Third-Party Technical Peer Review of Hanford Site Performance Assessment and Grout Performance Assessment

Final Report

Prepared for the U.S. Department of Energy
Assistant Secretary for Environment, Safety and Health

Westinghouse
Hanford Company Richland, Washington

Hanford Operations and Engineering Contractor for the
U.S. Department of Energy under Contract DE-AC06-87RL10930

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Richland, Washington 99352

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EXECUTIVE SUMMARY

This report presents the results of an independent third-party technical peer review of Westinghouse Hanford Company performance assessment activities. The objective of the technical peer review panel was to obtain independent, third-party expert opinions on the apparent adequacy of the current and planned efforts of Westinghouse Hanford Company and its Hanford Site subcontractor, Pacific Northwest Laboratories, a division of Battelle Memorial Institute, to develop and apply the data base and predictive analytical tools needed to achieve the goals of the Hanford Site performance assessment program. Additionally, the peer review panel was assembled to serve as a Technical Advisory Panel for Hanford Site Performance Assessments. During this review, the panel reviewed the performance assessment of grouted double-shell tank wastes. The ultimate objective of the technical peer reviews is to improve the cost-effectiveness and defensibility of decisions regarding the suitability of methods of remediation and permanent disposal of radioactive and hazardous chemical wastes at the Hanford Site.

The peer review panel was composed of nationally known scientists selected from the following disciplines: groundwater hydrology/hydrogeology; hydrochemistry/geochemistry; soils physics; and health physics/risk analysis. The panelists reviewed six documents related to performance assessment and participated in a technical workshop at the Hanford Site on July 25-27, 1989.

In review of both the Hanford Site performance assessments and the grout performance assessment, the panel found strong, clear consensus on the following two principal concerns:

- The performance assessment function is not sufficiently integrated with other, related program functions

- Performance assessment activities are not sufficiently sensitive to the need for a sound data basis for predictive models and results.

The panel found that performance assessment activities appeared to be isolated and focused inward on code-development and code-function concerns and that the data basis for performance assessment model development and use is insufficient. The panel recommends that action should be taken to assure adequate links between data acquisition, model development and selection, results utilization, and program evolution decisions. Additionally, the panel recommends that effort be dedicated to assurance that data acquisition activities are commensurate with needs for performance assessment activities and for use of performance assessment results.

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1.0 INTRODUCTION

Westinghouse Hanford Company (Westinghouse Hanford), operating contractor of the Hanford Site in Washington State for the U.S. Department of Energy (DOE), is developing and applying the technology to assess the suitability of methods proposed for remediation and disposal of radioactive and hazardous chemical wastes. These wastes have accumulated at the Hanford Site during the past 40 years as by-products of the production of fissionable materials for defense purposes. Management of these wastes in the future is expected to include various cost-effective remediation and disposal activities that ensure long-term public health and safety.

This report describes the results of an independent third-party technical peer review of Westinghouse Hanford performance assessment activities. The activities reviewed included the Hanford Site Performance Assessment (HSPA) and the Grout Performance Assessment. Advanced Sciences, Inc. (ASI) provided support to Westinghouse Hanford in conducting this review by identifying and retaining qualified scientists to serve as panelists, coordinating arrangements for a workshop with the panelists at the Hanford Site, and documenting the findings of the panelists.

This report is organized into two sections. Section 1 is the introduction describing the objectives of the peer review panel, and the approach used to meet those objectives. Section 2 presents the comments and recommendations of the peer review panel in two subsections, one of which reports the panel's comments on the Grout Performance Assessment and the other, the panel's comments on HSPA. Appendices to this report contain resumes of the panelists, the workshop agenda, and detailed comments received from the individual panelists.

1.1 OBJECTIVES OF PERFORMANCE ASSESSMENT

Performance assessment (PA) is a multidisciplinary "systematic analysis of the potential risks posed by waste management systems to the public and environment and a comparison of those risks to established performance objectives" (DOE 1989). Performance assessment at the Hanford Site consists of both technology development activities (i.e., HSPA) and applications activities (e.g., the Grout PA). The HSPA provides basic investigations for developing analytical capabilities and the data base to be used in the applications programs. The applications programs, such as the Grout PA, implement the performance assessment process to estimate whether a system, as designed, will comply with applicable performance measures.

1.2 OBJECTIVES OF THE PEER REVIEW PANEL

The objective of the technical peer review panel was to obtain independent, third-party expert opinions on the apparent adequacy of the current and planned efforts of Westinghouse Hanford and its Hanford Site subcontractor, Pacific Northwest Laboratories (PNL), a division of Battelle Memorial Institute, to develop and apply the data base and predictive

analytical tools needed to achieve the goals of the program. Additionally, the peer review panel was assembled to serve as a Technical Advisory Panel for Hanford Site Performance Assessments. During this review, the panel reviewed the performance assessment of grouted double-shell tank wastes. The ultimate objective of the technical peer reviews is to improve the cost-effectiveness and defensibility of decisions regarding the suitability of methods of remediation and permanent disposal of radioactive and hazardous chemical wastes at the Hanford Site.

1.3 APPROACH

To achieve the stated objectives, the performance of the peer review consisted of: a) identification and selection of qualified experts to serve as panelists; b) review by the panelists of six PA-related documents; c) participation by the panelists in a workshop at the Hanford Site on July 25-27,1989, consisting of technical presentations and tours of facilities; and d) obtaining written comments from the panelists both individually and collectively. This section describes the selection of panelists, documents reviewed, and the content of the Hanford Site workshop. The comments and recommendations of the panelists are presented in Section 2.0.

1.3.1 Selection of Panelists

The selection of the peer review panel consisted of identifying qualified scientists and engineers who are not members of the organizations that completed the work being reviewed. Panelists were selected from the following technical disciplines:

1. Groundwater Hydrology/Hydrogeology: Experience in arid-lands groundwater hydrology, with knowledge of modeling water balance and vadose-zone groundwater movement.

2. Hydrochemistry/Geochemistry: Experience specific to issues concerning release and transport of contaminants in groundwater -- for example, leaching and corrosion modeling, groundwater chemistry, complexation of contaminants, and sorption/desorption of chemical and radioactive contaminants by soil minerals.

3. Soils Physics: Experience specific to the field measurement and simulation by computer-encoded models of vadose zone soil-moisture balance and groundwater movement in arid climates, including the effects of plant-uptake, heat transfer, and hysteresis.

4. Health Physics/Risk Analysis: Experience specific to assessing the effects on human health of radionuclides and hazardous chemicals, resulting from waste disposal and subsequent transport of contaminants to the accessible environment through groundwater and atmospheric pathways.

Candidates within each technical discipline were selected based upon the following criteria:

1. National reputation for expertise in one of the disciplines identified above, and additional familiarity with uncertainty, sensitivity, or probabilistic risk analyses.

2. Knowledge of nuclear and hazardous chemical waste clean-up and disposal issues and problems, including pertinent federal and Washington State regulations.

3. Area-specific knowledge of the Hanford Site or analogous arid-lands hydrogeologic environments.

4. Absence of real, apparent, or potential conflicts of interest.

Based on the criteria presented above, the following panelists were selected from the technical disciplines indicated:

1. John W. Bartlett, Ph.D., Health Physics/Risk Analysis

2. Donald Langmuir, Ph.D., Hydrochemistry/Geochemistry

3. Shlomo P. Neuman, Ph.D., Groundwater Hydrology/Hydrogeology

4. Daniel B. Stephens, Ph.D., Groundwater Hydrology/Hydrogeology and Soils Physics

5. Edwin P. Weeks, Groundwater Hydrology/Hydrogeology

Appendix A contains resumes for each of the panelists selected. Dr. John W. Bartlett was selected by the panelists to serve as chairman. Dr. Bartlett was responsible for coordinating the receipt of comments from the individual panelists and preparing the panel's consensus report.

1.3.2 Documents Reviewed

Before attending the Hanford Site workshop, the panelists were provided the following documents for their review:

1. Davis, Performance Assessment Technology Developments for Cleanup and Disposal of Hanford Defense Wastes.

2. McNair, et al. Performance Assessment of Grouted Double-Shell Tank Wastes at Hanford.

3. Seitz, et al. Compliance Strategy for Performance Analysis Requirements in the U.S. Department of Energy Order 5820.2A.

4. DOE, 1989a, "Third-Party Benchmark and Verification Testing of the PORFLO-3 Version 1.0 Computer Code for Simulating Fluid Flow, Heat and Mass Transport in Variably Saturated Media."

5. DOE, 1989b, "Third-Party Benchmark and Verification Testing of the UNSAT-H Computer Code for Simulating Vadose Zone Water Balance-Versions 1.1 and 2.0."

6. Westinghouse Hanford Company, 1989, "Performance Assessment Section, Single-Shell Tank Waste Action Plan" (Draft).

1.3.3 Hanford Site Workshop

The peer review panelists attended a technical workshop at the Hanford Site on July 25-27, 1989. The workshop agenda is provided in Appendix B. The workshop consisted of two days of technical presentations. The presentations provided insight into the technology development process being conducted by the HSPA and provided details regarding the performance assessment of grouted double-shell tank wastes at the Hanford Site. The third day of the workshop was devoted to tours of several of the Hanford Site facilities that are conducting research related to the PA programs. An executive session was also held on the third day of the workshop to allow the panelists time to formulate their consensus comments.

2.0 COMMENTS AND RECOMMENDATIONS

This section presents the comments and recommendations of the peer review panel. The section is divided into two subsections. The first subsection presents comments related to the Grout Performance Assessment. The second subsection presents the consensus of the panel. The consensus is primarily directed to HSPA but, as is evident in the following sections, the comments apply equally to the Grout Performance Assessment. This section is intended only to provide an overview of the panel's comments and recommendations. The comments and recommendations of each panelist are contained in Appendices C-G and provide details on the findings of the panel.

2.1 COMMENTS ON GROUT PERFORMANCE ASSESSMENT

The following comments and recommendations on the Grout Performance Assessment are extracted from the panelists' individual comments (Appendices C-G). The comments generally point to the need for further characterization of the site and waste forms, thorough uncertainty analyses, and complete integration of data collection and modeling activities as indicate in Section 2.2.

2.1.1 Site Characterization Data and Uncertainty Analysis

The site characterization efforts, as presented in McNair et al. (1989) and in the technical presentations, appear to be insufficient for a final performance assessment of the grouted double-shell tank wastes. Hydrogeologic characteristics of the vadose zone based on disturbed samples collected from

three boreholes, as described in McNair et al. (1989), contribute substantial uncertainty to the conceptual model. Further hydrologic and geochemical tests and measurements, including in-situ tests, are recommended. Additionally, analysis of the following should be undertaken: uncertainty due to such factors as sedimentary textural interfaces, hydraulic properties, geologic heterogeneities such as clastic dikes, desiccation or cracking of the grout, or differential settlement or cracking of the clay cap.

2.1.2 Waste-Form Characterization

There appears to be insufficient characterization of the grouted waste forms. Diffusion studies performed using distilled water or Hanford groundwater are inadequate by themselves to provide useful predictive data. Experiments involving vadose water interaction with grouted waste forms should be performed. Detailed characterization of the waste using optical thin section and scanning electron microscopy analyses to learn how salts are incorporated in the grout should also be initiated. Additionally, analysis of the thermal and physical stability of the grouted waste and a comprehensive uncertainty analysis of grout stability are needed.

2.2 COMMENTS ON HANFORD SITE PERFORMANCE ASSESSMENT

This section presents the panel's principal findings and recommendations. These comments are primarily directed to the HSPA, but based on the findings presented above, also apply to the Grout Performance Assessment. In overview, the panel found strong, clear consensus on two principal concerns:

- The performance assessment function is not sufficiently integrated with other, related program functions; and
- Performance assessment activities are not sufficiently sensitive to the need for a sound data basis for predictive models and results.

These and related key findings and recommendations are discussed below. Many of the comments of each panelist contained in Appendices C-G provide detail for the comments and recommendations presented below; others address other subjects considered during the review.

2.2.1 Programmatic and Organizational Integration of Performance Assessment

On the basis of information presented to the panel and dialogue between the panelists and Hanford Site personnel, the panelists developed a strong consensus and concern that the performance assessment activities, attitudes, and management are not sufficiently integrated with related environmental program functions.

Specifically, the regulatory-requirements basis for performance assessment (PA) activities, the data basis for PA effectiveness, and the (expected) PA role in overall program evolution were not evident to the

panel. The PA activities appeared to be isolated and focused inward on code-development and code-function concerns.

The PA function should have and display (more clearly than was shown at this review) a clear sense of programmatic mission. Organization interfaces, input and output requirements, and job performance criteria (e.g., capabilities of models and quality of modeling results) should be clearly defined, especially with regard to regulatory compliance requirements.

The panel considers this -- with the closely-related data-basis concern discussed in Section 2.2.2 -- to be its most significant finding and concern. If PA is not sufficiently integrated with related program functions, there is great potential that results (i.e., performance predictions) will be insufficient and indefensible in their applications. The overall program will also be vulnerable to criticisms concerning costs and planning and functional effectiveness.

Programmatic integration of PA functions is a long-standing concern. It was a problem for the Basalt Waste Isolation Project, it is currently a problem for the commercial High Level Waste (HLW) program; and it is a problem for environmental programs at other DOE sites. To resolve these problems, it is essential that management dedicate attention and effort to issues, information, requirements, and decisions involving the <u>interfaces</u> between PA and related program activities.

The panel recommends that the Hanford Site program exhibit strong, effective stewardship and leadership by dedicating effort to eliminating this concern for this program. Management action should be taken to assure adequate links between data acquisition, model development and selection, results utilization, and program evolution decisions.

2.2.2 Data Basis for PA Model Development, Selection, Verification, and Use

The panel found, on the basis of presentations and discussions, that the PA function is insufficiently sensitive to the need for, and use of, data as the basis for model-related activities. The panel is concerned that this deficiency will produce indefensible models and assessment results.

There are numerous subsets in this concern; e.g., code content, code calibration and verification, matching of data-code-results scales, uncertainty in results, and defensibility of results. These are addressed further in the panelists' individual comments in Appendices C-G. Overall, as presented to the panel, the model-development-and-use part of the program appears to be outstripping the data base development activities that are essential in support of PA, and the program does not appear to be aware of the gap and its significance.

The panel recommends that the program, as a priority action, dedicate management and staff effort to assurance that data acquisition activities are commensurate with needs for PA activities and for use of PA results. Because of the complexity and diversity of the Hanford Site geologic setting, contamination, and waste forms, this effort should include evaluations of the

feasibility of uncertainty reduction through data acquisition in order to meet regulatory requirements. In this activity it would be useful for the program to interact with T. W. Woods and G. Jansen of Westinghouse Hanford System Engineering Technologies.

2.2.3 Explanation of Past and Present to Add Credence to Predictions

The panel found that the program could beneficially apply more effort to modeling and data acquisition activities related to explaining present Hanford Site contamination conditions and their prior evolution. In the panel's opinion, capability to demonstrate, with models, understanding of existing Hanford conditions would add significantly to the credibility of predictive models and to defense, in the regulatory arena, of the results they produce.

The Hanford Site provides numerous opportunities to characterize and model contamination conditions which are "initial conditions" or analogs of conditions for which predictions will be required. The record of past environmental stewardship that was made available to the public by DOE several years ago should be useful for this activity. The PA staff should also contact G. Jansen, who is modeling contamination releases based on process flow sheets and operating history at the Hanford Site.

2.2.4 Expansion of Technical Communications

The panel found that the Hanford Site PA program is engaged in state-of-the-art activities analogous to those in the commercial HLW program and at other major DOE sites such as Oak Ridge, Tennessee. The panel believes that PA program activities and personnel would benefit greatly from peer interactions with personnel of other programs, and suggests that the program take initiatives to accomplish such interactions, e.g., in topical workshops.

The panel also believes the PA program personnel would benefit from review of the Performance Assessment portion of the Yucca Mountain Site Characterization Plan (SCP), Section 8.3.5. The SCP reflects comprehensive consideration of requirements for PA in a regulatory compliance arena such as the Hanford Site program will face.

The panel particularly recommends review of the SCP sections concerning probabilistic PA evaluations and scenarios of future conditions. Information presented to the panel indicated that a narrow range of deterministic scenarios for the future is being considered. In regulatory practice, a broader approach to scenario selection and evaluation will probably be needed.

2.2.5 Need for Site Characterization and Resolution of Scientific Issues

This is a subset of finding 2.2.2 concerning expansion of the data basis for model-related activities. The panel is especially concerned that the presentations and discussions did not show sufficient understanding of the need for greatly improved characterization of the Hanford geologic setting or of scientific issues embedded in model development and selection.

With regard to the Hanford Site geologic setting, the panel believes the site is at present very poorly characterized in comparison with what will be needed to produce reliable models and results for contaminant transport, and also believes the presentations did not reflect sufficient sensitivity to this issue. The panel urges priority attention to this topic, with focus on site-scale characterization.

With regard to scientific issues, the panel is particularly concerned about program understanding and treatment of issues involving transitions between scientific principles and "engineering approximations", e.g., modeling of retardation. The panel urges great attention to the details of such transitions and to requirements for data to substantiate them. A thorough audit trail of approximations, concomitant uncertainties, and impacts on uncertainty in predictions will be needed for regulatory reviews.

3.0 REFERENCES

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APPENDIX A

RESUMES OF PANELISTS

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JOHN W. BARTLETT

1978-Present. THE ANALYTIC SCIENCES CORPORATION, READING, MA.

