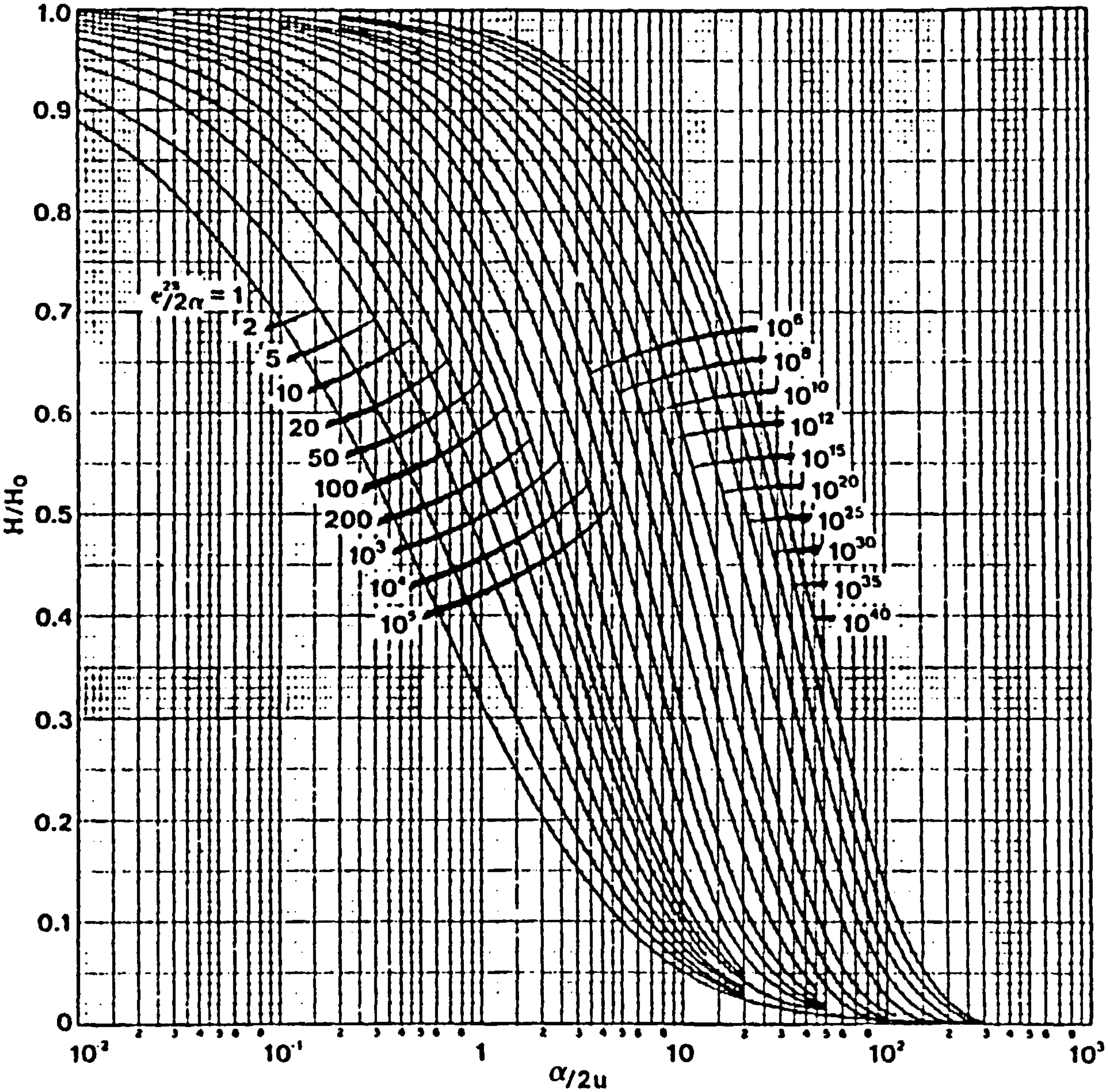
2.2.1 The completion integrity of existing wells in the study area, their static water levels, and associated transmissivities were evaluated by application of the slug-test method. A slug test is a simple and economical means of evaluating hydrologic properties of an aquifer at a point source (i.e., at a single well) and its immediate surroundings. The test basically involves the injection or withdrawal of a slug (a volume) of water into or from a well. Pressure buildup or decay is then measured against time until the pressure in the well attains, or closely approaches, its "pre-slug" value.

The mathematical expression of pressure changes during a slug test was translated into a set of type curves (Figure 2) for various hydrologic conditions. The values of hydraulic conductivity and well damage (skin) can be calculated with the best fit of the data plot to the type curve (Figure 3).