Manager of Nuclear Technology. Significant functions and activities include:

- Management or oversight of all nuclear waste projects at TASC.
- Selected for People to People Radioactive Waste Disposal Delegation to the People's Republic of China.
- Directed 35-person nationwide team of academicians and consultants who performed a Licensing Assurance Review of the draft Site Characterization Plans for BWIP.
- Served for five years as Chairman of the Technical Review Group for DOE-BWIP.
- Selected as Chairman of Systems Engineering Peer Review Group for DOE.
- Serve as technical consultant to the Utility Nuclear Waste Management Group, with major contributions to utility inputs to: the NRC Confidence Proceedings; promulgation of 40 CFR 191, 10 CFR 60, and 10 CFR 960; comments on the Environmental Assessment documents; comments on the DOE/OCRWM Mission Plans.
- Participated in preparation of the Interagency Review Group report.
- Served as speaker at the Orcas Island Consultation and Concurrence Conference.
- Active in nuclear waste management activities of the American Nuclear Society including service as member of the Executive Committee of the Fuel Cycle and Waste Management Division (two terms); Waste Management Committee (two terms); President's Special Committee on Nuclear Waste and Transportation (three terms); Advisory Committee to University of Arizona Waste Management meetings.

1968-1978. BATTELLE, PACIFIC NORTHWEST LABORATORIES, RICHLAND, WA.

Manager of System Studies, Nuclear Waste Technology Program Office. Significant functions and activities included:

- Initiated and directed activities that have evolved into the performance assessment function in the HLW disposal program.
- Directed preparation of the waste disposal Technical Alternatives Document, ERDA-76-43, which involved a 60-person team from all National Laboratories.
- Had oversight responsibility for preparation of the draft Generic Environmental Impact Statement for the HLW disposal program.
- Conceived and guided the initial HLW program activities on public attitudes and institutional issues, conducted by the Battelle Human Affairs Research Centers.
- Served as US delegate to waste management programs of the International Atomic Energy Agency.
- Served as delegate to the first Pacific Basin Conference on HLW disposal.
- Appointed Exchange Executive under the President's Commission on Personnel Interchange, with service in the National Bureau of Standards and responsibility for defining and developing NBS programs concerning nuclear safeguards, and for strategic planning in the Center for Radiation Research.

PRIOR EXPERIENCE

1968-1969: Fulbright Professor of Nuclear Engineering, Istanbul Technical University, Istanbul, Turkey

1962-1968: Department of Chemical Engineering Faculty, University of Rochester, Rochester, NY

1957-1962: Knolls Atomic Power Laboratory, Schenectady, NY

EDUCATION

University of Rochester, B.S.ChE (1957)
Rensselaer Polytechnic Institute, MChE (1959)
Rensselaer Polytechnic Institute, PhD (1961)

RESUME

DONALD LANGMUIR

Department of Chemistry and Geochemistry (303) 273-3631
Colorado School of Mines
Golden, CO 80401

Education:

A.B. (cum laude) Harvard University, 1956; Geological Sciences
M.A. Harvard University, 1961; Geology
Ph.D. Harvard University, 1965; Geology

Work Experience:

1957-1959, Ensign and Lt. J.G., U.S. Navy, destroyer escorts, West Coast U.S. and Pacific Ocean

1964-1967, Hydrologist-Ground Water Geochemist, Ground Water Branch, Water, Resources Division, U.S. Geological Survey, Trenton, NJ
Research: Geochemistry of iron in ground water; ground water pollution.

1966-1967 Lecturer, Department of Environmental Sciences, Rutgers University, New Brunswick, NJ
Teaching: Ground water hydrology.

1967-1978, Staff Ground water Geochemist, Mineral Conservation Section, Pennsylvania State University
Research: Geochemistry of ground water: iron equilibria in sediments and ground water; stable carbon isotopes in carbonate ground waters; the chemistry of ground water recharge; heavy metals in leachates from landfills and in acid mine waters; uranium geochemistry; heavy metal solution and sorption equilibria; thermochemical properties of heavy metal solutes and minerals; methods of water and sediment analysis; uranium solution mining; and exploration for metal deposits using ground water as a prospecting tool.

1967-1976, Assistant and Associate Professor of Geochemistry, Department of Geosciences, Pennsylvania State University

1976-1978, Professor of Geochemistry, Department of Geosciences, Pennsylvania State University
Teaching: Introductory and Advanced Ground Water Chemistry, Geochemistry of Sedimentary Rocks, Heavy-Metal Sorption, Coordination and lectures in seminar courses on water pollution control and solid wastes.

DONALD LANGMUIR

1974-1975, (6 mos.) Adjunct Professor of Geochemistry, Center for Water Resources Research, Desert Research Institute, University of Nevada, Reno, Nevada.

1978-Pres. Professor of Geochemistry, Department of Chemistry and Geochemistry, Colorado School of Mines

Teaching: Introduction to Geochemistry; Aqueous Geochemistry; Hydrochemical Systems (trace metal geochemistry); and Advanced Techniques in Mineral and Petroleum Exploration: Gas Emission; Ground Water Tracers and Mineral Saturation (with R.W. Klusman).

Research: Uranium, thorium and radium geochemistry, and radioactive waste disposal; ground water prospecting for and in-situ leaching of ore deposits; mechanisms and modelling of metal and ligand sorption and solution-mineral equilibria in the saturated and unsaturated zones; thermodynamic and kinetic properties of water-rock systems; acid-rain weathering of building materials; ground water pollution.

1980 (2 mos.) Visiting Professor of Inorganic Chemistry, Department of Inorganic Chemistry, University of Sydney, Sydney, Australia

Publications:

Langmuir, D., 1965, Stability of carbonates in the system $MgO-CO_2-H_2O$: Jour. Geology, v. 73, p. 730-754.

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Macalady, D., Langmuir, D., Grundl, T. and Elzerman, A., 1988, Use of model-generated Fe^{3+} activities to compute EH and ferric oxyhydroxide solubilities in anaerobic systems: Abstract GEOC69. Am. Chem. Soc. Annual Meeting, Los Angeles, CA, Sept. 26-29.

Professional Society Memberships and Activities:

Society memberships: AAAS; Envir. Chem. Div. of Am. Chem. Soc.; Hydrology Div. of Am. Geophys. Union; Soc. Envir. Geochem. and Health; Geochem. Soc.; Internatl. Assoc. Geochem. and Cosmochem.; Natl. Water Well Assoc.; Soc. Econ. Paleont. and Mineralog.; Elected Fellow of Min. Soc. Am.; and Full Member of Sigma Xi.

Society Activities: Chairman of the Envir. Committee of Geochem. Soc. 1973-76. Chairman of Nominating Committee for Officers of the Geochem. Soc., 1975-76 and Member of that Committee 1974-1977. Chairman of Program Committee of the Geochem. Soc. 1983-85. Member, Nominating Committee for Officers, Mineralogical Soc. of Am. 1987-1988,

Editorial Services: Assoc. Editor of the Journal Geochimica et Cosmochimica Acta, of the Geochem. Soc. 1975-80. Editorial Board of "Interface", Journal of the Soc. of Envir. Geochem. and Health 1975-81. Member, Publications Committee of the Geochemical Society, 1983-86.

DONALD LANGMUIR

Offices Held and Committee Service:

Member of Subcommittee V61 of Solubility Data Project, Internatl. Union of Pure and Applied Chem. 1978- ;
Served on expert panel to review and critique funded research programs on environmental radioactivity supported by the Ecological Research Div. of the U.S. Dept. of Energy and prepared written report. Washington, DC, 1981 and 1987.
Served on expert panel appointed by the U.S. Natl. Committee on Geochemistry of the National Research Council, to review and critique the U.S. Dept. of Energy/ONWI Report titled "Status of technology for isolating radioactive wastes in geological repositories", 1981.
Member Technical Review Committee, Low Temperature Thermal Energy (Aquifer) Storage Program of U.S. Dept. of Energy 1978-1982.
Member of committee to recommend future research priorities for the U.S. Envir. Protection Agency in the area of "Measurement and Analysis of Sources and Ambient Levels of Substances in Air, Water and Earth Materials", 1979.
Member, Independent Review Committee for the Tansuranic Waste Management Program of the U.S. Dept of Energy, Rockwell Intl., Golden, CO 1979.
Member, Selection Committee for the Brainert F. Phillipson Professor of Environmental and Mining Chemistry endowed chair, Dept. of Chemistry, Univ. of Denver (Funded by AMAX, Inc.) 1984.
Member, Performance Assessment National Review Group, (Expert panel critiquing the U.S. Dept. of Energy programs in selection of sites for geological disposal of high level nuclear wastes) 1984-85.
Member, Panel on Coupled Thermo-Mechanical-Hydro-Chemical Processes Associated with a Nuclear Waste Depository. (Expert panel assessing the importance of coupled processes for the U.S. Nuclear Regulatory Commission) 1984-86.
Served on (1985 and 1987) and chaired (1988) The Earth Sciences Division Review Committee, to critique research programs of the Earth Sciences Division of Lawrence Berkeley Laboratory, Univ. California, Berkeley, CA.
Member, Licensing Assurance Review Team to critique major issues in geochemistry in the Site Characterization Plans for the Basalt Waste Isolation Program in high-level nuclear waste disposal for the U.S. Dept. of Energy, 1987.
Member, President's Nuclear Waste Technical Review Board. 1989-1992.

Other Services:

Chaired sessions in Sed. Geochem. at Annual Meetings of Geol. Soc. Am., Atlantic City, NJ, Nov. 1969.
Discussion Leader for session on Ground Water-Carbonate Interactions, Penrose Conf. on "Water in Carbonate Rocks", Vail, Co, Sept. 1973.
Co-arranger and Master of Ceremonies for Natl. Science Teaching Assoc. Program on "Earth Science, Energy and Environment", Chicago, IL, Mar. 1974.
Chaired and organized Envir. Geochem. Symp. at Geol. Soc. Am. Meeting, Miami, Nov.1974.
Science Producer, nightly television program "The State of the Weather, Shape of the World", Pennsylvania State Univ., 1974-76.

DONALD LANGMUIR

Co-chairman of Unpolluted Waters Session of Internatl. Symp. on Geochem. of Natural Waters, Burlington, Ont., Aug. 1975.
Chairman and organizer of Envir. Geochem. Symp., Salt Lake City, Utah, Oct. 1975.
Co-chairman of Session on "Geochemistry of Ground Water" at Geol. Soc. Am. Meeting, Denver, Nov. 1976.
Expert for Envir. Evaluation Group, New Mexico Health and Envir. Dept., on ground water geochemistry related to radioactive waste disposal, 1979-
Expert witness, including written and oral testimony on the geochemistry of uranium, radium and thorium for the Royal Commission of Inquiry into Uranium Mining, Province of British Columbia, Canada, 1979.
Expert witness, including written and oral testimony before the Colo. Water Quality Control Commission, on proposed State numerical guidelines and standards for toxic metals in streams, 1978-79.
Expert witness, including oral and written testimony and coordinator of geochemical and related aspects of permitting applications for several corporations involved in uranium and other mining ventures, 1978-.
Prepared and delivered a 1-week short course on methods of exploration for ore deposits of copper, zinc, gold and nickel (etc.) using ground-water geochemical methods and computer models, to staff of Western Mining Corp., Ltd., in Kalgoorlie, Western Australia, Aug. 1981.
Co-Chairman and organizer of symposium on "Ground Water Chemistry Associated with Mining and Waste Mangement" at Am. Chem. Soc. Meeting, El Paso, TX, Dec. 1982.
Session co-chairman for Geochemistry III: Geochemistry of Igneous and Metamorphic Rocks, at 96th Annual Meeting, Geol. Soc. of America, Nov. 2, 1983, Indianapolis, IN.
Consultant to the Swedish Government in the Geochemistry of high level nuclear waste disposal in geological media, 1984-86.
Chaired session of "Chemical Modeling in Aqueous Systems II", Am. Chem. Soc. Meeting, Los Angeles, CA, Sept. 1988.
Vice-President (1989), and President (1990) of 7000-member Colorado Mountain Club.

Contract and Grant Reports:

Parizek, R.R., Langmuir, D. and Apgar, M.A., Sanitary Landfills in Carbonate Rock Terranes. Research Progress Reports to Pa. Dept. of Health, 8 pp. (Dec. 31, 1969), 16 pp. (March 31, 1970) and 17 pp. (June 10, 1970).

Langmuir, D., Parizek, R.R. and Apgar, M.A., The Chemical interaction of Sanitary Landfill Leachate with Unsaturated Soil in a Carbonate Terrane. Research Progress Reports to Pa. Dept. of Health, 18 pp. (Sept. 30, 1970), 11 pp. (Dec. 31, 1970), 32 pp. (June 30, 1971).

Langmuir, D., Suarez, D.L. and Gang, M.W., The Mobility of Toxic Trace Elements in Landfill Leachates. Research progress reports to Pa. Dept. of Environmental Resources, 32 pp. (Dec. 31, 1972), 41 pp. (March 31, 1973), 35 pp. (June 30, 1973), 33 pp. (Sept. 30, 1973).

DONALD LANGMUIR

Langmuir, D., Uranium solution-mineral equilibria at low temperatures with applications to sedimentary ore deposits. U.S. Dept. of Energy, Grand Junction Office, Contract E(05-1)-1659, Report GJP-1659-3, 39 pp., (Dec. 1977).

Applin, K.R. and Langmuir, D., Ground water geochemistry as a prospecting tool for uranium deposits in Pennsylvania. U.S. Dept. of Energy, Grand Junction Office, Contract E(05-1)-1659, Report GJO 1659-4, 145 pp. (Aug. 1978).

Amell, A.R. and Langmuir, D., Solution mining of sedimentary uranium deposits: Development of theoretical and practical geochemical approach. I. Solution Kinetics of Uraninite in Acid Alkali Waters. Quarterly Report, 45 pp. (Aug. 1977). II. Kinetics or uraninite dissolution under conditions applicable to in-situ leaching. Annual Report, 124 pp. (Dec. 1978), U.S. Dept. of Interior, Bureau of Mines, Contract HO 272019.

Barnes, H.L. and Langmuir, D., Geochemical prospecting handbook for metals and associated elements. Vol. II. The computer program for preparing Eh-pH diagrams. Natl. Science Foundation, Grant No. AER77-06511 A02, Annual Report, 248 pp. (Dec. 1978).

Chatham, J.R., Wanty, R.B. and Langmuir, D., Ground water prospecting for sandstone-type uranium deposits: The merits of mineral-solution equilibria versus single element tracer methods. U.S. Dept. of Energy, Grand Junction Office, Contract 79-360-E. First Interim Report, 37 pp. (Nov. 1979). Second Interim Report, 39 pp. (May 1980). Final Report, 169 pp. (Dec. 1980).

Hsi, C-K.D. and Langmuir, D., Experimental results on the adsorption of uranium(VI) by iron(III) oxides, U.S. Geol. Survey, Uranium-Thorium Branch, USGS Grant 14-08-0001-G-606. Annual Report 28 pp. (May 1980).

Catts, J.G. and Langmuir, D., Sorption of copper and lead by manganese oxides: development of predictive models. U.S. Geol. Survey, Water Resources Division, USGS Grant 14-08-0001-18701. Annual Report, 45 pp. (Oct. 1980).

Langmuir, D., Sorption of heavy metals from ground water: Development of predictive models. U.S. Dept. of Interior, Office of Surface Mining OSM Grant G5195011. First Quarterly Report, 1 p. (Dec. 1979); 2nd quarterly Report, 1 p. (Apr. 1980); 3rd Quarterly Report, 59 pp. (July 1980); First Annual Report, 3 pp. (Oct. 1980).

Chatham, J.R., Wanty, R.B. and Langmuir, D., Ground water prospecting for sandstone-type uranium deposits: The merits of mineral-solution equilibria versus single element tracer methods. U.S. Dept. of Energy, Grand Junction Office, Contract 79-360-E. Final Report, Vol. II (Aug. 1981), 91 pp.

Henderson, T., Melchior, D.C., III and Langmuir, D., 1981, Solubility of uranium in six ground water types at temperatures from 25-250°C: Report to Battelle Northwest Laboratories, by Hydrochem Systems Corp. of Golden, CO, under consultant agreement B-93961-A-U, 58 pp.

Catts, J.G., Pavelich, M.J. and Langmuir, D., 1981, Dissolution and precipitation kinetics of calcite and gypsum, some ferric oxyhydroxides and silica polymorphs: A literature survey and critique: Report to Battelle Northwest Laboratories, by Hydrochem Systems Corp. of Golden, CO, under subcontract B-A4062-A-Q, 110 pp.

Langmuir, D., Mahoney, J. and Ranville, J., 1985, Task status report on CSM contract E512-09500, Geochemistry of Rdionuclides in Natural Brines. Office of Nuclear Waste Isolation, U.S. Dept. of Energy, Columbus, OH, 116 pp.

Langmuir, D., and Schmiermund, R.L., 1986, Geochemistry of Lime Mortar and Portland Cement Weathering by Acid Rain. Phase I Report, Part 1, for the period 7/15 to 9/30/86. Report to National Park Service. Cooperative Agreement CA-0424-6-8001, Nov. 16, 1986, text 55 pp., appendices 57 pp.

Langmuir, D., and Schmiermund, R.L., 1986, Laboratory Study of acid Rain Weathering of Shelburne Marble, Salem Limestone and Lime Mortar, Report to National Park Service. Cooperative Agreement CA-0424-6-8001, November, 1986, 23 pp.

Langmuir, D. and Schmiermund, R., 1987, Geochemistry of Lime Mortar and Portland Cement Weathering by Acid Rain, Report to Natl. Park Service, Supplement to Phase I Report. Part 1, March 1987. 19 pp. plus appendices.

Langmuir, D. and Schmiermund, R., 1987, A Laboratory Study of the Acid Rain Weathering of Salem Limestone, Shelburne Marble and Lime Mortar. Interim Progress Report to Natl. Park Service for the period Oct. 1, 1986 to Sept. 30, 1987, 37 pp.

Langmuir, D., Schmiermund, R. and Kishiyama, G., 1987, A Laboratory Study of the Acid Rain Weathering of Salem Limestone and Shelburne Marble. Annual Report to Natl. Park Service for th period Oct. 1, 1986 to Sept. 30, 1987, 37 pp.

Langmuir, D., Schmiermund, R., and Kishiyama, G., 1988, A laboratory study of the acid rain weathering of Salem Limestone and Shelburne Marble, Annual Report, National Park Service, Oct. 1988, 20 pp.

Langmuir, D., Schmiermund, R., and Kishiyama, G., 1988, Laboratory measurement and modeling of carbonate stone weathering by acid rain. Submitted for the National Acid Precipitation Assessment Program, Task Group VII - Effects on Material, Peer Review Meeting, to be held Jan. 22-27, 1989, 15 pp.

Grant and Contract Research:

Parizek, R.R. and Langmuir, D., 1969-70, Sanitary landfills in carbonate terrains: Pennsylvania Dept. of Health, SP-37437, $15,000.

Langmuir, D., 1970, Nitrogen and phosphorus variation in ground waters beneath farmland, Mahantango Watershed, PA; U.S. Dept. of Agriculture, $3,000.

Langmuir, D. and Parizek, R.R., 1970-71, The chemical interaction of sanitary landfill leachate with unsaturated soil in a carbonate terrane: Pennsylvania Dept. of Health, SP-37350, $8,000.

Langmuir, D., 1972-73, The mobility of toxic trace elements in landfill leachates: Pennsylvania Dept. of Envir. Resources, 35-46-0013, $13,230.

Langmuir, D., 1973 (summer), Hydrology in the mountain area in Jefferson County, CO: Water Resources Div., USGS, $2,500.

Langmuir, D., 1973-74, Controls on heavy metals in surface and ground waters affected by coal mine drainage: Water Resources Div., USGS, $8,000.

Rose, A.W., Keith, M.L. and Langmuir, D., 1975-77, Uranium reconnaissance in Northeastern Pennsylvania: U.S. Energy Research and Devel. Admin., E(05-1)-1659, $74,298.

Deines, P. and Langmuir, D., 1976-78, Isotopic study of ground water evolution and water quality in a karst terrain: Natl. Science Foundation, Earth Science Section, $67,300.

Langmuir, D., 1977-79, Solution mining of sedimentary uranium deposits: development of theoretical and practical geochemical approach: U.S. Bureau of Mines, HO 272019, $43,745.

Langmuir, D. and Barnes, H.L., 1977-79, "Geochemical prospecting handbook for metals and associated elements". Natl. Science Foundation, Div. of Advanced Energy Research and Technol. AER77-06511, $134,500. Subcontract to CSM and D. Langmuir, NSF-TPSU-CSM-06511-132, CSM Project No. 505, $19,570.

Langmuir, D., 1979-1980, "Modeling the ground water geochemistry in two aquifers of the northern Great Plains". U.S. Geol. Survey, Dept. of Interior. CSM Project No. 622. $27,606.

Langmuir, D., 1979-80, "Geochemical interpretation of ground water data in the NURE program". Bendix Field Engineering Corp. Contract 79-360-E (U.S. Dept. of Energy) CSM Project No. 547. $93,850.

Langmuir, D., 1979-80, "Sorption of lead and copper from ground water onto clays and ferric oxyhydroxides: Development of predictive models". Office of Surface Mining, Dept. of Interior. CSM Project No. 620. $35,160.

Langmuir, D., 1979-81, "Sorption of copper and lead onto manganese oxides: Development of predictive models". U.S. Geol. Survey, Dept. of Interior. CSM Project No. 621. $37,102.

Langmuir, D., 1980-81, "Geochemical exploration for sandstone-type uranium ores: Studies of anomalies in ground water". Bendix Field Engineering Corp. Extension of Contract 79-360-E (U.S. Dept. of Energy) CSM Project No. 547. $24,421.

Langmuir, D., 1979-81, "Sorption of uranium by iron oxides". U.S. Geol. Survey, Dept. of Interior. CSM Project No. 555. $54,164.

Langmuir, D., 1980-81, "Sorption of lead and copper from ground water onto clays and ferric oxyhydroxides: Development of predictive models". Office of Surface Mining, Dept. of Interior. CSM Project No. 697. $28,191.

*Riese, A.C., 1980-81, "Transport and attenuation of thorium and radium in ground water". Gulf Research and Development. CSM Project No. 624. $54,142. *(Ph.D. Candidate in Geochemistry. Research Advisor D. Langmuir. Proposal written with D. Langmuir).

Langmuir, D., "Geochemistry of subsurface waters", L.J. Backham Fund. CSM Project #533, $10,000. 2/28/79.

Langmuir, D., "Applications of ground water geochemical concepts to the selection of sites for mined radioactive waste repositories in the Basin and Range Province", U.S. Geol. Survey, Dept. of Interior. CSM Project #730, $111,693. 9/1/81-8/31/83.

Langmuir, D., 1981-83, "Applications of ground water geochemical concepts to the selection of sites for mined radioactive water repositories in the Basin and Range Province". U.S. Geol. Survey, Dept. of Interior. CSM Project No. 730. $111,693.

Langmuir, D., 1982-85, "Geochemistry of radionuclides in natural brines". Office of Nuclear Waste Isolation, Battelle Laboratories, Columbus, OH. Contract No. E512-09500. CSM Project No. 747. $250,000. 6/82-5/85.

ABBREVIATED CURRICULUM VITAE

SHLOMO P. NEUMAN

January, 1989

Born	Marital Status
October 26, 1938, Czechoslovakia	Married, three children

Education

University of California, Berkeley	Ph.D., Engineering Science,	1968
University of California, Berkeley	M.S., Engineering Science,	1966
Hebrew University, Jerusalem, Israel	B.S., Geology	1963

Positions Held

1988- Regents Professor, Department of Hydrology and Water Resources, University of Arizona, Tucson.

1975-1988 Professor of Hydrology, Department of Hydrology and Water Resources, University of Arizona, Tucson.

1974-1975 Visiting Associate Professor, Department of Civil Engineering, University of California, Berkeley.

1970-1974 Senior Scientist and Associate Research Professor, Institute of Soil and Water, Agricultural Research Organization, Bet-Dagan, Israel.

1968-1970 Acting Assistant Professor and Assistant Research Engineer, Department of Civil Engineering, University of California, Berkeley.

Short-Term Appointments

Fall, 1981 Visiting Professor, Department of Fluid Mechanics and Heat Transfer, Tel-Aviv University, Israel.

Summer, 1981 Directeur de Recherche, Centre d'Informatique Geologique, Ecole des Mines de Paris, Fontainebleau, France.

Summer, 1978 Maitre de Recherche, Centre d'Informatique Geologique, Ecole des Mines de Paris, Fontainebleau, France.

Summer, 1976 Visiting Scientist, Isotope Department, Weizmann Institute of Science, Rehovot, Israel.

Informal Foreign Visits

Summer, 1988	Department of Chemical Engineering, Royal Institute of Technology, Stockholm, Sweden.
Fall, 1988	Institute of Applied Mathematics, University of Padova, Italy.

Awards and Honors

1988	Science Award, Association of Ground Water Scientists and Engineers, National water Well Association.
1988	Elected Fellow, Geological Society of America.
1988	Appointed Regents' Professor, University of Arizona
1984	Elected Fellow, American Geophysical Union
1983	Paper selected for inclusion in Benchmark Papers in Geology (see second page of publications list).
1976	O.E. Meinzer Award, Geological Society of America, for distinguished contribution to hydrogeology during the past five years.
1975	Certificate of Appreciation, a team award for cooperation and technical capabilities brought to bear in the successful completion of a major research effort, granted by the United States Department of Agriculture.
1969	Robert E. Horton Award, American Geophysical Union, for the best hydrology paper to appear in Water Resources Research during 1969.
1966-1968	Jane Lewis Fellowship, University of California, Berkeley.
1965-1966	Edwin Letts Oliver Scholarship, University of California, Berkeley.
1962-1963	Undergraduate Scholarship, Hebrew University, Jerusalem, Israel.

Distinguished Lectureships

1986-1987	Birdsall Distinguished Lecturer of the Geological Society of America; invited by over 30 institutions across North America.
1986 & 1987	Two-day short course each year under the Distinguished Seminar Series on Ground Water Science by the national Water Well Association.

Distinguished Lectureships (Continued)

1985 Presented one of five in a series of Distinguished Lectures on Hydrogeology, Department of Geology and Mineralogy at Ohio State University, Columbus.

Honorary Societies

Member of Sigma XI (1980)

Membership in Professional Societies

American Geophysical Union
Geological Society of America
Society of Petroleum Engineers of AIME
Assoc. Groundwater Scientists and Engineers of NWWA
International Association of Hydrogeologists
Arizona Hydrological Society

Editorial Duties

1987- Associate Editor, Water Resources Research (AGU)

1983-1986 Member, Editorial Advisory Board, Water Science and Technology Library, D. Reidel Publishing Company, Dordrecht, Holland.

1977-1984 Member, Editorial Advisory Board, Journal of Hydrology.

Publications

135; see attached list.

ADDENDUM TO CURRICULUM VITAE OF

SHLOMO P. NEUMAN

January 1989

Recent Invited (*Keynote) Lectures and Session Chairing

*1. NATO Advanced Study Institute on Geostatistics, Lake Tahoe, California, September 1983.

2. 5th International Conference on Finite Elements in Water Resources, Burlington, Vermont, June 1984 (delivered by J. Carrera).

*3. OECD Workshop on Coupling Hydrological and Geochemical Models, Paris, France, June 1984.

*4. Gordon Conference on Modeling of Fluid Flow in Porous Media, Andover, New Hampshire, July-August 1984.

*5. GSA Penrose Conference on Transport Processes in Fractured Rock, Park City, Utah, September 1984.

6. Invited lecture tour in Sweden including Swedish Geological Company at Uppsala, University of Lulea, and Royal Institute of Technology in Stockholm, June 1985.

7. Invited to chair a session at the International Symposium on the Stochastic Approach to Subsurface Flow, Montvillargenne, France, June 1985.

8. NATO Advanced Study Institute on Fluid Flow through Porous Media, University of Delaware, July 1985 (delivered by R. Cady).

*9. North American Council on Geostatistics, Dubois, Wyoming, July 1986.

10. U.S. - Japan NSF Seminar on Hydrology, Honolulu, Hawaii, January 1987.

*11. Workshop on Leaky Aquifer Mechanics, Mexico City, January 1987.

*12. NWWA Conference on Solving Ground Water Problems with Models, Denver, Colorado, February, 1987.

13. NATO Advanced Research Workshop on Advances in Analytical and Numerical Groundwater Flow and Quality Modelling, Lisbon, Portugal, June 1987.

14. 28th U.S. Symposium on Rock Mechanics, Tucson, Arizona, June-July 1987.

Recent Invited (*Keynote) Lectures and Session Chairing: (continued)

15. Session Chairman, Annual Meeting, North American Council on Geostatistics, Chiracahua Mountains, Arizona, August 1987.

*16. International Conference on Fluid Flow in Fractured Rocks, Atlanta, Georgia, May 1988.

17. 7th International Conference on Finite Elements in Water Resources, Cambridge, Massachusetts, June 1988.

18. Invited to chair a session at the Third International Geostatistics Conference, Avignon, France, September 1988.

Recent Panel (*Moderator) Member

*1. 17th International Congress of the International Association of Hydrogeologists on the Hydrogeology of Rocks or Low Permeability, Tucson, Arizona, January 1985.

*2. Symposium on Groundwater Flow and Transport Modeling for Performance Assessment of Deep Geologic Disposal of Radioactive Waste: A Critical Evaluation of the State-of-the-Art, U.S. DOE and U.S. NRC, Albuquerque, New Mexico, May 1985.

3. International Symposium of Coupled Processes Affecting the Performance of a Nuclear Waste Repository, Lawrence Berkeley Laboratory, Berkeley, California, September 1985.

*4. Panel on Modeling, Short Course on Management of Hazardous Chemical Waste Sites, in conjunction with the 28th Annual Meeting of Association of Engineering Geologists, Winston-Salem, North Carolina, October 1985.

Organization of Conferences

1. Chairman, Technical Program Committee, 17th International Congress of International Association of Hydrogeologists, Tucson, Arizona, January 1985.

2. Organizing Committee, and Scientific Secretary, NATO Advanced Research Workshop on Advances in Analytical and Numerical Groundwater Flow and Quality Modelling, Lisbon, Portugal, June 1987.

3. Organizing Committee, 28th U.S. Symposium on Rock Mechanics, Tucson, Arizona, June-July 1987.

4. Co-organizer, Meeting of Geostatistical Council of North America, Chiricahua Mountains, Arizona, August 1987.

Organization of Conferences: (continued)

5. Co-organizer, Symposium on Hydrology of Rocks of Low Permeability, 28th International Geological Congress, Washington, D.C., July 1989.

6. Organizing Committee, NWWA Meeting on New Field Approaches and Measurement Techniques for Quantifying the Heterogeneous Physical and Chemical Properties of Aquifers, Dallas, Texas, March 1989.

7. Advisory Committee, VIII International Conference on Computational Methods in Water Resources, Venice, Italy, June 1990.

8. Scientific Committee, International Conference on Calibration and Reliability in Groundwater Modeling, The Hague, The Netherlands, September, 1990.

Research Grants at University of Arizona

$33,750 (Federal), OWRT, 1976-1978, S.P. Neuman and S.J. Yakowitz, Identification of Aquifer Parameters Using Numerical Techniques.

$45,000 (Federal), OWRT, 1976-1977, E.S. Simpson and S.P. Neuman, Aquifer Modeling by Numerical Methods Applied to an Arizona Groundwater Basin.

$17,350 (Federal), OWRT, 1976-1978, S.P. Neuman and L.G. Wilson, Developing Methods for On-Site Determination of Unsaturated and Saturated Hydraulic Conductivity above the Water Table.

$8,000 (Federal), OWRT, 1977-1978, S.P. Neuman and S. Resnick, Developing a New Deconvolution Technique to Model Rainfall-Runoff in Arid Environments.

$38,969, NSF, 1978-1980, S.P. Neuman, Dynamics of Land Subsidence due to Subsurface Fluid Withdrawal.

$51,083 (Federal), OWRT, 1978-1980, E.S. Simpson and S.P. Neuman, Comparative Analysis and Development of Models for Groundwater Quality Prediction.

$109,691 (Federal; $31,568 for Univ. Arizona, the rest New Mexico Tech), OWRT, 1980-1983, D.B. Stephens and S.P. Neuman, In Situ Determination of Hydraulic Conductivity in the Vadose Zone Using Borehole Infiltration Tests.

$9,100 (Federal), OWRT, 1979-1981, S.P. Neuman, Estimation of Aquifer Transmissivities and Storativities Using Numerical Models.

$17,100 (Federal), OWRT, 1979-1983, S.P. Neuman, Groundwater Recharge in Arid Regions.

Research Grants at University of Arizona: (continued)

$2,350,000, U.S. NRC, 1978-1985, E.S. Simpson and S.P. Neuman, Field and Theoretical Investigations of Mass and Energy Transport in Subsurface Materials at Waste Disposal Sites.

$60,000, NSF/U.S. - Spain Joint Committee for Scientific and Technological Cooperation, 1985-1986, S.N. Davis and S.P. Neuman, Methodology for Combined Analysis of Hydrological, Hydrochemical and Isotopic Data from Aquifers.

$99,466, Pima Country Transportation and Flood Control District, 1985-1986, L.G. Wilson, S.P. Neuman, and B. Cluff, Effect of Bank Protection in the Tucson Streams with Regard to Infiltration and Ground Water Recharge.

$95,604, U.S.-Spain Joint Committee for Scientific and Technological Cooperation, 1986-1989, Optimal Design of Sampling and Observation Networks.

$497,865, U.S. NRC, 1986-1989, Improved Methods of Characterizing and Modeling Contaminant Transport Around High Level Radioactive Waste Sites.

Total of Grants to Date at U of A: $3,354,855.00

Former Doctoral Students

D. Stephens, 1979, Head, Geoscience Department, New Mexico Tech., Socorro.

A. Bin-Sariti, 1980, University of Benghazi, Libya.

L. Winter (codirected with C.M. Newman of the Mathematics Department), 1982, Science Applications Intern., Tucson, Arizona.

P. Hsieh, 1983, U.S.G.S., Menlo Park, California.

J. Carrera, 1984, Department of Civil Engineering, Polytechnical University of Barcelona, Spain.

E. Adar, 1984, Ben-Gurion University of the Negev, Sede-Boquer Campus, Israel.

E. Jacobson, 1985, Batelle Pacific Northwest Laboratories, Richland, Washington.

J. Samper, 1986, Department of Civil Engineering, Polytechnical University of Barcelona, Spain.

S. Silliman, 1986, Department of Civil Engineering, Notre Dame University.

Current Doctoral Students

R. Cady, G. Wittmeyer, Y. Zhang, E. Paleologos, A. Guzman, S. Or, O. Levin.

Former M.S. Students

G. Fogg (1978), M. Boggs (1980), P. Clifton (1981), D. Dunbar (1981), R. Henriques (1981), R. Karls (1982), P. Fennesy (1982), D. Matlock (1983), F. Lewis (1984), F. Marinelli (1984), J. Depner (1985), A. Aikens (1985), D. Williams (1987), T. Leo (1988), A. Guzman (1988).

Current M.S. Students

C. Woloshun

National Delegations and Committees since Summer 1983

1. NRC delegation to Japan concerning cooperative research between the U.S. and Japanese governments on subsurface nuclear waste disposal, July 1983.

2. Search Committee for new Chief Science Editor of Water Resources Research, spring 1984. Was nominated for this position but declined due to lack of time.

3. Chairman, AGU Horton Award Committee, 1984.

4. Delfi Panel on the hydraulic properties of basalts at the proposed Hanford Nuclear Waste Disposal site, June-July 1984.

5. Review Panel of the DOE program for high-level nuclear waste repository in salt rock, continuing since summer 1983.

6. Peer Review Panel for the research program of the Earth Sciences Division, Lawrence Berkeley Laboratory, May 1984 and May 1985.