2.2.2 A diamond core-drill program was designed and applied to sample the Wanapum Formation and the upper Grande Ronde Formation. Specific information sought in this program included: lithologies comprising the previously designated "first and second shallow aquifers" (as depicted by Tera (1980) and by Wildrick (1982)), basalt thickness and fracture development (see Task 1), nature of possible aquicludes and tectonic structures. Bid quotations for geophysical electric logging and drilling were evaluated for this program. The final selection for the drilling contractor was based upon: basalt drilling experience, operator experience, service and maintenance capability, site familiarity, availability, prior client recommendations and bid-price quotations. Diamond Drill Contracting Company was selected among six competitive bidders for two NX (approximately 3-in) diamond-drilled core holes. A drilling contract was written by In-Situ and agreed mutually with Diamond Drill Contracting Company. Geophysical logging of those holes was performed by Washington State University. Site logistics requests were submitted and approved by private and State of Washington landowners. Private usage of drilling-water sources was cooperatively arranged with Houger Culture Limited.

2.2.3 Core Drilling and Preliminary Findings.--The first diamond core drill hole in the northwest corner Section 16, R. 34E, T. 25N (Figure 1) was completed to 455 ft on September 5, 1986. The hole penetrated basalt flows of varied vesicular to massive textures, cooling fractures, and two sedimentary interbeds. The interbed between the Wanapum and Grande Ronde Formation basalts is the Vantage Member of the Ellensburg Formation. It was extremely expansive on wetting and quickly bridged the borehole and sealed the Wanapum Formation aquifers from flowing down the 3-in well bore out of the Grande Ronde Formation "thief zone" aquifer. A possible fault zone was indicated by chlorite-filled slip surfaces.

FIGURE 2.- SLUG-SWAB TEST TYPE CURVES



After Ramey, Agarwal, and Martin (1975). Modified from Earlougher (1977).

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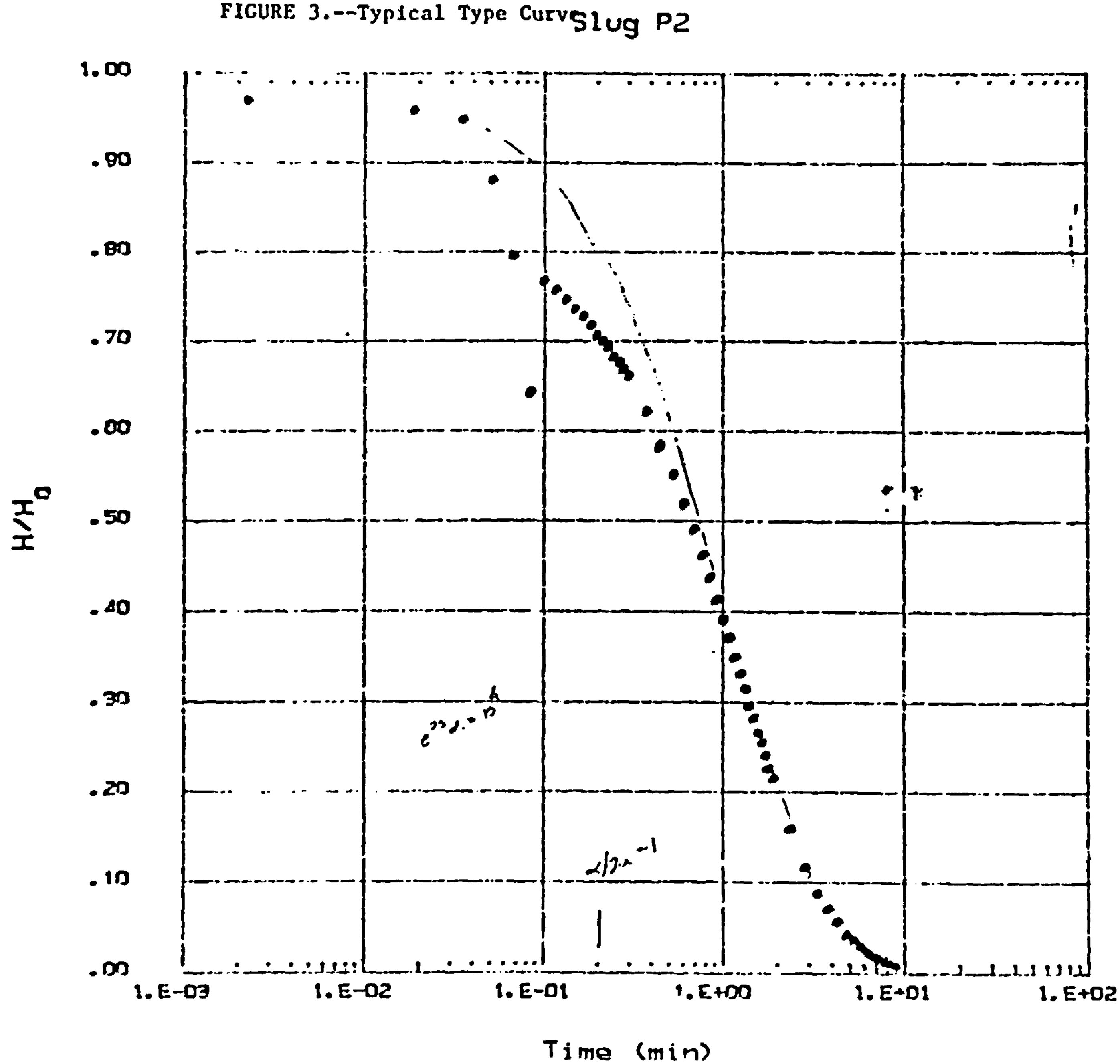
FIGURE 3.--Typical Type Curve