7. Member, Executive Committee, North American Council on Geostatistics, 1986-88.

8. Earth Science Advisory Board, Stanford University, 1988-89.

Campus-wide Committees since 1983

1. Promotion and Tenure Committee, College of Engineering, 1983-1984.

2. Committee on the merger of the colleges of Mines and Engineering, 1984.

Campus-wide Committees since 1983: (continued)

3. University of Arizona Negev Committee for cooperation with Ben Gurion University, Israel (1985-).

4. Chairman, Dean's Committee to evaluate the Head of the Department of Hydrology and Water Resources, 1985-1986.

5. Search Committee for Department Head of Electrical and Computer Engineering, 1985-1986.

6. Search Committee for Department Head of Civil and Mechanical Engineering, 1986-1987.

7. Advisory Committee, College of Engineering and Mines, 1987-.

8. University review team for Department of Mining and Geological Engineering, 1988.

Consulting Activity

Varied consulting for private entities and government agencies such as DOE and EPA. Activity as expert witness on behalf of Heller Construction Co., New Jersey; the Bureau of Indian Affairs, Department of Justice, New Mexico; and currently EPA, Region 10, Washington.

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Shlomo P. Neuman
January 1989

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1. Neuman, S.P., and P.A. Witherspoon, Transient Flow of Ground Water to Wells in Multiple Aquifer Systems, Geotechnical Engineering Publication 69-1, University of California, Berkeley, 182 p., 1969.

2. Braester, C., G. Dagan, S.P. Neuman, and D. Zaslavsky, A Survey of the Equations and Solutions of Unsaturated Flow in Porous Media, First Annual Report, Project A10-SWC-77, Hydrodynamics and Hydraulic Engineering Lab., Technion, Haifa, 176 p., 1971.

3. Neuman, S.P., Finite Element Computer Programs for Flow in Saturated-Unsaturated Porous Media, Second Annual Report, Project No. A10-SWC-77, Hydrodynamics and Hydraulic Engineering Laboratory, Technion, Haifa, 87 p., 1972.

4. Neuman, S. P., and S. Dasberg, Hydrology of Drained Peats in the Hula Basin, Israel, Preliminary Report for April 1972-July 1973, Institute of Soils and Water, Agricultural Research Organization, Bet Daga, 51 p., 1973 (in Hebrew).

Technical Reports: (continued)

5. Neuman, S.P., R.A. Feddes, and E. Bressler, Finite Element Simulation of Flow in Saturated-Unsaturated Soils Considering Water Uptake by Plants, Third Annual Report, Project A10-SWC-77, Hydrodynamics and Hydraulic Eng. Lab., Technion, Haifa, 104 p., 1974.

6. Dasberg, S., S.P. Neuman, and B. Mandel, Hydrology of Drained Peats in the Hula Region, Israel, Progress Report for July 1973-1975, Institute of Soils and Water, Agricultural Research Organization, Bet Dagan, 9 p., 1975 (in Hebrew).

7. Neuman, S.P., User's Guide for Program FREESURF I, Department of Hydrology and Water Resources, University of Arizona, Tucson, 1976.

8. Braester, C., H. Fligelman, U. Kroshinski, and S.P. Neuman, Numerical Simulation of Three-Phase Flow in Two Dimensional (Areal) Hydrocarbon Reservoirs, Department of Civil Engineers, Technion, Israel Institute of Tech., Haifa, 60 p., 1976.

9. Fogg, G.E., E.S. Simpson, and S.P. Neuman, Aquifer Modeling by Numerical Methods Applied to an Arizona Groundwater Basin, Natural Resources Systems Report No. 35, Department of Hydrology and Water Resources, University of Arizona, Tucson, 1979.

10. Simpson, E.S., S.P. Neuman, G. de Marsily, and B. Sagar, Progress and Problems in the Analysis and Prediction of Subsurface Mass Transport, Topical Report to Nuclear Regulatory Commission, Department of Hydrology and Water Resources, University of Arizona, Tucson, 1979.

11. Stephens, D.B., and S.P. Neuman, Analysis of Borehole Infiltration Tests Above the Water Table, Natural Resource Systems Technical Report No. 36, Department of Hydrology and Water Resources, University of Arizona, Tucson, 1980.

12. Wilson, L.G., K.J. DeCook, and S.P. Neuman, Regional Recharge Research in Southwest Alluvial Basins, final rep. to U.S.G.S., Water Resour. Res. Ctr., University of Arizona, 1980.

13. Neuman, S.P., Leakage of Gas Through Fractures from Subsurface Storage Cavities, Department Fluid Mech. and Heat Transfer, Tel-Aviv University, Israel, 54 p., 1982.

14. Stephens, D.B., S.P. Neuman, S. Tyler, K. Lamert, D. Watson, R. Rabold, R. Knowlton, E. Byers, and S. Yates, Insitu Determination of Hydraulic Conductivity in the Vadose Zone Using Borehole Infiltration Tests, Tech. Compl. Rep., Project No. 1423648, New Mexico Water Resour. Res. Inst., 165 p., November 1983.

Technical Reports: (continued)

15. Wilson, L.G., S.P. Neuman, A.G. Guzman, T.P. Leo, and M.D. Osborn, Effects of Channel Stabilization in Tucson Streams Reaches on Infiltration and Ground-Water Recharge. Vol. 1: Model Studies, Final Rep. to Pima County Dept. Transp. and Flood Control District, Water Resour. Res. Center, Univ. of Arizona, June 1987.

16. Neuman, S.P., A Proposed Conceptual Framework and Methodology for Investigating Flow and Transport in Swedish Crystalline Rocks, Arbetsrapport 88-37, 39 pp., SKB Swedish Nuclear Fuel and Waste Management Co., Stockholm, September, 1988.

Total publications: 135

Statement of Qualifications

RESUME

DANIEL B. STEPHENS

Specialization:

Hydrogeology; seepage through unsaturated material; applications of numerical models; aquifer contamination problems; vadose zone and aquifer monitoring.

Academic Degrees:

Ph.D. Hydrology, University of Arizona	1979
M.S. Hydrology, Stanford University	1974
B.S. Geological Science (with honors), Pennsylvania State University	1971

Professional Experience:

New Mexico Institute of Mining and Technology	
Chairman, Geoscience Department	1984-1987
Associate Professor of Hydrology	1983-present
Assistant Professor of Hydrology	1979-1983
University of Arizona	
Instructor of Hydrogeology	1978
Harshbarger and Associates, Tucson, AZ	
Hydrologist	1976-1978
Fugro, Inc., Long Beach, CA	
Hydrologist	1974-1975
Bechtel, Inc., San Francisco, CA	1973
Gilbert and Associates, Inc., Reading, PA	
Geologist	1972

Professional Affiliations:

American Geophysical Union
National Water Well Association
Soil Science Society of America
New Mexico Geological Society
Sigma Xi

Professional Registration:

American Institute of Hydrology, Hydrogeologist

Statement of Qualifications

DANIEL B. STEPHENS

Articles in Professional Journals:

Stephens, D.B. and S.P. Neuman, 1982, Vadose Zone Permeability Tests 1: Review, ASCE J. Hydraulics Division, 108, (HY5):623-639.

Stephens, D.B. and S.P. Neuman, 1982, Vadose Zone Permeability Tests 2: Steady State, ASCE J. Hydraulics Division, 108, (HY5):640-659.

Stephens, D.B. and S.P. Neuman, 1982, Vadose Zone Permeability Tests 3: Transient Case, ASCE J. Hydraulics Division, 108, (HY5):660-677.

Stephens, D.B. and S.P. Neuman, 1982, Free Surface and Saturated-Unsaturated Analysis of Borehole Infiltration Tests Above the Water Table, Advances in Water Resources, (5):111-116.

Hawkins, D.C. and D.B.Stephens, 1983, Ground Water Modeling in a Southwestern Alluvial Basin, Groundwater, 21(6): 733-740.

Byers, E. and D.B. Stephens, 1983, Statistical and Stochastic Analysis of Hydraulic Conductivity and Particle Size in a Fluvial Sand, Soil Sci. Soc. Amer. Proc. 47(6):679-688.

Person, M., R. Antle, D.B. Stephens, 1983, Evaluation of the Surface Impoundment Assessment in New Mexico, Ground Water 12(6):679-688.

Stephens, D.B., 1985, Comments on "A Reexamination of the Constant Head Well Permeameter Method for Measuring Saturated Hydraulic Conductivity" by W.D. Reynolds, E.D.Elrick, G.C. Topp; Soil Science 139:2 (190).

Stephens, D.B. and K. Rehfeldt, 1985, Evaluation of Closed-Form Analytical Models to Calculate Unsaturated Conductivity in a Fine Sand, Soil Sci. Soc. Am. J. 49:1 (12-19).

Stephens, D.B., 1985, A Field Method to Determine Unsaturated Hydraulic Conductivity Using Flow Nets, Water Resources Research, 21(1):45-50.

Statement of Qualifications

DANIEL B. STEPHENS

Articles in Professional Journals Continued:

Stephens, D.B., 1985, Comments on "A Reexamination of the Constant Head Well Permeameter Method for Measuring Saturated Hydraulic Conductivity: by W.D. Reynolds, E.D. Elrick, G.C. Topp; Soil Science; 139(2).

Stephens, D.B. & Knowlton, R. Jr., 1986, Soil Water Movement & Recharge through Sand at a Semi-Arid Site in New Mexico, Water Resources Research, 22(6):881-889.

McCord, J.T. and Stephens, D.B., 1987, Lateral Moisture Flow Beneath a Sandy Hillslope Without an Inpeding Layer, Hydrological Processes Journal, 1: 225-238

Stephens, D.B., 1987, The significance of Natural Ground-water Recharge in Site Selection for Mill Tailings Disposal. AIME Trans.; Vol. 280: pp. 2064-2068

Stephens, D.B., K.Lambert, and D. Watson, 1987, Regression models for hydraulic conductivity and field test of the borehole permeameter, Water Resources Research, 23(12): 2207-2214

Stephens, D.B., J. Havlena, R.G. Knowlton, Jr., E. Mattson, W. Cox, Spring 1988, Vadose Zone Characterization of Low-Permeable Sediments Using Field Permeameters, Ground-Water Monitoring Review (in review).

McCord, J.T. and D.B. Stephens, 1987, Comment on "Effect of Ground-Water Recharge on Configuration of the Water Table Beneath Sand Dunes" by T.C. Winter, J. Hydrology, V. 95, pp. 365-367.

McCord, J.T. and D.B. Stephens, 1988, Comment on "Effectibve Relative Permeabilities of Anisotropic Porous Media" by Bear, Braester, and Menier, Transport in Porous Media, 3:207-210

Stephens, D.B. and S.E. Heermann, 1988, Dependence of Anisotropy on Saturation in a Stratified Sand, Water Resources Research, 24(5):770-778.

Stephens, D.B., W. Cox, J. Havlena, 1989, Field Study of Ephemeral Stream Infiltration and Recharge, Ground Water Journal (in review).

Statement of Qualifications

DANIEL B. STEPHENS

Articles in Symposia Proceedings:

Siegel, J. and D.B. Stephens, 1980, Numerical simulation of seepage beneath lined ponds, Proc. Symposium on Uranium Mill Tailings Management, Ft. Collins, CO, Nov. 24-25, pp. 219-232.

Stephens, D.B. and S.P. Neuman, 1980, Free surface and saturated-unsaturated analyses of borehole infiltration tests above the water table, IN Third International Conf. on Finite Elements in Water Resources, Oxford, MS, May 19-23, USDA-ARS, pp. 2.229-2.238.

Stephens, D.B. and J. Siegel, 1981, Fluid waste movement through the vadose zone, IN Environmental Geology and Hydrology in New Mexico, S.G.Wells and W. Lambert (eds.) NM Geol. Soc., Special Pub. 10, pp. 103-110.

Stephens, D.B., S. Tyler, K. Lambert, S. Yates, 1983, Field experiments to determine saturated hydraulic conductivity in the vadose zone, IN Role of the Unsaturated Zone in Radioactive and Hazardous Waste Disposal, J.W. Mercer et al. (eds.), Ann Arbor Sci, Ann Arbor, MI, pp. 113-126.

Stephens, D.B., K. Lambert, D. Watson, 1983, Influence of entrapped air on field determinations of hydraulic properties in the vadose zone, Proc. Conf. on Vadose Zone Characterization and Monitoring, Las Vegas, NV, Dec. 8-10, Nat. Water Well Assoc., Columbus, OH.

Stephens, D.B. and C. Spaulding, 1984, Oil-field brine contamination- a case study, Lea Co., NM Bur. Mines and Min. Resour., Hydrol. Report Series.

Stephens, D.B., 1984 Groundwater flow and implications for groundwater contamination in sedimentary formations of the Southern San Juan Basin, New Mexico, USA, Int. Groundwater Symposium on Groundwater Res. Utilization and Contaminant Hydrology, Montreal, May 21-23, Canada Water Well Assoc.

Statement of Qualifications

DANIEL B. STEPHENS

Articles in Symposia Proceedings continued:

Larson, M.B. and D.B. Stephens, 1985, A comparison of methods to characterize unsaturated hydraulic properties of mill tailings, Proc. Seventh Symp. on Management of Uranium Mill Tailings, Low-level Waste and Hazardous Waste, Ft. Collins, CO., Feb. 6-8, Colo. State Univ.

Lewis, B. and D.B. Stephens, 1985, Analysis of infiltration through mill tailings using a bromide tracer, Proc. Seventh Symp. on Management of Uranium Mill Tailings, Low-Level Waste and Hazardous Waste, Ft. Collins, CO, Feb. 6-8, Colo. State Univ.

Stephens, D.B., 1986, Saturated-unsaturated flow relationship, 15th Annual Rocky Mountain Groundwater Conference, Phoenix, AZ, September 13-16.

McCord, J.T. and D.B. Stephens, 1987, Infiltration and recharge on a sandy hillslope in an arid climate, Int'l Conf. on Infiltration Dev. and Appl., U. of Hawaii, Manoa, January 6-9.

Stephens, D.B., May 27, 1987, NM Environmental Improvement Division, Processes affecting the movement and fate of pesticides in soil and groundwater, Santa Fe, NM

Parsons, A.M., E.D. Mattson, D.B. Stephens, K. Flanigan, K. Black, 1988, Field simulation of waste impoundment seepage in the vadose zone, Proc. FOCUS on Southwestern Groundwater Issues Conf., Nat. Water Well Assoc., March 23-25, Albuquerque, NM.

Cox, W.B. and D.B. Stephens, 1988, Field study of ephemeral stream-aquifer interaction, Proc. FOCUS on Southwestern Groundwater Issues Conf., Nat. Water Well Assoc., March 23-25, Albuquerque, NM.

McCord J.T., D.B. Stephens, J.L. Wilson, 1988a, Field experiments and numerical simulations of unsaturated flow and transport: the role of hysteresis and state-dependent anisotropy, NATO Advanced Study Institute on Recent Advances in Modeling Hydrologic Systems, July, 1988 Sintra, Portugal

Statement of Qualifications

DANIEL B. STEPHENS

Articles in Symposia Proceedings continued:

McCord J.T., D.B. Stephens, J.L. Wilson, 1988b, Field-scale unsaturated flow and transport in a sloping, uniform porous media: field experiments and numerical simulation, (Abs), Intl. Conf. and Workshop on Validation of Flow and Transport Models for the Unsaturated Zone, Poster Session, May 22-25, Ruidoso, NM

Stephens, D.B., E.D. Mattson, A.M. Parsons, K. Black, K. Flanigan, 1988, A field experiment of three-dimensional flow and transport in a stratified soil, (Abs), Intl. Conf. and Workshop on Validation of Flow and Transport Models for the Unsaturated Zone, Poster Session, May 22-25, Ruidoso, NM.

Stephens, D.B., J.T. McCord, R.G., Knowlton, Jr., B. Kickham, E. Hicks, T. Stein, 1988, Three-dimensional soil-water flow in semi-arid terrain, (Abs), Intl. Conf. on Advance in Ground-Water Hydrol., November 16-18, Tampa, Fl.

Statement of Qualifications

DANIEL B. STEPHENS

Representative Professional Assignments:

* Design and supervise computations of contaminant releases from unsaturated material at a field site

* Perform field investigations of seepage from an impoundment using hydraulic properties of core samples, seepage meters and piezometers

* Evaluate unsaturated zone monitoring and sampling instrumentation; design unsaturated zone transport field experiment

* Collect field samples and supervise laboratory analyses of unsaturated hydraulic properties; interpret results with respect to monitoring system design

* Design a ground-water monitoring program for delineating contamination at an oil refinery

* Identify sources of ground-water contamination in an oil field

* Predict impacts of ground-water withdrawal on a near-by brine plume for a water rights project

* Assess the validity of a water budget study prepared for a high-level waste repository

* Determine saturated hydraulic conductivity in the vadose zone using borehole infiltration tests and air-entry permeameters

* Assess the availability of design concepts and analytical procedures for evaluating waste repository sealing methods in Nevada

* Review licensing documents for uranium mills for adequacy of hydrogeologic data in Colorado and New Mexico

* Simulate the rate of seepage through a landfill in New Jersey

* Provide technical direction on a project to evaluate the ground-water monitoring program at Utah oil shale tracts U-a, U-b

Statement of Qualifications

DANIEL B. STEPHENS

Representative Professional Assignments continued:

* Analyze hydrogeologic data and design aquifer tests, mine dewatering plans, and monitoring networks for coal leases in Wyoming, Texas, and Arkansas

* Prepare a water budget analysis in the Lower Colorado River Basin near Yuma, Arizona

* Compile basic hydrologic data on ground-water basin along the United States - Mexico border

* Identify the extent of ground-water contamination from a salt water impoundment in North Carolina

* Collect hydrogeologic and geophysical data and prepare reports for Preliminary Safety Analysis Reports for Nuclear Power Plants in California and Arizona

* Design aquifer exploration and baseline data collection program for Utah oil shale tracts; supervision of technical field tests including core sampling, packer testing, aquifer tests, geophysical logging

* Inventory wells, interpret results of packer tests, and evaluate hyrogeologic framework at a nuclear power plant near Boardman, Oregon

* Log cutting and prepare detailed geologic logs for a nuclear power plant in Central Alabama

* Geologic mapping, packer testing in off-shore drill rig, well inventory, well logging, coordinate field operations at Perry Nuclear Power Plant, Ohio

March 1989

CONDENSED AUTOBIOGRAPHY

NAME: Edwin P. Weeks
REGION: CR
PROJECT SHORT TITLE: Unsaturated zone field studies
PROJECT CHIEF: Same
GRADE AND DATE OF LAST PROMOTION: GS-15, 6/75
DATE AND LOCATION OF ENTRANCE WITH WRD: June/58 Cheyenne, Wyoming

EDUCATION: Colorado School of Mines, B.S. 1958

LANGUAGES: None

PROFESSIONAL SOCIETIES: American Geophysical Union
Society of Petroleum Engineers

AWARDS AND HONORS: Distinguished Service Award, Sept. 1988
Meinzer Award, Hyrogeology Division, GSA, Nov. 1983
Meritorious Service Award, June 1982
Quality increase, 1971

PROFESSIONAL EXPERIENCE:

June 1979 to Present. Assigned as Chief, Unsaturated Zone Field Studies in Denver, CO. During that time, I have conducted or directed field-oriented research on anisothermal vapor transport in unsaturated media, gaseous diffusion and reactions in the unsaturated zone, methods for determining unsaturated zone flow properties, the measurement of evapotranspiration by the eddy-correlation method, and topographyically affected gas circulation through fractured rock. Also served as Chief, Drilling, Sampling, and Testing Project, 75 CR 103, until January 1983 and as Assistant Research Advisor for Ground Water from April 1981 until present.