A second core drill hole in the southwest corner of Section 3, R. 34E, T. 25N.(Figure 1) was inclined at -80.5 degrees and complete to 480 ft on October 1, 1986. This inclination on the second drill core hole was used to assure intersection of the borehole with vertical basalt cooling fractures. This hole, located about 1-1/2 miles northeast of the first, penetrated the same lithologies. Specific differences noted at the second hole included: varied number and thickness of basalt flows, less pyrite and chlorite, fewer and tighter fractures, absence of tectonic structures, a prominent breccia zone, a prolific aquifer and prominent "thief zone" in the Wanapum Formation.

Regarding this core-drilling program, extending from August 22 through October 1, 1986, progress reports were made about weekly by In-Situ to NRC by phone. A written preliminary field report on the 16-C hole was sent to NRC on September 17, 1986 (Appendix B), and a field report on the 3-C hole was given to NRC during discussions in Denver on October 14, 1986 (Appendix C).

2.3 WORK SCHEDULED FOR OCTOBER-DECEMBER 1986

2.3.1 During mid-October 1986, install a water-level monitoring network of selected wells in the part of the study area of immediate interest. This network program will be operated during approximately 6-7 months from mid-October 1986 to about mid-April or mid-May 1987. Also, measure other static water levels and collect water samples for selected chemical characterization.

2.3.2 Select the stratigraphic horizon in the Wanapum Formation or upper Grande Ronde Formation that optimizes the overall objectives of the study.

2.3.3 Finalize a wellfield design for the study-site tests for the 1987 summer field season.

2.3.4 Plan and design well specifications for aquifer characterization and tracer testing.

2.3.5 Develop contractor-bid documents for rotary/hammer drilled pumping and observation wells.

3.0 TASK 3: CONTINUUM MODELS VERSUS DISCRETE-FRACTURE MODELS

The objective of Task 3 is to provide the NRC with guidance on which types of models are appropriate for various types of saturated fractured rocks.

3.1 WORK SCHEDULED FOR JULY-SEPTEMBER 1986

3.1.1 Continue development of the model-comparison analysis for saturated fractured geologic media.

3.1.2 Complete comparisons among simulated contaminant transport in saturated fractured geologic media using the selected alternatives of a discrete fracture model, analytical model and continuum model.

3.1.3 NRC is to assist In-Situ in obtaining access to documentation and source codes from Sandia National Laboratories for the following computer programs: (1) SWIFT II, (2) NWFT/DVM, and (3) Latin Hypercube Sampling (LHS).

3.2 WORK PERFORMED DURING JULY-SEPTEMBER 1986

3.2.1 The stochastic discrete-fracture, two-dimensional code developed at the University of Alberta, Canada (Schwartz and Crowe, 1980; Schwartz, Smith, and Crowe, 1983; Smith and Schwartz, 1984) is operational on In-Situ's VAX 11/780. This code can simulate flow and transport through stochastically generated orthogonal-fracture networks.

3.2.2 On September 10, we submitted to NRC the necessary user forms obtained on August 27 for access to SWIFT II through time-sharing on DOE's INEL computer in Idaho Falls, Idaho. We have not yet received the NWFT/DVM or LHS codes from NRC. Therefore, the only discrete-fracture code available to us at this time is that from the University of Alberta. We have not yet run any computer-model test cases, because we are waiting for the NWFT/DVM and LHS codes. Upon receipt of these codes, we can proceed with the model-comparison analysis.

3.3 WORK SCHEDULED FOR OCTOBER-DECEMBER 1986

3.3.1 Continue a model-comparison analysis for fractured porous media.

3.3.2 Complete a preliminary analysis of comparisons among simulated contaminant transport in fractured porous media using the discrete-fracture model, an analytical model, and a continuum model.

4.0 TASK 4: EFFECTIVE POROSITY

The objective of Task 4 is to assess effective porosity more accurately with respect to identified modeling needs.

4.1 WORK SCHEDULED FOR JULY-SEPTEMBER 1986

4.1.1 Complete detailed design of field aspects of the selected tracer tests. The resultant design should take into consideration the placement and completion of new wells included in the drilling and aquifer-characterization program (see Task 1); this aspect may not be completed during this quarter. A long-term laboratory-column test for assessing adsorption or absorption process and other losses of tracers will be designed.