June 1976 - June 1979. Served as Chief, High Plains Artificial Recharge Research Project in Lubbock, Texas. Conducted field experiments involving both spreading and well-injection experiments, including a massive tracer experiment at Stanton, Texas.

August 1972 - June 1976. Served on staff of Ground Water Branch. Responsible for training, including development of new courses and teaching at those and at existing courses. Also responsible for technical review of reports and some District reviews. A major assignment involved a report mediating the hydrologic facts in a dispute between USBR and USF & WS concerning the Nebraska Midstate Diversion. Served as Research Advisor for the Unsaturated Zone and Evapotranspiration from 1974-1977.

August 1968 - August 1972. Served as Chief, Multiphase Flow Project. Principal research was on the use of air-permeability techniques to determine in situ unsaturated zone properties and to determine water-budget evapotranspiration from a five-point observation well array.

February 1962 - August 1968. Served as Chief of two sequential projects to determine the effects of ground-water development on streamflow in the Central Sandplain area of Wisconsin. Work included aquifer-test analysis, ground-water flow modeling, and estimation of evapotranspiration using water-balance modeling techniques.

June 1958 - February 1962. Served as Chief of a project to determine effects of proposed ground-water development for irrigation on water levels and streamflow in the Wheatland Flats area, Wyoming. Work involved test drilling, aquifer test performance and analysis, and areal system analysis.

BIBLIOGRAPHY

Gordon, E. D., McCullough, R. A., and Weeks, E. P., 1963, Ground water at Grant Village site, Yellowstone National Park: U.S. Geological Survey Water Supply Paper 1475-F, p. 173-200.

Weeks, E. P., 1964, Use of water-level recession curves to determine the hydraulic properties of glacial outwash in Portage County, Wisconsin: in Geological Survey Research 1964: U.S. Geological Survey Profes sional Paper 501-B, p. B181-B184.

Weeks, E. P., 1964, Field methods for determining vertical permeability and aquifer anisotropy, in Geological Survey Research 1964: U.S. Geological Survey Professional Paper 501-D, p. D193-D198.

Weeks, E. P., 1964, Hydrologic conditions in the Wheatland Flats area, Platte County, Wyoming: U.S. Geological Survey Water-Supply Paper 1783, 79 p.

Weeks, E. P., Ericson, D. W., and Holt, G. L. R., Jr., 1965, Hydrology of the Little Plover River basin, Portage County, Wisconsin, and the effects of water-resource development: U. S. Geological Survey Water-Supply Paper 1811, 78 p.

Welder, G. E., and Weeks, E. P., 1965, Hydrologic conditions near Glendo Platte County, Wyoming: U.S. Geological Survey Water-Supply Paper 1791, 82 p.

Weeks, E. P., 1969, Determining the ratio of horizontal to vertical permeability by aquifer-test analysis: Water Resources Research, v. 5, no. 1, p. 196-214, illustrations, table..

Weeks, E. P., and Stangland, H. G., 1970, Effects of irrigation on stream flow in the central sand plain of Wisconsin: U.S. Geological Survey Open-File report, 224, p. illustrations.

Weeks, E. P., and Sorey, M. L., 1973, Use of finite-difference arrays of observation wells to estimate evapotranspiration from ground water in the Arkansas River Valley, Colorado: U.S. Geological Survey Water-Supply Paper 2029-C, C27 p.

Weeks, E. P., Lappala, E. G., and Sauer, V. B., 1975, Review of hydrologic data and interpretations, Nebraska-Mid State Division, Pick-Sloan Missouri River Basin Program: U.S. Geological Survey Administrative Report, 105 p.

Weeks, E. P., 1978, Field determination of vertical permeability to air in the unsaturated zone: U.S. Geological Survey Professional Paper 1051, 41 p.

Weeks, E. P., 1978, Aquifer tests-- the state of the art in hydrology: Proceedings of the Invitation Well-Testing Symposium, Lawrence Berkeley Laboratory, Berkeley, California, p. 14-26.

Weeks, E. P., 1979, Barometric fluctuations in wells tapping deep unconfined aquifers: Water Resources Research, v. 15, no. 5, p. 1167-1176.

Bassett and others, 1981, Preliminary data from a series of artificial recharge experiments at Stanton, Texas: U.S. Geological Survey Open-File report 81-149, 235 p.

Weeks, E. P., and Appel, C. A., 1982, Optimum location of a well near a stream--an apparent paradox: American Geophysical Union John Ferris Symposium Monograph, in press.

Weeks, E. P., Earp, D. E., and Thompson, G. M., 1982, Use of atmospheric fluorocarbons F-11 and F-12 to determine the diffusion parameters of the unsaturated zone in the Southern High Plains of Texas: Submitted for publication in Water Resources Research, 57 p.

Thorstenson, D. C., Weeks, E. P., Haas, H., and Fisher, D. W., 1983, Distribution of gaseous 12CO213CO2, and 14CO2 in the sub-soil unsaturated zone of the western U.S. Great Plains: Radiocarbon, v. 25, no. 2, p. 315-346.

Haas, H., Fisher, D. W., Thorstenson, D. C., and Weeks, E. P., 1983, 14CO2 measurements on soil atmosphere sampled in the subsurface unsaturated zone in the western Great Plains of the US: Radiocarbon, v. 25, no. 2, p. 301-314.

Weeks, E. P., and Wilson, W. E., 1984, Preliminary evaluation of hydrologic properties of cores of unsaturated tuff, test well USW H-1, Yucca Mountain, Nevada: U.S. Geol. Survey Water-Resources Investigations Report 84-4193, 30 p.

Weeks, E. P., Weaver, H. A., Campbell, G. S., and Tanner, B. D., 1985, Water use by saltcedar and by replacement vegetation in the Pecos River floodplain between Acme and Artesia, New Mexico: U.S. Geol. Survey Professional Paper (in press). Also U.S. Geol. Survey open-file report 85-326, 105 p.

Kraemer, D. K., Weeks, E. P., and Thompson, G. M., 1986, A field technique to measure the tortuosity and effective porosity for gaseous diffusion of materials in the unsaturated zone: Water Resources Res., in press. Contributed much (50%) of the writing and analysis).

Montazer, Parviz, Weeks, E. P., Thamir, Falah, Yard, S. N., and Hofricter, P. B., 1985, Monitoring the vadose zone in fractured tuff, Yucca Mountain, Nevada in Proceedings, National Water Well Association Conference on Characterization and monitoring of the Vadose (Unsaturated) Zone, Denver, Colorado. Contributed the section on air permeability plus substantial technical review on other topics.

Yang, I. C., Haas, H., Weeks, E. P., and Thorstenson, D. C., 1985, Analysis of gaseous phase stable and radioactive isotopes in the unsaturated zone, Yucca Mountain, Nevada in Proceedings, National Water Well Association Conference on Characterization and Monitoring of the Vadose (Unsaturated) Zone, Denver, Colorado. Contributed sections on sampling and analyzing sulfur hexafluoride and of CO2 contents, along with major editing of manuscript.

Weeks, E. P., 1987, Effects of topography on gas flow in unsaturated fractured rock--concepts and observations: Am. Geophys. Union Geophysical Monograph 42, p. 165-170.

ADDITIONAL SCIENTIFIC CONTRIBUTIONS

I. LECTURES GIVEN AT UNIVERSITIES:

1986 Invited participant and panel member on "Effects of Gas Phase" at University of Arizona - Sandia National Laboratory -NRC Workshop III on flow and transport in unsaturated fractured rock.

1985 Seminar on work in progress, New Mexico Tech, Socorro.

1985 Invited paper at the Water and Science Symposium, New Mexico WRRI Annual Water Conference.

1985 Lecture to hydrology class of New Mexico Tech, Socorro, on work in progress.

1984 Invited participant, University of Arizona-Sandia Labs workshop on flow and transport in the unsaturated zone as related to radioactive waste disposal, Tucson AZ.

1984 Lewis G. Weeks lecture to Geology Department, University of Wisconsin, Madison.

1984 Seminar to hydrogeology class at University of Wisconsin, Madison, on work in progress.

1984 Ph.D. Thesis Examainer, Harold A. Weaver, Dept. of Soils, Washington State University, Pullman.

1983 Ph.D. Thesis Examiner, David K. Kreamer, Dept. of Hydrology, University of Arizona, Tucson.

1981 Seminar on work in progress, Washington State University

1978 Seminar on work in progress, University of Arizona, Tucson.

2. PAPERS GIVEN AT SCIENTIFIC MEETINGS:

1988 Cochaired a special one-day session of the Fall AGU meeting of Gases in the Unsaturated Zone-Transport and Chemistry".

1988 Contributed paper on topographyically affected gas flow at Yucca Mountain, Nevada, AGU Fall Meeting.

1986 Contributed paper on topographyically affected gas flow at Yucca Mountain, Nevada, AGU Fall Meeting.

1986 Invited paper on unsaturated zone instrumentation, AGU Fall Meeting.

1985 Invited paper at the 17th Annual meeting of the International Association of Hydrogeologists.

1985 Invited paper at the Southwest and Rocky Mountain Division AAAS Meeeting.

1981 Paper given at the John Ferris Symposium of the American Geophysical Union.

1978 Invited paper at the Salt River Project Ground Water Recharge Symposium, Phoenix, AZ.

1977 Invited paper at the First Invitational Well-Test Symposium, hosted by Lawrence Berkeley National Laboratory, Berkeley, CA.

3. TRAINING GIVEN AT USGS NATIONAL TRAINING CENTER:

1974-89 Coordinator and principal lecturer, (2 1/2 days) Analytical methods to determine aquifer properties: given once or twice annually at the USGS NTC (National Training Center), Lakewood, CO.

1976-89 Two days of lectures at the USGS NTC course Ground Water Concepts - once or twice annually.

1977-88 Two and one-half days lecture, coordination of USGS NTC course, Flow in the unsaturated zone--taught four times.

4. PROFESSIONAL SOCIETY COMMITTEE ASSIGNMENTS:

1985-87 Member of the Unsaturated Zone Committee, AGU.

1975-77 Member of the Consumptive Use Committee, Irrigation and Drainage Division, American Society of Civil Engineers.

5. OTHER COMMITTEE ASSIGNMENTS:

6. INFORMAL SEMINARS, USGS:

7. OTHER TALKS AND ASSIGNMENTS:

1985 Served as Chairman of a panel of University Professors and myself to review the unsaturated zone studies being conducted by Pacific Northwest Laboratories to evaluate current shallow unsaturated zone waste-disposal practices at Hanford, Washington.

1984-86 Serve as member of a team to periodically evaluate hydrogeologic work done by the Basalt Waste Isolation Project for Department of Energy.

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APPENDIX B

WORKSHOP AGENDA

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AGENDA FOR TECHNICAL REVIEW OF HANFORD SITE PERFORMANCE ASSESSMENT PROGRAMS

July 25, 1989

DAY 1: Review of Hanford Site Performance Assessment Technology Development Programs

Location: Environmental Technology Center Bldg. 2, Room 24
Morning Session: 8:00-11:30

8:00 Welcome, Introduction, and Overview

- Opening Statement (T.L. Cheatham, ASI) — 15 minutes
  - Welcome
  - Statement of workshop purpose and issues
  - 3-day agenda
  - Introduction of participants
- Performance Assessment Overview (J. W. Cammann, WHC) — 30 minutes
  - Types of wastes and disposal sites
  - Role of performance assessment at Hanford
  - Technology development programs
  - Applications programs
- Hydrogeologic Overview of Hanford (K. R. Fecht, WHC) — 30 minutes

9:15 Performance Assessment Experience at Hanford (C. T. Kincaid, PNL) — 30 minutes
- Hanford Defense Waste Environmental Impact Statement

9:45 Lysimeters and Recharge (G. W. Gee, PNL) — 30 minutes
- Facilities description
- Results to date

10:15 15-Minute Break

10:30 Near-Surface Flow Modeling (M. J. Fayer, PNL) — 30 minutes
- UNSAT-H Model
- Current capabilities
- Development work

11:00 Contaminant Release (R. J. Serne, PNL & M. I. Wood, WHC) — 30 minutes
- Status

11:30 Lunch Break

July 25, 1989

1:00	**Contaminant-Soil Interactions** (R. J. Serne, PNL & M. I. Wood, WHC) - Status	30 minutes
1:30	**Vadose and Saturated Zone Flow and Transport Modeling** (B. Sagar, PNL) - PORFLO-3 Model - Current capabilities & development work	45 minutes
2:15	**15-Minute Break**	
2:30	**Benchmark and Verification Testing of Models** (R. G. Baca, EG&G Idaho) - UNSAT-H model - PORFLO-3 model	45 minutes
3:35	**Open Discussions**	15 minutes

July 26, 1989

DAY 2: Review of Performance Assessment Applications

Time: 8:00 a.m.
Location: Environmental Technology Center Bldg. 2, Room 24

8:00	**RCRA/CERCLA Support** (J. C. Sonnichsen, WHC)	20 minutes
8:20	**LLW Burial Support** (R. R. Seitz, WHC)	20 minutes
8:40	**Effect of Varying Recharge Rates on Radionuclide Fluxes** (R. Khaleel, WHC)	20 minutes
9:00	**T-106 Tank Leak Simulation** (B. Sagar & J. L. Smoot, PNL)	30 minutes
9:30	**Waste Disposal Site Soil Stability and Contaminant Isolation** (S. J. Phillips & J. F. Relyea, WHC)	30 minutes
10:00	**Grout Program Overview** (T. B. Bergman, WHC) - Statement of objectives - Grout program context, history, and status - Overview of grout performance assessment work - Agenda	30 minutes
10:30	**15-Minute Break**	
10:45	**Regulatory Framework** (G. W. McNair, PNL) - Performance standards - Performance durations - Point of compliance and apportionment of releases	30 minutes
11:15	**System Description and Design** (G. W. McNair, PNL) - Grout vault design and site layout - Description of key components - Conceptual model of contaminant release	30 minutes
11:45	**Lunch Break**	
1:00	**Grout Release and Retardation Models/Data** (R. J. Serne, PNL)	30 minutes
1:30	**Diffusion Barrier** (J. L. Conca, PNL) - Experimental determination of diffusivity - Materials selection	30 minutes

July 26, 1989

2:00	**Hydrologic Data** (G. W. Gee, PNL) - Diffusion barrier - Soils	30 minutes
2:30	**15-Minute Break**	
2:45	**Subsurface Models Selection and Application** (R. W. Nelson, PNL) - Model selection process - Description of selected models - Model results	30 minutes
3:15	**Grout Performance Assessment Results to Date** (G. W. McNair, PNL) - Cases considered - Summary of parameter values used - Sensitivities evaluated - Summary	15 minutes
3:30	**Additional Data Requirements and Assessment Uncertainties** (D. H. Mitchell, PNL) - Osmotic effects - Asphalt durability - Protective barriers performance	15 minutes

July 27, 1989

DAY 3: **Tours of the Field Lysimeter Test, Grout Treatment, and Sigma V Facilities, and Panel Executive Session**

Time: 7:00 a.m.
Location: Bus departs front of Vitro Bldg.

7:30	**Field Lysimeter Test Facility Tour** (S. J. Phillips, WHC & M. D. Campbell, PNL)	1-2 hours
9:15	**Grout Treatment Facility Tour** (J. E. Van Beek, WHC)	1-2 hours
11:00	**Sigma V Laboratory Tour** (G. W. Gee, PNL)	1 hour
12:00	**Lunch Break**	
1:30	**Afternoon Session**	

Executive Session (ASI Conference Room, Vitro Bldg.)
- Discuss documents reviewed and materials presented
- Formulate comments and recommendations
- Develop statement of findings for ASI deliverable to WHC

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APPENDIX C

COMMENTS OF JOHN W. BARTLETT

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July 6, 1989

Mr. Terrance L. Cheatham
Advanced Sciences, Inc.
1835 Terminal Drive, Suite 200
Richland, WA 99352

Dear Terry:

With reference to your letter of June 20, I have reviewed the documents you sent as background for the performance assessment peer review meeting to be held during the week of July 24.

I found the discussions of the models and their use to be thorough and sound. High-quality transfer of concepts and methods from the BWIP is evident, and appropriate QA for the codes is underway. In short, as represented by these documents, everything needed for quality effort in performance assessment activities is in place.

Accordingly, I believe the peer review meeting might beneficially focus on the interactions of the performance assessment function with related functions such as data acquisition and results utilization.

I am aware, for example, that accurate characterization of the contents of the single-shell tanks is a formidable if not intractable problem. In this sector of effort there is high potential for "good" performance assessments using "bad" data, with the consequence that results will not be defensible. Similarly, I am aware that Hanford groundwater is at present not well characterized in terms of contamination levels and flow patterns. In general, an appropriate subject for the meeting would be criteria and methods for interactions between performance assessment and data acquisition.

Another subject for the meeting would be the scope of performance assessments for degradation or disruption scenarios. This subject is discussed somewhat in Section 6.0, Areas of Uncertainty, of the Grouted Double-Shell Tank Wastes report. In the commercial HLW disposal program, the art of performance assessment for such scenarios has been raised to a very high level (see, for example, Section 8.3.5.13 of the Yucca Mountain Site Characterization Plan). I suspect that the scope and sophistication of the Hanford program will have to be comparable.

Yet another potential subject for the meeting is the ability of probabilistic results to distinguish the merits of alternative waste management actions. This question is raised implicitly by the contents of the strategy document, WHC-EP-0072. It is closely tied to the question of data sufficiency and accuracy.

I am really looking forward to participation in the peer review meeting. Please let me know if you have questions concerning these suggestions for the agenda.

Very truly yours,

THE ANALYTIC SCIENCES CORPORATION

John W. Bartlett

John W. Bartlett

JWB/ri

APPENDIX D

COMMENTS OF DONALD LANGMUIR

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Comments on Third-Party Technical Peer Review of the Hanford Site Performance Assessment Programs

Donald Langmuir, Ph.D.
Hydrochem Systems Corporation

1. Performance assessment at Hanford is emphasizing model development, verification and benchmarking, with models to be used for predicting site performance. However, little or no emphasis is being placed on the development of fundamental scientific understanding of the hydrogeological and geochemical characteristics and properties of the Hanford site. Such an understanding, which must involve the collection and interpretation of laboratory and field data, should form the basis for any models intended to predict future site performance. Without it, scientifically defensible model validation is impossible. There are at least three potential sources of data that can be considered in model validation. The most definitive is in-situ data collected following historic spills/seepages in the unsaturated zone at Hanford, for which the movement of water and contaminants has bee documented over time. A second and related approach, is the sampling and analysis of emplaced wastes and unsaturated zone waters and geological materials: (1) to update historic records describing the consequences of waste releases; and (2) to determine the in-situ hydrologic and geochemical properties and behavior of unsaturated zone materials that might contact such wastes. The third approach is to perform laboratory experiments which focus on specific material properties, reactions or processes that can influence waste migration at the site. According to report WHC-EP-0072 (Performance Assessment Technology Development for Cleanup and Disposal of Hanford Defense Wastes, 1988, J.D. Davis), the performance assessment technology development program does not have responsibility for the collection of site characterization and performance data, which is within the purview of other WHC defense waste management programs. Clearly, the proper collection and interpretation of such data is critical to the accomplishment of successful performance assessment program. Obviously, WHC needs to implement a team approach involving the several groups engaged in data collection in the unsaturated zone, and the performance assessment technology development (PA) group. The impression was that the PA group had little or no say in what or how geochemical and hydrologic data was collected at Hanford, except in a few instances, such in the unsaturated zone lysimeter studies. Unless WHC structures a multiple-team approach in which PA staff participate in the site characterization effort, or at least have a strong say in what and how such data is collected, it seems probable that the development of a defensible PA program involving long-term prediction of site performance is doomed to failure.

2. As a related issue, the PA program needs to define and implement a methodology for validating all computer codes, and to decide what validation means in terms of each code and measurable variable. The definition of validation given by Davis (WHC-EP-0072) is a "comparison of the computational results of a specific application of a mathematical model with empirically derived data or information, for the purposes of demonstrating that the results correctly represent the process and conditions that the model purports to simulate." Insofar as the goal of PA is to predict site performance for

times up to 10,000 years, the most useful empirically derived data for validation purposes, is that describing the long-term fate of historic leaks or spills in the unsaturated zone at Hanford. Such information obtained from a 1973, 115,000 gallon tank lead was effectively used by Smoot and Sagar as input for validation of the transport code PORFLO-3. At the peer review workshop, Serne noted the existence of detailed information from the leakage of 19 single-shell tanks, in the form of 30 samples of drainable liquor, 30 water leaches from 30 cores, and analytical data for 30 chemical species and 10 radionuclides, with more such data to be obtained starting in 1990. Such chemical data, combined with hydrologic data should form one basis for validation of proposed unsaturated zone transport codes. Based on documents provided to the panelists prior to the peer review meeting, it is clear that WHC intends for PORFLO-3 to be properly validated by its subcontractor EG&G, Idaho. However, given that validation was to be completed by August 15, 1989, shortly after the meeting, it seems doubtful from what was presented at the meeting, that an adequate validation effort could be demonstrated by then.

3. It was mentioned that in a number of instances the timing and required standards for compliance with government agency regulations had not yet been set. When this is the case, it clearly represents an opportunity for WHC staff to provide input to the decision-making process.

4. The following suggestions relate to the site characterization program, and assume that WHC can properly facilitate the implementation of such a program, driven primarily by the needs of the PA group. A detailed site characterization program to evaluate the hydrogeological and geochemical properties of the site, should be defined and put into place. The program should involve the following activities, a few of which are in progress or planned:

a. Collect data from records of past spills/leaks of wastes into the unsaturated zone as the critical input to site characterization.

b. Based in part on a., perform further in-situ hydrologic and geochemical tests and measurements to further detail and extend the results of a. in time.

c. Initiate sampling and analysis of vadose materials to establish their hydrologic and geochemical properties and probable performance when contacted with expected wastes.

d. Sample vadose waters and sediments and chemically and isotopically analyze them, to compute in-situ Rd's in both pristine and waste-affected zones. These Rd's should be comparable to laboratory measure values, or the latter are of questionable value.

e. Construct a hydrologic and related geochemical budget of the unsaturated and associated saturated zones at Hanford. Use suction lysimeters, and collect cores from sandy and silty zones in order to obtain samples of vadose water, which can then be analyzed for its oxygen/deuterium and tritium (etc.) content to assist in defining the hydrologic budget. The hydrologic budget will be directly related to

the historic migration patterns of vadose and saturated zone contaminants such as nitrate and tritium.

f. Study the hydrologic properties of the clastic dikes and their occurrence relative to existing and propose waste disposal sites. Are they located in any predictable pattern? Might they play a dominant role in contaminant migration to the water table?

5. The following suggestions relate to the characteristics and behavior of the wastes, including grouted wastes:

a. As proposed, the waste must be fully characterized, including their study using optical thin sections and SEM analyses to learn how salts are incorporated in the grout; as free salt inclusions, or in solid solution (such as nitrate), for example. Studies should also be initiated of the interaction of wastes with vadose media, assuming failures of engineered barriers. Such proposed work is inadequate in scope and detail.

b. The thermal and physical stability of initial-setting grouts above 75° C with radionuclides present, and with salt contents up to 27 % should be studied.

c. It seems likely that salts in the waste will dehydrate on setting of the grout at elevated temperatures. Rehydration of these salts and readsorption of water by hygroscopic salts could lead to grout rupture and should be studied in laboratory tests.

d. The possibility of volatilization of noxious grout components at the highest grout temperatures should be considered. Such components could include radioisotopes of Cd, Pb, Tc, and Hg, and $^{14}CO_2$.

e. What are the reaction products of the radioactive brines and grout, insoluble minerals, solid solutions? What are their thermodynamic stabilities, which should allow the computer modeling of reactions, and prediction of salt leachabilities.

f. Experiments could be performed involving vadose water interaction with grout/waste mixes, with the results being modeled using a high ionic strength computer model such as PHRQPITZ. Reaction rates should be studied and could also be modeled. What are the fundamental processes involved when grout/waste mixes contact vadose water?

6. The following comments relate to retardation coefficients (Rd's) chosen for use in modeling the transport of radionuclides and other species in the vadose zone at Hanford. Practically all such data in the literature has been obtained in saturated laboratory column and especially batch tests. Such conditions are vastly different than occur in the vadose zone, making the application of such values to transport modeling at Hanford a dubious exercise. As suggested above in 4d., in-situ Rd's can be obtained from sampling and analysis of vadose zone moisture and associated geological materials. In the laboratory, experimental adsorption studies can be performed using radionuclides or their analogs at different moisture contents

in experiments such as have been described and begun by Conca and Wright. These studies should be run for defined values of pH, and concentrations of competing and complexing ions (etc.). Alternatively, if uncertainties in Rd values remain very large, and include or approach no retardation, then the latter should be assumed to be conservative.

A surprising lack, is information on the amounts, compositions and distributions of solid phases most important to the adsorption process in the unsaturated zone at Hanford. Such data is essential if adsorption of chemical and radionuclide species is to be understood and predicted. What is the occurrence of clays, zeolites and ferric and manganese oxyhydroxides relative to pathways of vadose zone water flow? The program should consider using the PNL-developed model FASTCHEM (Krupka) to predict adsorption during transport. Other PNL staff such as E. Jenne, have been able to usefully estimate adsorption parameters for certain trace species which can be used in the surface ionization and complexation model in FASTCHEM.

APPENDIX E

COMMENTS OF SHLOMO P. NEUMAN

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Shlomo P. Neuman
Groundwater Consultant
3861 N. Crestwood Place
Tucson, Arizona 85715

July 3, 1989

Mr. Terrance L. Cheatham
Advanced Sciences, Inc.
1835 Terminal Drive, Suite 200
Richland, WA 99352

Dear Mr. Cheatham:

I read the material you sent me on June 13, 1989, preliminary to the third-party technical peer review of Westinghouse Hanford Company (WHC) program for developing and applying performance assessment technology to take place during the week of July 24, 1989. In response to your request, I wish to offer the following preliminary comments stressing a few items which I feel may need to be discussed in the forthcoming peer review session.

1. **Performance Assessment as Applied to Geologic Environment:** Performance assessment is an integral part of engineering design. As such, it is a useful concept when applied to the design of man-made systems or system components. Such systems or system components are designed on the basis of technology developed by man and are thus much better understood than natural systems (or simply *nature*). This understanding makes it possible to *assess* the *performance* of an engineered system or system component by means of reasonably well founded conceptual, mathematical, and computer-encoded models.

The geologic environment is part of nature which man can *integrate* into an engineered system but one which man cannot *design*. The geology is neither man made nor does it *perform* to man's specifications. Therefore, the term *performance assessment* does not apply to it. The application of this term to a natural system is misleading because it implies that the system is part of an engineered construct over which man has *control* through the process of *design*. Unless man deliberately alters nature, he does not exercise such control over it. A natural system can *respond* to man induced inputs or stresses and man *should* therefore perform an *assessment of natural response* to his engineering designs in the form of environmental impact studies. However, man should not pretend that the environment is *part* of his designs.

There is a fundamental difference between assessing the performance of an engineered system and assessing the response of nature to this system. The difference stems from the fact that natural responses to man induced inputs and stresses are understood to a far lesser extent than are engineered systems. While there exist conceptual, mathematical, and computer-encoded models for certain natural phenomena that affect such responses, their foundations are generally much shakier than those of similar models for the performance of man made systems. The documents that I have read do not reflect an understanding of this fundamental difference. Yet this difference must be squarely faced and acknowledged by the DOE if it is to recover public trust and confidence in its ability to handle radioactive and chemical wastes in a responsible manner.

2. **Validation of Environmental Response Models:** The documents you sent me talk routinely of *validating* models which are intended to predict the response of the subsurface environment at Hanford to releases of radioactive and chemical substances created by man, which he is able to control in a partial manner by means of engineered barriers, over time spans of up to 10,000 years and distances of up to several kilometers. The term *validation* is defined on p. 38 of the document by Davis (WHC-EP-0072, 1988) as "comparison of the computational results of a specific application of a mathematical model with empirically derived data or information, for the purposes of demonstrating that the results correctly represent the process and conditions that the model purports to simulate." Missing from the documents is even a hint of recognition that no data or information will become available within the time frame of the proposed performance assessment by WHC to perform such comparisons, in a meaningful and convincing manner, over temporal and spatial scales of such magnitude. Yet the models discussed in the documents purport to simulate radionuclide and chemical transport in the geologic environment of Hanford over such scales. How will these simulations be validated?

I propose that the DOE drop the term validation from its vocabulary and openly recognize that its environmental models can at best be *calibrated* against sparse data representing existing conditions on much smaller space-time scales than the models purport to simulate. Such calibration provides no assurance that the same models will predict, with reasonable accuracy, system response on the desired scales. This is especially true with respect to the vadose zone in which models of water flow and chemical transport have, to my knowledge, never been tested against real data (nor will they apparently be at Hanford) on scales exceeding at best a few meters and/or months. I propose that a thorough literature survey be conducted to document cases in which vadose zone models have been successfully calibrated (and perhaps validated?) against real data to provide at least some support for their use by the WHC.

3. **Prediction of Model Uncertainties:** The documents sent to me for review convey a belief that uncertainties in model predictions of radiation doses, chemical concentrations, and travel times (a term nowhere defined which I find ambiguous) can be estimated beneath the Hanford site over distances of up to several kilometers and periods of up to ten thousand years. Appendix 1 in Seitz *et al.* (1989) goes as far as implying that if this uncertainty cannot be estimated objectively, it can nevertheless be quantified sufficiently well on the basis of expert opinion for a systems approach to "result in **definitive** [emphasis added] evaluations and optimization of the mixed-waste disposal problem." This is equivalent to saying that where scientific knowledge is insufficient to describe uncertainties in the response of a natural environment to man induced stresses, a sophisticated engineering systems approach will overcome the difficulty. Can the DOE document cases where systems approaches have been able to do so in complex geologic (or other) environments over space-time scales of magnitude even remotely comparable to those one has to deal with at Hanford? If not, the issue must be squarely faced and acknowledged as being, to a large extent, unsolvable within the framework of the current waste-disposal efforts at Hanford. In other words, the public should be made aware that decisions about waste disposal options at Hanford will have to be made in the face of unresolvable uncertainties, as are decisions about almost all other aspects of our lives. The one thing we should not do is pretend that these uncertainties can be quantified where in fact our ability to do so has not been demonstrated.

The manner in which model uncertainities relate to data and propagate with time has been the subject of intensive research among subsurface hydrologists in recent years. Most of this work is limited to relatively simple models of groundwater flow in saturated, statistically homogeneous media and applies only through conjecture to the

vadose zone. I am not aware of similar work that would make it possible to quantify the ability, or inability, of models such as UNSAT-H and PORFLO-3 to correctly estimate recharge at the water table deep below the surface as is the case at Hanford, especially its distribution in space-time, even when atmospheric conditions are prescribed, or mass fluxes of dissolved chemicals within the vadose zone, even if source terms are known precisely, given uncertainty about material heterogeneity and its effect on dispersion, instability and fingering, or geochemical retardation. We need to discuss this issue and its effect on the proposed WHC approach to performance assessment.

4. **Role of Peer Review:** The documents imply that unresolved scientific and technical issues will be partially resolved with the help of peer review panels. It is my experience that peer reviewers are generally better equiped to point out weaknesses in scientific and technological programs than to work out detailed remedies; the latter would require a much greater effort than the peer review process allows. I propose that part of the Hanford meeting during the last week of July be devoted to a clarification of this important issue; in particular, the panel should not be viewed or portrayed as being in any way responsible for work conducted by the WHC.

I do have many other detailed comments and questions about the documents but should probably reserve them for our meeting at the end of the month. I look forward to meeting you and your colleagues on that occasion.

Sincerely,

Shlomo P. Neuman

ADDENDUM TO REPORT OF THE HANFORD SITE PERFORMANCE ASSESSMENT REVIEW PANEL

by

Shlomo P. Neuman

This addendum supplements the panel's concensus report with some personal comments and observations. My comments are based on documents listed in a letter from Mr. Terrance L. Cheatham dated June 13, 1989, and the technical review meeting held in Richland during July 25 - 27, 1989. Preliminary comments on these documents were sent to Mr. Cheatham on July 3, 1989, and are still valid. I would like to especially reemphasize my concern, strengthened during the technical review meeting, that Peer Reviews are portrayed by the Westinghouse Hanford Company (WHC) in a manner which may be misinterpreted as endorsement of the WHC Performance Assessment (PA) program by the Peer Review Panels. Such a misinterpretation can be easily avoided by freely circulating the Peer Review Reports among parties concerned with the PA program.

According to the above documents, the PA program will place heavy emphasis on the calibration and validation of computer encoded models (codes) describing fluid flow and contaminant transport through both unsaturated and saturated geologic environments at the Hanford site. Sensitivity and uncertainty analyses are to be an integral part of such model calibration and validation. However, the documents leave the terms calibration, validation, sensitivity analysis, and uncertainty analysis largely undefined and provide little information about the approach that will be adopted to perform such analyses. It is important for the WHC to develop a convincing strategy for the calibration and validation of models so that their reliability as PA tools is clearly demonstrated.

Calibration is the process of fine-tuning a model so that it reproduces observed system behavior such as the propagation of a contaminant plume through the vadose and saturated zones. A model that cannot be so fine-tuned while maintaining its input parameters within the range of measurement errors is in conflict with reality and therefore clearly inadequate for PA. While it is important to demonstrate through calibration that a model is not in conflict with the system it purports to mimick, such a demonstration is not sufficient to insure that the same model can be relied on to predict future system behavior. For this, the model must be validated. Though the meaning of this term remains vague, it is generally understood to imply testing the model's ability to simulate system behavior under conditions other than those prevailing during the calibration period. Validation thus requires field data in excess of those used for calibration.