4.1.2 Review and continue work on tensorial porosity and prepare a progress report.

4.2 WORK PERFORMED DURING JULY-SEPTEMBER 1986

4.2.1 Analysis was performed of a segment of the 16-C NX core discussed under Task 2. The segment analyzed for mineralogy was in the Wanapum Formation at about 39 ft below land surface. The core was analyzed by Dr. J. I. Drever. The core contained a large number of vesicles on a scale of about 1-10 mm. Some vesicles were empty; however, many contained a white material and fewer contained a buff-colored material. These materials were analyzed in the laboratory and were found to be mineralogically essentially identical. The observed color difference may be due to minor iron-oxide staining. Mineralogically, the material constitutes a smectite, with major ionic components of Al with reduced amounts of Mg and Fe and trace quantities of Ca and Na.

4.2.2 Some theories on tensorial porosity were reviewed; however, no progress report has been prepared during this period. The basic equation for tensorial porosity has been derived, giving the following expression

$$q_i(\vec{F}) = \bar{K}_f \, \bar{n}_{ij} \, F_j,$$

in which the flow, q_i, is related to the fracture characteristics, K_f, the hydraulic gradient, F_j, and a second-rank porosity tensor, n_{ij}.

This equation might well be the final result; however, proof and checking of the concepts leading to the development of the equation would still be required.

4.2.3 A long-term column test was initiated in mid-July 1986. Wamapum Formation samples were placed into two 6-ft columns that were 1.5-in in diameter. The Wanapum Formation sample was broken up and sieved, and only the basalt materials between 3/8 and 1-1/2 in in diameter were used in the column test. Two water samples were used; one was obtained from the Houger domestic well (May 2, 1986) and one was from the Houger irrigation well (June 26, 1986). These water samples were collected by an In-Situ field investigator. A 2-L sample of each water sample was used, mixed with 5 mg/L each of iodide, bromide, and Amino-G tracers. The sampling or testing period will be to draw off a sample for chemical analysis every three months. In each column, the Wanapum Formation basalt has been inundated completely with the water/tracer solution.

4.3 WORK SCHEDULED FOR OCTOBER-DECEMBER 1986

4.3.1 Continuation of the long-term column basalt-tracer test, along with a brief progress report of preliminary study findings.

4.3.2 Continue the review of theories pertaining to tensorial porosity; begin preparation of a task-level progress report on this topic.

4.3.3 Inititate a preliminary design of outlining details for tracer-study applications to field conditions at the study site. This will include specification of spacing criteria between injection and sampling points, recommendations of types and strengths of tracers, and formulation of field and analytical methods for execution of this program component. Aspects of this tracer-study design are to be coordinated with the wellfield design for hydraulic characterization (Task 2, see Section 2.3.3).

5.0 TASK 5: TESTING THEORIES FOR SPATIAL PROJECTIONS OF DISPERSIVITY

The objective of Task 5 is to compare and to correlate selected theoretical techniques on varying distance scales affecting dispersivity with a large-scale tracer-testing program.

5.1 WORK SCHEDULED FOR JULY-SEPTEMBER 1986

5.1.1 Initial work will begin to review theories for spatial projections of dispersivity.

5.1.2 Theories by Gelhar and Collins (1971); Winter, Neuman and Neuman (1984); de Josselin de Jong (1969), and de Josselin de Jong and Way (1972) will be reviewed (references are included in Appendix A). The relationship between dispersivities and fracture distribution will be investigated. Methods for assessing dispersivity at varying distance scales will be examined to compare theory with designed field experiments (see Task 2).

5.2 WORK PERFORMED DURING JULY-SEPTEMBER 1986

Review and critical evaluation were begun on theories indicated above as well as those by Gelhar (1982); Gelhar and Axness (1983); Gelhar, Gutjhar, and Naff (1979); Grove and Beetem (1971); and Pickens and Grisak (1981).

Gelhar (1982) performed a two-well circulation test at the Rockwell Hanford site to compute effective porosity and dispersivity. His assumption of isotropic flow resulted in a lower-than-actual formation porosity, if the flow is strongly anisotropic. His calculation for dispersivity also assumed an isotropic formation.

Gelhar, Gutjhar, and Naff (1979) and Gelhar and Axness (1983) developed specific predictive models of large-scale field dispersion based on the stochastic theory. Simplifications and approximations will be required before their theories can be applied to actual field conditions and associated testing.

Grove and Beetem (1971) used the streamline and developed an equation for concentration as a function of location, time and dispersion. An example was given to illustrate the use of the equation to calculate field dispersion coefficient from a two-well tracer test. Their solution can be applied only in an isotropic formation.