To calibrate and validate PA models one must have a good amount of quality data about the spatial and temporal propagation of contaminant plumes, their sources, the geologic environments within which the plumes migrate, and the hydraulic parameters and state of these environments. Some such data are available at the Hanford site but appear not to be fully utilized by the PA program. It is important to thoroughly document the available data base and determine the extent to which it can be utilized for model calibration and validation within the context of the PA program. If the existing data base is found to be defficient, additional data need to be collected in support of the modeling effort. The importance of collecting hydrologic data as an integral part of the PA program appears to be dangerously underestimated by the

WHC. Without a greatly expanded effort to obtain good data for calibration, the models in the PA arsenal of the WHC will remain suspect as being unable to reproduce past and present hydrologic conditions at the site. An even greater data collection effort will be required if the models are to be validated so as to gain a measure of confidence in their ability to analyze future scenarios at the Hanford site.

From the documents mentioned earlier, and some of the presentations during the review meeting, it appears that the WHC has confidence in the ability of uncalibrated and unvalidated models to generate bounds on prediction uncertainty. It is my opinion that this confidence is unfounded and such models are unsuitable for PA. In my view, no amount of parameter variation in uncalibrated and unvalidated models can compensate for a lack of demonstrated capability to simulate observed behavior.

To make such a demonstration possible, it would be necessary for the WHC to develop a well thought out plan of data collection and analysis utilizing state-of-the-art calibration and validation methodologies. A good start is the attempt by B. Sagar and J. L. Smoot to compare model predictions with field data relating to a plume of contaminants in the vadose zone caused by a documented leak from Tank T-106 at Hanford in the early 1970's. These data demonstrate that brine from the leaking tank has initially caused saturation of the soil immediately below the tank, but with time spread laterally and vertically to an extent which resulted in soil desaturation. This plume thus provides a real example of how contaminants propagate through the vadose zone at Hanford under both saturated and unsaturated conditions. It might be very useful to expand the work of Sagar and Smoot by deepening the existing dry wells at the site in an attempt to delineate the present location and three-dimensional extent of the plume; drilling and coring if necessary to characterize the site and the plume in sufficient detail for a meaningful calibration of a vadose zone transport model; using this model to predict the fate of the plume over the next several years; monitoring the migration of the plume in three-dimensions and finally comparing the observed migration with that predicted by the model. If the observed and predicted behaviors match, one has validated the ability of the model to predict the near future; if they don't, the model may require modifications. A number of similar studies at other locations within the Hanford reservation may greatly enhance the credibility of WHC transport models and its PA program.

In addition to intensive site-specific field-based modeling studies of this kind, there is a need to develop a program of extensive field investigation on the regional scale at Hanford. The Peer Review Panel has been presented with groundwater flow models of the local unconfined aquifer which its developers could not defend due to a lack of information about key items such as mean annual recharge rate; the spatial and temporal distribution of recharge; water levels at depths greater than 20 to 40 feet below the water table; temporal fluctuations of water levels in the aquifre; the relationship between such fluctuations and variations in precipitation, evapotranspiration, and river stages; and the distribution of environmental isotopes such as tritium, deuterium, carbon-14, oxygen-18, or chlorine-36 within the aquifer and vadose zone. The latter two categories of data are essential for the characterization of recharge which in turn is one of the most important hydrologic variables controlling the distribution of contaminat travel times and concentrations in the vadose zone.

The current modeling effort in the context of PA at Hanford is based on a number of conceptual errors. To calculate travel times through the vadose zone, several models represent this zone as a sequence of continuous horizontal soil layers across which flow is strictly vertical. The reason is not only simplicity but the belief that such a one-dimensional approach is "conservative" by minimizing travel

time. In reality, the vadose zone at Hanford is extremely nonuniform with only limited continuity of soil layers in the lateral direction. In more realistic two- or three-dimensional models one might find that (a) by allowing water to spread horizontally the travel time would increase, yet (b) by allowing water to flow preferentially through gaps in the soil layers the travel time would decrease. It is not possible to predict which of these effects dominates at a given site without having thoroughly characterized the local soil structure, hence the claim that a one-dimensional layer-cake model is conservative lacks justification.

Another conceptual error stems from the tendency of many WHC models to deal solely with mean travel time due to advection and ignore or underplay the space-time distribution of travel times due to dispersion. The latter is caused by soil heterogeneities on scales smaller than those sampled: the less information one inputs into his model about the spatial variability of soil properties and the temporal fluctuation of variables such as recharge, the larger is the dispersivity parameter one must use in the model to compensate for such lack of information. By ignoring this parameter or assigning to it relatively small values obtained from laboratory column experiments, and by disregarding the well known tendency of dispersivities to increase with travel distance, the WHC transport models may grossly overestimate contaminant travel time through the vados zone. This is so because the models consider only mean travel time based on the velocity of a plume's center of gravity. This travel time is longer than that corresponding to the leading edge of a plume which is undergoing dispersion due to soil heterogeneity, the discrepancy between the two travel times becoming larger as the distance traveled by the plume increases.

In the vadose zone, dispersion may be greatly enhanced by wetting front instability which often develops when water descends from a less to a more permeable soil layer. This phenomenon is not considered in existing WHC models yet it could have an important effect on the design of gravel barriers for the grout waste disposal facilities planned at Hanford. Current designs do not consider such instability and assume that water can migrate downward through the gravel barriers only by gaseous diffusion. The issue is being studied by PNL with the aid of small scale laboratory models but thought should be given to an enlargement of these models so as to more closely represent conditions in the prototype.

At present, there appear to be no plans to investigate the possibility that the grouted waste will crack due to heat generated by hydration and radioactivity or due to fatigue; that the grout will deteriorate due to weathering at its contact with the gravel, aided by convective air and vapor circulation within this high permeability medium; or the effect that such cracking and/or weathering may have on contaminant release from the grout over the 10,000 year PA horizon. Current scenarios of contaminant release rates from the grout are based on experiments of relatively short duration on samples immersed in water which appear to be only marginally relevant to actual conditions under the existing design.

In all calculations to date the shallow barrier overlying the grout has been assumed to retain its integrity and effectiveness over long time periods. Since this cannot be assured, it seems more appropriate not to give any credit to this barrier during PA. Credit should also not be given to the retardation of contaminants by sorption because this process appears to be very poorly understood under the current design conditions.

Existing WHC models treat contaminated brines in the vadose zone as if they had the physical properties of pure water. Many of these models disregard airflow, vapor transport, and temperature effects. The credibility of these models could be

enhanced by demonstrating, through careful and exhaustive modeling studies, that these simplifying assumptions have validity under the conditions envisioned at Hanford.

Recharge at the soil surface is assumed to be distributed evenly over time. In reality, infiltration of rainfal at the soil surface occurs in short pulses and tends to concentrate in depressions. The effect of such space-time localization of moisture during recharge events may be very important and must not be overlooked. The prevailing notion that smoothing of input data, and simplification of models, constitute conservatism is in my view unfounded.

The WHC documents make a distinction between deterministic and stochastic models; the latter are to be used only if required explicitly by regulatory agencies. Since the parameters and forcing terms of "deterministic" models are uncertain, this distinction is artificial. It might be useful to eliminate this ambiguity and define precisely what is meant by uncertainty analyses in the context of PA.

The Unsat H model appears to be doing poorly at high soil saturation values, an issue worth investigating further by means of lysimeters. The WHC may also consider exploring possible biases in results from existing lysimeter studies due to the instruments' relatively limited surface exposure.

In summary, the WHC PA program appears to be in need of a major restructuring with the aim of (1) setting well thought out, clearly defined goals which recognize that modeling must be strongly supported by real data, and (2) improving coordination between the various modeling and data collection teams so as to maximize their efficiency in focusing jointly on these goals.

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APPENDIX F

COMMENTS OF DANIEL B. STEPHENS

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DANIEL B. STEPHENS & ASSOCIATES, INC.
CONSULTANTS IN GROUND-WATER HYDROLOGY

• GROUND-WATER CONTAMINATION • UNSATURATED ZONE INVESTIGATIONS • WATER SUPPLY DEVELOPMENT •

July 7, 1989

Mr. Doug Dennison
Advanced Sciences, Inc.
1835 Terminal Drive, Suite 200
Richland, WA 99352

Subject: Preliminary Written Comments on DOE-RL Third Party Review of WHC Performance Assessment

Dear Mr. Dennison:

I have briefly reviewed all of the documents you sent to me. I anticipate that my comments will be revised after the meeting and site visit in Washington later this month. On the whole, the program appears to be thorough and carefully developed. I have a few minor comments which I prefer to address in my report on the final comments; however, there are two points which I do want to mention here regarding performance assessment.

First, the program as outlined seems to emphasize model verification and benchmarking as means to gain confidence in the performance assessment. There is a need to include a model validation stage as well, in my opinion. There are a few sets of data available to conduct a model validation exercise; in fact, I recall that several years ago Buck Sission at Rockwell was involved in an injection test in the vadose zone somewhere near the Hanford Site. The models must be shown to accurately simulate field-scale behavior.

The second item is that hydrologists are coming to recognize that there are physical processes which are not accounted for adequately in most analytical and numerical models. In dry layered media, it is likely that fluid movement may occur in preferential paths. This process will tend to cause fingering in the advancing wetting front. The occurrence of macropores is a separate issue. Another process is anisotropy of unsaturated soil. In finely stratified soil anisotropy tends to increase with decreasing saturation. Consequently, the advancing wetting front and solutes can have a significant horizontal component. Additional work is needed in evaluating the importance of these physical processes in the performance assessment, and if the processes are important, then a methodology must be developed to obtain the relevant field data to account for these processes. Then, the models must be revised and validated.

Mr. Doug Dennison
July 7, 1989
Page 2

I look forward to the meeting and hope these preliminary comments are helpful.

Yours sincerely,

Daniel B. Stephens & Associates, Inc.

Daniel B. Stephens

Daniel B. Stephens, Ph.D.
President

DBS/alm

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DANIEL B. STEPHENS & ASSOCIATES, INC.
CONSULTANTS IN GROUND-WATER HYDROLOGY

• GROUND-WATER CONTAMINATION • UNSATURATED ZONE INVESTIGATIONS • WATER SUPPLY DEVELOPMENT •

September 21, 1989

Mr. Terrance L. Cheatham
Advanced Sciences, Inc.
1835 Terminal Drive, Suite 200
Richland, WA 99352

Subject: Comments for DOE-RL Third Party Review of WHC Performance Assessment

Dear Mr. Cheatham:

Enclosed herein are my detailed technical review comments of the Westinghouse Hanford Company Performance Assessment Program. The comments are contained in the attached report. It is my intent that these comments are constructive and contribute positively toward the overall waste management and remedial action program.

Please feel free to contact me if any comments require further explanation. I will be very glad to participate on future review panels.

Yours sincerely,

Daniel B. Stephens & Associates, Inc.

Daniel B. Stephens, Ph.D.
President

DBS/alm

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File: Report.989

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1.0 SUMMARY

A third party review panel was convened by Advanced Sciences, Inc. on behalf of Westinghouse Hanford Company to evaluate performance assessment activities. The review included six documents and a two-day workshop. The review herein addresses elements which are related mostly to ground-water hydrology and vadose zone processes.

The performance assessment activities presented are very impressive. Much of the technology development work is valuable research that is relevant to improving our basic understanding of flow and transport in hydrologic systems.

Four general comments are offered as a summary. First, performance assessment activities should explicitly identify the important physical and chemical processes which will be operative at the field scale. Second, reliability in the predictions of mathematical models must be improved significantly through demonstration that known releases at Hanford or other sites can be reconstructed accurately. Third, recognize the limitations in our ability as environmental scientists to accurately predict environmental conditions 10,000 years into the future. And fourth, improve communication and coordination among managers, modelers, experimentalists and subcontractors so that the performance assessment program is implemented rapidly in a cost-effective manner.

Pacific Northwest Laboratories (PNL), Advanced Sciences Inc. (ASI), as well as off-site consultants, the U.S. Geological Survey and Idaho National Engineering Laboratory.

Dr. Daniel B. Stephens was selected by ASI to serve as a member of a technical peer review panel of experts to provide independent third party opinions on the adequacy of the current and planned performance assessment efforts. The basic tasks assigned to the panel include:

1. study the issues and programmatic needs that must be addressed by the WHC performance assessment program;
2. review the current status, strategy, planned work, current organization, and division of responsibilities of the program;
3. make recommendations on how the program can be enhanced or improved; and
4. serve as a Technical Advisory Panel for Hanford Performance Assessments, such as that for the grout program.

To accomplish these tasks, the panel was requested to: a) review six PA-related documents; b) attend a workshop at Hanford on July 25-27, 1989, consisting of technical presentations and a tour of facilities; and c) provide written comments both individually and collectively. The areas of expertise of the panel include chemical engineering, hydrology, hydrogeology and geochemistry. Dr. Stephens' area of expertise is ground-water

2.0 INTRODUCTION

Performance assessment (PA) is "a systematic analysis of the potential risks posed by waste management systems to the public and environment and a comparison of those risks to established performance objectives" (DOE order 5820.2A). The Westinghouse Hanford Company (WHC) is conducting PA activities for the remediation and disposal of wastes at the Hanford site. The wastes include buried radioactive and mixed solid wastes, as well as hazardous chemical wastes, that have been disposed in engineered tanks and cribs or discharged to soil, for example, through ponds, drains or accidental surface spills. A PA is an important part of the site clean up and selection of remedial action plans that will bring the waste sites into compliance with RCRA and CORCLA regulations. WHC has implemented both a technology development program and an applications program which support the PA. The technology development program provides basic investigations to identify important physical and chemical processes and predictive tools, such as computer codes, to be used in the applications of the PA to a site or scenario. The applications program implements the performance assessment process which includes: establishing objectives for engineered systems; characterizing the site; monitoring; applying models; evaluating results; and assessing regulatory compliance. WHC is assisted in the PA program by

3.0 CRITIQUE OF DOCUMENTS

Prior to attending the workshop, the following documents were reviewed:

1. Davis, J.D. 1988, Performance Assessment Technology Development for Cleanup and Disposal of Hanford Defense Wastes, WHC-EP-0072, Westinghouse Hanford Company, Richland, WA.

2. McNair, G.W., et al., 1989, Performance Assessment of Grouted Double-Shell Tank Waste at Hanford (Draft), Pacific Northwest Laboratory, Richland, WA.

3. Seitz, R.R., et al., 1989, Compliance Strategy for Performance Analysis Requirements in the U.S. Department of Energy Order 5820.2A (Draft), Westinghouse Hanford Company, Richland, WA.

4. Statement of Work 636309, "Third-Party Benchmark and Verification Testing of the PORFLO-3 Version 1.0 Computer Code for Simulating Fluid Flow, Heat and Mass Transport in Variably Saturated Media".

5. Statement of Work 636310, "Third-Party Benchmark and Verification Testing of the UNSAT-H Computer Code for Simulating Vadose Zone Water Balance-Versions 1.1 and 2.0".

6. "Performance Assessment Section Single-Shell Tank Waste Action Plan" (Draft).

The review herein will follow the sequence as shown above and will consist of a very brief review of the document and a critical evaluation. In all cases, the documents are very clearly written, well organized and technically sound. Identification of these strengths will not be repeated in the critique.

hydrology, including vadose zone processes and characterization of hydraulic properties. Based on the initial review of the documents provided, preliminary written comments were submitted to ASI on July 7, 1989, (Attachment 1). The report herein details the individual comments of Dr. Stephens pertaining to the documents provided and the workshop presentations. General comments are also included; however, the comments are limited mostly to the area of hydrology.

3.1 Performance Assessment Technology Development for Cleanup and Disposal of Hanford Defense Wastes, by J.D. Davis, 1988.

This report describes a strategy for identifying, developing and applying the technology needed to evaluate the long-term environmental consequences of actions proposed for remediation and disposal of radioactive and chemical wastes from defense-related activities. The report defines performance assessment, describes how objectives of the performance assessment are established, lists general activities and tasks that comprise a performance assessment, and the DOE regulatory framework that guides the performance assessment. Key performance issues are a) what technology is required to credibly evaluate impacts, and b) what technology or data are needed to ensure that health effects are as low as can reasonably be achieved. Definitions of key technical terms in performance assessment are presented.

This report presents a very thorough and logical description of a performance assessment. For potential transport to the accessible environment by ground water, mathematical models will be used. In section 2.2 the question is raised about whether the models require further development. It is not at all clear how one can determine whether additional model development is needed until the models are verified and validated. There are no models of flow and transport in the vadose zone, either deterministic, stochastic or otherwise, which have been validated for conditions and for

problems of the scale of those at Hanford. Mathematical model validation is mentioned in section 3.2 as a pre-requisite to assessing performance; however, model validation seems to be omitted as a specific task. As part of model validation some site characterization will be required, important physical or chemical processes will be defined, and limitations of field or laboratory techniques will be identified. After validation experiments are complete, then deterministic or stochastic models can be modified to account for specific processes and conditions observed in the validation experiments.

The report indicates that performance standards, the scales used to measure the success of the remedial action, are given in Chapter 6 of the HDW-EIS. The contents of this document were not available for the review. It is presumed that the scales are quantitative and similar to drinking water standards or to standards for the high-level waste program regarding ground water travel time and cumulative chemical releases to the accessible environment (10 CFR 60 and 40 CFR 191). For CERCLA cases, clean up (performance) standards are generally negotiated; therefore, a separate task in the performance assessment may be to establish a performance standard. The introduction to Section 3.0 indicates that performance criteria standards will be developed later (Task DCS 1.2?); nevertheless, it should be clear how these tasks are related. If specific standards are to be proposed by DOE, then vague suggestions of standards in this report should be avoided. In particular, Section 2.2, page 7, suggests that the remedial action will "ensure that adverse health effects are as low as can

reasonably be achieved." What is reasonably achievable to DOE may not be reasonable to regulators or the public. It may be anticipated that performance standards will not be technically or economically feasible to meet in actual practice. Therefore, the above general statement of commitment to a level of clean-up should be worded more carefully.

As written in Figure 1, page 2, the performance assessment ends with the selection of a disposal option. It is not clear where site monitoring fits in. To a layman, performance assessment should include more than performance prediction, and it seems reasonable that a performance assessment would include monitoring of the actual performance of the disposal system. If the system does not behave as predicted by the mathematical models, then contingency remedial action plans should be set in-place. The performance assessment could be expanded to include the development of monitoring criteria to be used to signal a failure in the design. The uncertainty and sensitivity analyses could be used for this purpose provided that some site characterization data are available.