Pickens and Grisak (1981) developed a theoretical scale-dependent dispersivity expression which related the magnitude of longitudinal dispersivity to the statistical properties of the stratified medium and the mean travel distance of the solute.

5.3 WORK SCHEDULED FOR OCTOBER-DECEMBER 1986

This time schedule for this work has shifted, due to schedule modifications encountered in performing Tasks 1 through 4. Continue work on those aspects originally scheduled for July through September 1986.

7.0 TASK 7: MODEL CALIBRATON BASED UPON GROUNDWATER DATING AND HYDRAULIC-PARAMETER ESTIMATION BASED UPON USE OF ENVIRONMENTAL TRACERS

7.1 WORK SCHEDULED FOR OCTOBER-DECEMBER 1986

Work scheduled to begin this quarter is delayed until certain facets of field investigations have progressed further. Specifically, we propose to postpone work on this task until the primary basalt unit/formation of interest is identified.

8.0 TASK 8: ANNUAL SEMINARS

According to the originally prepared task-schedule bar charts, a project-related annual seminar was to have been designed, approved, and executed during the July-September 1986 quarter. Given the delays in several project-related activities and a certain degree of project-study reorientation as discussed at the June 25-26 project-review meeting and field trip, scheduling of the annual seminar was premature. In the last quarterly report, we suggested that the initial seminar be postponed until the last quarter of calendar year 1986 or the first quarter of calendar year 1987. Given the study progress completed to date, and as discussed in a Denver meeting during October 14-15, 1986, we propose to conduct this seminar during the first quarter of calendar year 1987, with a target date tentatively scheduled for late January 1987. We plan to prepare an agenda for this seminar in late November 1986 for comment and review by NRC.

APPENDIX A

AUTHOR	YEAR	TITLE	SOURCE	Ref. No.
	1984	Revised Modeling Strategy Document for HLW Performance Assessment	US NRC (Lakewood)	720
Abdassah, D., I. Ershaghi	1986	Triple-Porosity Systems for Representing Naturally Fractured Reservoirs	SPE Form. Eval., April, pp. 113-127	610
Adyalkar, P.G., V.V.S. Mani	1972	Hydrologic Boundary Analysis in Basaltic Aquifers	Current Sci., v.41, no.4 (Feb. 20), pp. 127-129	806
Aguilera, R., H.K. Van Poollen	1978	Geologic Aspects of Naturally Fractured Reservoirs Explained	Oil & Gas Journal, v.76, no.51, pp. 47-51	107
Ahlstrom, S.W., R.J. Serne, R.C. Routson, D.B. Cearlock	1974	Methods for Estimating Transport Model Parameters for Regional Groundwater Systems	Battelle Pacific Northwest Labs, Richland, WA, for Atlantic Richfield and US AEC, BNWL-171.	713
Anderson, M.P.	1984	Movement of Contaminants in Groundwater: Groundwater Transport - Advection and Dispersion	In Groundwater Contamination: Studies in Geophysics (Washington, D.C.: National Academy Press), pp. 37-45	210
Athy, L.F.	1930	Density, Porosity, and Compaction of Sedimentary Rocks	Bull., Amer. Assoc. Petrol. Geol., v.14, no.1, pp. 1-24	303
Bardsley, W.E., A.D. Sneyd, P.D.M. Hill	1985	An Improved Method of Least-Squares Parameter Estimation with Pumping-Test Data	J. Hydrol., v.80, pp. 271-281	612
Barker, J.A.	1985	Generalized Well Function Evaluation for Homogeneous and Fissured Aquifers	J. Hydrol., v.76, pp. 143-154	60
Bauer, H.H., J. J. Vaccaro, R.C. Lane	1985	Maps Showing Ground-Water Levels in the Columbia River Basalt and Overlying Materials, Spring 1983, Southeastern Washington	USGS Water-Resources Inv. Rept. 84-4360 (map)	512
Bencala, K.E., et al.	1984	Interactions of Solutes and Streambed Sediment, 1: An Experimental Analysis of Cation and Anion Transport in a Mountain Stream	Water Resour. Res., v.20, no.12, pp. 1797-1803	403
Bibby, R.	1981	Mass Transport of Solutes in Dual Porosity Media	Water Resour. Res., v.17, no.4, pp. 1075-1081	304
Bottomley, D.J., J.D. Ross, B. W. Graham	1984	A Borehole Methodology for Hydrogeochemical Investigations in Fractured Rock	Water Resour. Res., v.20, no.9, pp. 1277-1300	123

AUTHOR	YEAR	TITLE	SOURCE	Ref. No.
Brown, M.C., D.C. Ford	1971	Quantitative Tracer methods for investigation of Karst Hydrologic Systems	Trans. Cave Research Group of Gt. Britain, v. 13, no. 1, pp. 37-51	407
Campbell, J.E., D.E. Longsine, R.M. Cranwell	1981	Risk Methodology for Geologic Disposal of Radioactive Waste: The NWFT/DVM Computer Code, Users Manual	Sandia National Labs for US NRC, NUREG/CR-2081, SAND81-0886	2081
Carrera, J., S.P. Neuman	1986	Estimation of Aquifer Parameters under Transient and Steady State Conditions: 3, Application to Synthetic and Field Data	Water Resour. Res., v.22, no.2, pp. 228-242	811
Carrera, J., S.P. Neuman	1986	Estimation of Aquifer Parameters under Transient and Steady State Conditions: 2, Uniqueness, Stability, and Solution Algorithms	Water Resour. Res., v.22, no.2, pp. 211-227	810
Carrera, J., S.P. Neuman	1986	Estimation of Aquifer Parameters under Transient and Steady State Conditions: 1, Maximum Likelihood Method Incorporating Prior Information	Water Resour. Res., v.22, no.2, pp. 199-210	809
Cathles, L.M., H.R. Spedden, E.E. Malouf	1974	A Tracer Technique to Measure the Diffusional Accessibility of Matrix Block Mineralization	Solution Mining Symposium, 103rd AIME Ann. Mtg., Dallas, TX, Feb. 25-27, ed. F. F. Aplan et al., pp. 129-147	408
Chapman, T.G.	1986	Entropy as a Measure of Hydrologic Data Uncertainty and Model Performance	J. Hydrol., v.85, pp. 111-126	718
Chen, C.-S.	1985	Analytical and Approximate Solutions to Radial Dispersion from an Injection Well to a Geological Unit with Simultaneous Diffusion into Adjacent Strata	Water Resour. Res., v.21, no.8, pp. 1069-1076	208
Chen, C.-S.	1986	Solutions for Radionuclide Transport from an Injection Well into a Single Fracture in a Porous Formation	Water Resour. Res., v.22, no.4, pp. 508-518	712
Chu, M.S., N.R. Ortiz, K.K. Wahi, R.E. Pepping, J.E. Campbell	1983	An Assessment of the Proposed Rule (10CFR60) for Disposal of High-level Radioactive Wastes in Geologic Repositories, 2 volumes	Sandia National Labs for US NRC, NUREG/CR-3111, SAND82-2969, 2 volumes, report & appendices	3111

AUTHOR	YEAR	TITLE	SOURCE	Ref. No.
Cline, D.R.	1984	Ground-Water Levels and Pumpage in East-Central Washington, Including the Odessa-Lind Area, 1967 to 1981	Washington State Dept. of Ecology, Water-Supply Bull. 55	503
Coffman, W., D. Vogt, M. Mills	1984	A Summary of Computer Codes for Waste Package Performance Assessment	CorSTAR Research Inc. for US NRC, NUREG/CR-3699	3699
Cornwell, D.K., M.D. Murphy	1985	Experiments with Non-Darcy Flow in Joints with Large Scale Roughness	Proc., Int. Symp. on Fundamentals of Rock Joints, Bjorkliden, Sweden, Sept. 15-20, 1985, pp. 323-332	112
Cranwell, R.M., J.E. Campbell, S.E. Stuckwisch	1982	Risk Methodology for Geologic Disposal of Radioactive Waste: The DNET Computer Code Users Manual	Sandia National Labs for US NRC, NUREG/CR-2343, SAND81-1663	2343
Crittenden, J.C., et al.	1986	Transport of Organic Compounds with Saturated Groundwater Flow: Model Development and Parameter Sensitivity	Water Resour. Res., v.22, no.3, pp. 271-284	709
Crosby, J.W., III, J.V. Anderson	1971	Some Applications of Geophysical Well Logging to Basalt Hydrogeology	Ground Water, v.9, no.5, pp. 12-20	903
Curtis, R.H., R.J. Wart	1983	Parameters and Variables Appearing in Repository Design Models	Acres American Inc. for Teknekron Research Inc. for US NRC, NUREG/CR-3586	3586
Curtis, R.H., et al.	1983	Summary of Repository Design Models	Teknekron Research Inc. for US NRC, Final Report, NUREG/CR-3450 (Fiche)	3450
Daemen, J.J.K., et al.	1985	Rock Mass Sealing: Experimental Assessment of Borehole Plug Performance	Univ of Arizona for US NRC, Annual Report June 1983 - May 1984, NUREG/CR-4174	4174
Daemen, J.J.K., et al.	1983	Rock Mass Sealing: Experimental Assessment of Borehole Plug Performance	Univ of Arizona for US NRC, Annual Report June 1982 - May 1983, NUREG/CR-3473	3473
Davis, A.D.	1986	Deterministic Modeling of Dispersion in Heterogeneous Porous Media	Ground Water, v.24, no.5, pp. 609-615	219
Davis, S.N., D.J. Campbell, H.W. Bentley, T.J. Flynn	1985	Ground Water Tracers	National Water Well Assoc., Worthington, OH; project coordinated by the Robert S. Kerr Env. Res. Lab., US EPA	414
De Josselin de Jong, J.	1969	The Tensor Character of the Dispersion Coefficient in Anisotropic Porous Media	Proc., Int. Assoc. Hydrol. Res., Haifa Symposium, pp. 259-267	222

AUTHOR	YEAR	TITLE	SOURCE	Ref. No.
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APPENDIX B

FIELD REPORT 4, Creston Study Area, Washington, September 10, 1986

ISI Project 1057: Flow of Groundwater and Transportation of Contaminants through Fractured Geologic from High-Level Radioactive Waste (Contract No. NRC-04-85-114)

TO: Timothy D. Steele, Project Manager
FROM: Jim A. Paschis, Geologist

SUBJECT: Core-Drilling Summary, Site 3-C (August 22-September 5, 1986)

This report briefly summarizes diamond core drilling at the first location of two planned drill holes. The vertical, NX (3.0 inch diameter) core hole is located in the northwest corner of Section 16, R34E at an elevation of 2245 feet MSL. The core drilling was conducted during the period from August 22 through September 5, 1986. The core is 2 inches in diameter and tested parts of the basalts and sedimentary interbeds and revealed; lithologies, cooling fractures, tectonic structures and hydrologic qualities of formations to the drilled depth of 455 feet.

Core recovery exceeded 97% and loss was mainly due to incompetent fault filling. The drill core has been photographed and lithologically characterized. The drill hole was geophysically logged to a depth of 427 feet. The geophysical logs are in processing and have not been compared to the lithologic log. The hole location was on an abandoned roadway and drill-site reclamation has been completed. These test wells are secured by a locked threaded cap.

Abbreviated summary of drill hole 16-C

Footage: (ft)	Description
0-1	Overburden soil
1-34	Thin interlayered vesicular and massive textured but locally scoracious basalts. Driller reported all drill fluid (well water of Kevin Huger well in Section 9 likely "sourcing" from flowtop A which is coincident with Sinking Creek) lost to formation at 26 feet. Lithology at this location was scoracious basalt and rubblized vesicular basalt. This position likely is correlative with flow top A ie., "first shallow aquifer" as used in prior reports.
34-120	Vesicular basalt with downward decreasing vesicles and decreasing fracture frequency; faults are intersected between 50 and 75 feet and character-

ized by slickensides and total chlorite filling to 1 1/2 inches width.

120-228 Massive basalt about twice as fractured as overlying vesicular portion of this flow. The base of the Priest Rapids Member of the Wanapum Formation is vesicular for about 4 inches. The lowest basalt flow of this member is 194 feet thick and contain no obvious "second shallow aquifer" or flow top B as expected other than several broken zones. Geophysical logs may define the aquifer along with detailed core review.

228-230 Sedimentary interbed of conglomeratic claystone that may be an aquiclude. This may be correlative with the Quincy diatomite.

230-240 Vesicular basalt, partly rubblized and rather strongly chloritized, and vulgar upper portion of the Roza Member of the Wanapum Formation. Entire member contains 1 cm tabular euhedral feldspar crystals.

240-256 Gradational decrease in vesicles and decrease in fracture abundance.

256-361.5 Massive basalt, fracture decreasing toward base. End of Roza Member and base of Wanapum Formation.

361.5-365.5 Sedimentary interbed of completely chloritized, possibly tuffaceous claystone. May be faices of Vantage Sandstone. Prominently expansive and caving. Likely an aquiclude.

365.5-390 Vesicular basalt of the Grande Ronde Formation.

390-404 Massive basalt with base of uppermost basalt flow.

404-455 Thin interlayered vesicular and massive textured basalt flows. Very prominent "thief zone" beginning at 404 feet lithologically coincident with interconnected vesicles and abundant fractures. A fault with 1 foot of core loss exists between 445-448 feet. The hole terminated in a clay filled fault zone with hematite alteration.

Upon removal of the drill string, in less than 20 hours the drill hole bridged at 365 feet, sealed the "thief zone" at 404 feet and permitted upper aquifers in the Wanapum to fill the borehole to a static water level which was maintained at approximately 45 feet prior to intersection of the Grande Ronde "thief zone".

The next hole, 3-C, will be located in the southwest corner of Section 3, one and one half miles north west of hole 16-C. The hole will be drilled at approximately -80°. This inclination will help assure intersection of potentially vertical colonnade fractures.

Revised 10/30/86

APPENDIX C

FIELD REPORT 5, Creston Study Area, Washington, October 7, 1986

ISI Project No. 1057: Flow of Groundwater and Transportation of Contaminants through Fractured Geologic Media from High-Level Radioactive Waste (Contract No. NRC-04-85-114)

TO: Timothy D. Steele, Project Manager
FROM: Jim A. Paschis, Geologist

SUBJECT: Core-Drilling Summary, Site 3-C (September 13-October 1, 1986)

This report briefly summarizes diamond core drilling at the second drill site (3-C) and the completion of this phase of core drilling. It was located in the southeast corner of Section 3, T. 25N, R. 34E at an elevation of 2265 feet MSL. The core drilling was conducted during the period from September 13 through October 1, 1980. The inclined -80.5 degrees NX (3.0 inch diameter) core hole had an unsurveyed bearing of 016 degrees. The purpose of inclination was to assure intersection of possible vertical basalt cooling fractures. This plan was justified, as shown by near 10 degree fractures in the core. This hole inclination also provided limited core orientation at horizontally intersected sedimentary rock bedding planes. The core is 2 inches in diameter and tested parts of the basalts and sedimentary interbeds and revealed: basalt flows, cooling fractures, no obvious tectonic structures, a high volume aquifer and "thief" zone and other hydrologic qualities of formations in the drilled course of 480 feet.

Core recovery was better than 99 percent. The drill core has been photographed and lithologically characterized. The drill hole was geophysically logged to a depth of 480 feet inside the drill string to protect the electric sondes from caving zones. Other segments of the hole were logged open where not caved. Drill hole 16-C was also re-entered for geophysical logging portions which now were believed to contain thermally equilibrated water which previously had been absent. Because drill hole OW-2 is located between the two core holes, several geophysical logs were also obtained there. These will be included in the correlation study being conducted by WSU.

Marquette spring, located approximately 2000 feet west of the 3-C drill site, was pumped at a rate of 8 gallons per minute (gpm) for drill-hole fluid. As formation characteristics warranted (regarding swelling and caving), several borehole fluid additives -- W-90 cement, Poly Drill, limited potassium chloride and bentonite -- were used in the drill hole below 350 feet.

The 3-C drill hole was located on the opposite side (east) of an extensive (10-mile long) photolineament in reference to drill hole 16-C.

An abbreviated summary of drill hole 3-C is as follows:

Footage (ft)	Description
0-1	Overburden soil
1-25.5	Priest Rapids Member basalt flows of the Wanapum Formation; vesicular upper third, outcrop to south (400 ft) shows 2 ft diameter colonnades, broken zone at base
25.5 - 42.5	Next older flow, upper 2/3 vesicular, locally containing montmorillonite; lower third dense massive basalt, generally well fractured.
42.5 - 102	Upper 20 ft vesicular; remainder dense massive basalt, locally containing pyrite.
102 - 130.5	Upper 2/3 vesicular, locally with interconnections, shows oxidation; very productive aquifer begins at 102 ft, capable of generating in excess of 100 gpm, specific conductance 140 umhos/cm, probably coincident with flowtop B, second shallow aquifer.

130.5 - 252	Oldest Priest Rapids basalt flow, upper 80 ft vesicular, contains fractured zone at 144-146 ft capable of "thiefing" 8 gpm drill water supply; lower 30 ft dense massive basalt, quite low fracture density in this flow.
252 - 254	Tan carboniferous, claystone interbed, aquiclude can provide core orientation and fossils. Possibly equivalent to the Quincy Member.
254 - 355	Roza Member of lowest part of Wanapum Formation. Interlayered vesicular to massive textures from 254 to 315 ft, 312 to 348 ft contains breccia zones with an especially prominent zone at 317-324 ft incompletely filled with about 5 percent voids. Thief zone shown and local caving disclosed by geophysical logging 320 to 330 ft. At 349 ft, core orientation possible, moderately fractured.
355 - 361	Sedimentary interbed: green chloritized tuffaceous expansive claystone locally containing carbonized wood probably equivalent to Vantage interbed of the Ellensburg Formation. Extremely difficult to core drill due to swelling which could best be achieved using potassium chloride and bentonite at 90+ cps viscosity.
361 - 480	Upper part of uppermost Grande Ronde Formation basalt. Upper 1.5 ft intensely chloritized as a rubbly paleo-weathered zone; down to 372 ft contains abundant, scattered but large vesicules thereafter only scattered vesicules; essentially dense massive basalt transitionally beginning about 380 ft and continuing to total depth drilled, except for local internal vesicular horizon 426.5 to 434.5 ft. Contains irregular, low-angle rough fractures, probably colonnade cooling fractures but mainly abundant, wavy, randomly oriented, tight fractures of short continuity. Contains sparse pyrite, chlorite and manganese oxides.

After removal of the drill string, the static water level was measured at 14.4 ft below ground level. The aquifer water was collected for chemical analysis and slug tests were obtained on both core holes 3-C and 16-C. The core will be reviewed for further detailed study, and it is planned that this core hole be set up with hydrologic-monitoring instruments for water-level measurements over the winter and early spring months.

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