A performance assessment methodology was recently published for high-level radioactive waste in basalt formations at Hanford (Bonano et al., 1989). A review of this document was not in the scope of work, because the analysis was applied to formations which are much deeper than those of interest in the present investigation. However, it could be useful to compare the two methodologies for consistency. If this has been done already, it may be worth stating this in the final report.

3.2 Performance Assessment of Granted Double-Shell Tank Wastes, by G.W. McNair et al., 1989 (Draft).

As described in the report, low-level radioactive liquid waste is scheduled to be mixed with grout and stored underground in concrete vaults. The concrete vaults will be surrounded by an asphalt-coated gravel diffusion barrier, and they will be covered with a sloping layer of clay to divert infiltration. The report describes the chemical waste inventory, grout composition and general stratigraphy. The performance of the system was simulated on computers using TRACER3D (vadose zone flow), Winfrith S 301-2 (vadose zone transport), SLAEM-2 (saturated flow and transport), and ONSITE/MAXII and DITTY (radiological impacts). Model input data limitations are presented. The results show the travel time and outflow of moisture from the vadose zone, contaminant concentrations arriving at the water table, and travel time and outflow volume from the grout site to the Columbia River and at a hypothetical down-gradient pumped well. The radiological dose assessment is calculated at a hypothetical pumped well and at the Columbia River. The performance assessment indicates, based on the assumptions made, that the grout disposal system will have approximately an order-of-magnitude design margin to meet apportioned standards (concentrations 20% of the existing drinking water standard) when the gravel diffusivity is 1×10^{-10} cm^2/s, and that impacts to down-river water users will be insignificant in all cases simulated.

The report clearly presents the approach used and data requirements and discusses areas of uncertainty. The approach appears generally consistent with that described by (Davis) 1988, and is, therefore, subject to the same criticisms described in section 3.1. Note is made that the report reviewed is still in draft form, with minor misspelling and/or typographical errors.

The data on hydrogeologic characteristics of the vadose zone are based on disturbed samples collected from three boreholes as described in Appendix C. The conceptual model, therefore, must have substantial uncertainty. The test holes produced only two samples within the upper 5 m of the Hanford Formation. Consequently, no data were collected from the interval approximately 32 meters above the water table. All textural interfaces are presumed straight, horizontal and continuous, and no sensitivity to the nature of the sedimentary contacts is recognized. There is also no analysis of the uncertainty due to hydraulic properties. Unsaturated hydraulic conductivity, a key parameter governing flow through heterogeneous soil layers, is calculated using moisture retention data from what appear to be textually similar stratigraphic units elsewhere at the Hanford Site. The calculation of unsaturated hydraulic conductivity uses a procedure developed by van Genuchten (1980) that produces results which can be very sensitive to fitted parameters, especially for the low moisture contents likely at Hanford. Available literature shows that the van Genuchten produce has not been thoroughly evaluated for dry conditions. The report does not indicate whether moisture retention data are from wetting or drying moisture

characteristic curves, and it does not describe whether hysteresis is included. Capillary properties of asphalt-coated gravel will be much different than those for a water-wet gravel as required in the van Genuchten analysis. The report does not discuss the significance of fine scale, intra-layer stratification which can produce a large moisture-dependent anisotropy (Stephens and Heerman, 1988; McCord and Stephens, 1987). The effect of partial saturation on retardation factors (K_d) and effective diffusivity should be supported by experiments with on-site materials. The significance of preferential flow and wetting front instability are also omitted. Geologic heterogeneities such as clastic dikes have not been incorporated in the conceptual model uncertainty. Differential settlement or cracking of the clay cap are not evaluated. Far-fetched, but not completely impossible scenarios, which could be considered, include large shifts in the position of the Colombia River (may erode vadose zone and vaults), migrating sand dunes (may increase recharge above the barrier) and glacial advances (may crack grout and/or compact soils to affect hydraulic properties). There was no analysis of the effect of grout desiccation and fracturing. Inasmuch as a thorough uncertainty analysis was not completed, the site characterization efforts appear to be insufficient for a final performance assessment.

Other comments pertain to the modeling and analysis of flow and transport. Transient simulations are likely to be sensitive to initial moisture content distribution in the native soil and engineered barrier. The initial condition for each simulation

should be specified in the text. Vadose zone flow model output should include total hydraulic head and stream lines for steady state conditions. The discussion should clarify whether steady state was achieved in the simulation at the end of transient infiltration or whether a direct solver was used to obtain the steady state result. The results of the flow analysis should show the portion of the flow field which passes through the vaults. Solute transport in the vadose zone begins after the flow field has reached steady state. Justification for this assumption should be included in the text or reference should be made to the discussion in Appendix E.2.1.

In the saturated flow and transport analysis, impacts are evaluated at a hypothetical well down-gradient. (The title of Section 4.5.3 should be "...Down-gradient..."). The chemical concentration in water produced at a well depends strongly upon contaminant distribution and plume geometry within a heterogeneous aquifer, in addition to well depth, perforated intervals and other well construction and hydrogeologic details. The analysis is for impact to a well which is steadily pumped and screened over its entire depth so that the flow and chemicals in the well are vertically averaged. It should be noted that a partially penetrating domestic or irrigation well in the upper part of the aquifer will be impacted to a greater extent than shown in the report. If the contaminants are restricted more to the upper part of the aquifer, then the shallow, partially penetrating domestic well, which is pumped intermittently at a low rate, could be impacted much more than a continuously pumped high capacity

irrigation well of equal depth, due to the dilution that occurs when uncontaminated water is drawn into the well.

Substantial credibility for the saturated and unsaturated flow and transport model could be derived by using the simulators to predict the past performance of waste disposal systems. In the absence of information on the source strength, the models could be used to predict changes in moisture content, hydraulic head or concentration between dates when monitoring data are, or could be, readily available. This process is essentially model validation.

3.3 "Compliance Strategy for Performance Analysis Requirements in the U.S. Department of Energy Order 5820.2A (Draft)" by R.R. Seitz

DOE order 5820.2A, issued October 1988, requires performance assessments to ensure that design alternatives are evaluated based on the ability of the facility to isolate waste from the environment and on cost effectiveness. The order pertains to radioactive waste and mixed (non-radioactive, hazardous) wastes and requires protection of ground-water resources consistent with Federal, State and Local requirements. As a result, performance assessments will be conducted to demonstrate compliance with CERCLA/SARA and RCRA. The objectives of the performance assessment will be to aid in engineering design, to demonstrate regulatory compliance and to guide site characterization activities. The report describes in general terms how performance assessments will be conducted. A hypothetical example of an optimization approach

for waste management systems performance assessments is presented in an appendix. The example includes assumed regulatory criteria, waste properties and site characteristics. The report outlines three tasks that will precede the performance assessments: 1) determination of baseline plumes and health effects; 2) projection of future plumes and health effects; and 3) data collection and storage. The report (page vii of Executive Summary) notes that after a waste management system is in-place, it will be monitored to provide data to validate the system characterization and models, and the evaluation will then be updated and the system modified if required.

My review of this report is very brief. There is little that is inconsistent, controversial or of technical relevance to ground water hydrology. In general, the report is very logical and seems that it will be a good management tool. Figure 2 of the report illustrates the performance assessment process, as described by Case and Otis (1988). (The reference to Case and Otis was not included in the report provided for review.) Site characterization and monitoring data were shown to be at the heart of the process which included numerous steps, each of which required interaction with the characterization and monitoring data. These steps include: 1) establish objectives; (Step 2 is site characterization); (3) develop exposure scenarios; 4) formulate conceptual models; 5) perform screening calculations; 6) prepare mathematical models; 7) conduct performance assessments; and 8) evaluate results. This figure is a very useful one and should be kept in mind for all performance assessment related activities.

It appears that, except for the general geologic descriptions and geochemical studies presented during the workshop, there is little site characterization and monitoring in the vadose zone at present. Nevertheless, the performance assessment process continues. The interaction of step 2 and steps 4, 5, 6, and 7 as shown in Figure 2 was not readily apparent from the workshop or from the performance assessment on the grouted double-shell tank waste. The performance assessment process allows for the reformulation of new conceptual models if new physical or chemical processes and/or conditions are recognized during modeling or site characterization. Model validation should be an explicit step in the performance assessment processes.

3.4 Statement of Work...Third-Party Benchmark and Verification Testing of the PORFLO-3 Version 1.0 Computer Code for Simulating Fluid Flow, Heat and Mass Transport in Variably Saturated Media

This document outlines computer model testing to be performed by E.G. & G. Idaho, Inc. The code PORFLO-3 is to be checked for accuracy against analytical solutions. Also, the code is to be benchmarked by comparing its predictions against results from other codes applied to the problem. The verification test cases include infiltration to the water table, unconfined aquifer flow, heat transfer in soil and contaminant transport in soil and groundwater. The benchmark test cases include two-dimensional fluid flow under saturated and unsaturated conditions, three-dimensional flow with

dikes and/or fractures, three-dimensional coupled heat and fluid flow and coupled flow and mass transport with dikes and/or fractures.

The work described appears to be an appropriate part of performance assessment. However, it is not clear why PORFLO-3 must be used when so many other codes are available. To some extent benchmarking of codes is an activity that has been going on for some time through the HYDROCOIN and INTERVAL programs. It may not be easily justifiable to the public that federal dollars have been used to duplicate the development of sophisticated computer models. Each national laboratory seems to have its own set of codes that only the in-house code developer knows how to manage fully. In the interest of being cost-effective, at some point it may be useful to select a comprehensive code and base all performance assessments at DOE sites on it or on derivatives of this comprehensive code that can be efficiently applied to specific problems.

The verification and benchmarking tests should consider processes such as preferential flow due to wetting front instabilities, hysteresis in the unsaturated hydraulic properties and the dependence of anisotropy on moisture content (Zaslavsky and Sinai, 1981, Mualem 1984, Yeh et al., 1985, McCord and Stephens, 1987). The most difficult tests of the model will be for transient infiltration into very dry soil consisting of alternating layers having coarse and fine texture. In addition, it will be important to demonstrate that the model grid block size is optimized with respect to both accuracy and computational efficiency for a field-scale problem. Specific criteria by which to evaluate the success

of the verification and benchmarking should be established in the work plan.

3.5 "Statement of Work...Third Party Benchmark and Verification Testing of the UNSAT H Computer Code for Simulating Vadose Zone Water Balance-Version 1.1 and 2.0"

This document describes computer code tests to be performed by EG&G Idaho Inc. the scope of work is to a) verify the code UNSAT-H by comparing model prediction against analytical solutions, and b) benchmark the code by comparing predictions to results of other codes using the same problem. The code simulates one-dimensional vertical soil-water flow with evaporation, transpiration, and heat transfer. The verification tests include: one-dimensional infiltration, infiltration with evaporation and transpiration, and heat conduction. Five benchmark tests are required. These tests will simulate homogeneous and heterogeneous soils, low initial moisture conditions and transient processes.

This exercise appears to be a good contribution to improving the technology available for performance assessments. I suspect that much of this work has already been done by PNL in developing the code. On page 3 among the capabilities of the code are "isotropic and anisotropic hydrology". The word "hydrology" should be replaced with "porous media". When anisotropic properties are simulated, the flow field is at least two-dimensional. However, the UNSAT-H code, as I understand from this document, is only one-dimensional; so, the code really cannot account for anisotropy.

The benchmark tests are not clearly delineated and the objectives of benchmarking do not seem to be accurately stated. The document should give more specific instructions on which scenarios should be simulated. For example, although other codes are capable of multi-dimensional flow, will the scenarios limit these codes to identical one-dimensional problems? If so, what is the purpose of comparing high-powered comprehensive codes against UNSAT-H? If the objective of the benchmarking is to evaluate the computational efficiency and versatility and to gain confidence in the codes, then this should be so stated. The objectives of benchmarking stated implicitly on page 5, Subtask 1B, are "to test the capability of the UNSAT-H code to simulate a range of physical processes and conditions". It may be helpful to explain how comparing the results of five other codes against UNSAT-H results will provide a test of the capability of UNSAT-H. If the test results agree, then it cannot necessarily be concluded that any of the results are accurate or that any of the models are capable of simulating field-scale behavior. Such a rigorous test constitutes model validation. For the reader of this document to better appreciate the significance of this task, it would be helpful to explain the objectives of benchmarking in more detail. In fairness to the programs, reference is made to the workshop presentation by Mr. Baca, which indicated that a great deal of the benchmarking has already been accomplished. Criteria for evaluating the codes were presented there.

3.6 "Performance Assessment Section Single-Shell Tank Waste Action Plan (Draft"

This document provides an overview of the performance assessment activities that will be conducted as part of the remediation of single-shell tank wastes. The document describes Phase 1 activities which emphasize verification and validation of computer models used to simulate flow and transport, and Phase 2 activities which will use model studies to guide the development and choice of a particular remedial action technology. Activities and tests required to implement Phase 1 and Phase 2 are also presented.

The program outlined appears to be very thorough in general and is consistent with the types of activities described in other documents provided on performance assessments. The principal concern is in regard to model validation. Validation of codes is mentioned on page 8, but there is no description of a task to accomplish it. Perhaps there is a misuse of terms here. The calibration of PORFLO-3, using field data from a tank leak, is discussed on page 11. Definitions of verification, calibration, and validation should be provided to avoid confusion.

4.0 EVALUATION OF WORKSHOP PRESENTATIONS

This section is a compilation of comments based on oral presentations and hand-out material provided during the workshop. The workshop presentations are enumerated in "Technical Review of Hanford Performance Assessment Programs", Volumes 1 and 2, July 25-27, 1989 Richland, Washington. All the presentations were very well organized and technically sound, and all of the presenters are to be commended for their excellent professional efforts. Each of the presentations will be critiqued subsequently. Once again, the review comments are restricted mostly to those of a hydrogeologic nature.

4.1 Performance Assessment Overview by J.W. Carmman

In the section on Applications Approach, WHC will conduct and document regulatory compliance assessments. It was not clear form the presentation how adequate protection of human health and the environment are to be defined. Is WHC developing performance criteria to protect human health and the environment? If so are these criteria based on epidemiological studies conducted by WHC, existing literature, or state and federal regulations. Based on other material presented in the workshop, it appears that the latter is the case.

4.2 Hydrogeologic Overview of Hanford by K.R. Fecht

Clastic dikes were shown to be important features in the vadose zone. The hydraulic properties of the sand filling in the dike should be characterized. The dikes may be barriers to lateral seepage, depending upon a) the nature of the source, b) the location of the source with respect to the dike, and c) the contrast of hydraulic properties in the dike and in the formation.

Dune fields occur in the area and could affect the location of recharge and discharge patterns shown in the presentation, especially over the long-time periods (10,000 years) for performance assessment modeling. The potential areas where dunes could migrate could be forecast.

The probability of glacial advances and its potential impact on hydrogeologic conditions should be considered as a remote possibility. The potential impacts could include effects on recharge rates, water table depths, and ground-water flow directions. The effect of glacial mass could consolidate the overburden and affect hydraulic properties in the vadose zone as well as destroy the engineered systems.

The water table elevation contour map for December 1985 indicates a ground-water mound at the B-Pond, as shown by the 410 feet contour. If the contour interval is 10 feet everywhere, then the water table elevation map is incorrect in the area just west of B-Pond.

The water table near B-Pond rose more than 20 feet from 1944 to 1978. The water level contour maps also show that the water table rose approximately 10 feet from December 1985 to June 1988. Either data are incorrect or an explanation for such a rapid rise should be offered.

In the table of water quality values for the unconfined aquifer, manganese is incorrectly included as a major cation.

The tritium and nitrate concentration show a plume that migrates from the 200-East area further to the south, toward the 300 and 400 Areas, than one would expect from a flow net drawn on any of the water table contour maps provided. The hydrogeologic controls on plume migration should be identified.

4.3 Performance Assessment Experience at Hanford HDW-EIS by C.T. Kincaid

Conceptual models of contaminant transport are shown in which stream tubes bound the contaminants pathways. The stream tubes are delineated from observed or simulated hydraulic head data. Neither observed nor simulated head data would suggest that chemicals (tritium and nitrate) from the 200 East Area have actually traveled along stream tubes, as discussed in section 4.2 above.

Unsaturated hydraulic conductivity is calculated from moisture retention data using models such as Brooks and Corey (1964), and van Genuchten (1980). Technical support should be provided to

demonstrate that the calculated hydraulic conductivity is accurate, especially the dry range for each representative soil unit.

Travel time through the vadose zone was calculated from approximate models of vertical flow using different values of steady downward seepage. Vadose zone travel time ranged from 76 to 4200 years. The travel time depends upon the thickness of the vadose zone. The water table elevation appears to have increased by more than 80 feet at a rate of more than 2 feet per year in places. The discussion of the calculation of travel time through the vadose zone should include the effect of future water table fluctuations.

4.5 Arid Site Recharge Characteristics, by G.W. Gee

Deep closed-bottom lysimeters show little accumulation of moisture at the bottom, based on water content measurements by neutron logging. This suggests that no downward deep percolation occurs. Strictly speaking no flow would only occur if either the hydraulic conductivity or hydraulic gradient were zero. Which is the case? Is it possible that moisture has actually accumulated in the bottom of the lysimeter below the depth of measurement by the neutron probe? Could tracers be placed in the deep lysimeters to quantify deep water movement?

4.6 Status of the UNSAT-H Model for Near-Surface Water Balance Studies by M.J. Fayer

An illustration shows observed and model predicted moisture storage in a section of the South Caisson at the buried waste test facility. The agreement over a nine year period is generally very good. However, the on-set of drainage observed from the caisson occurred 2 1/2 years before model predictions. Observed and simulated moisture storage for 4 November 1987 to 30 April 1989 in lysimeters W2 and W4 show rather poor agreement. In lysimeter W2 between day 350 to 475 the observed storage increased, whereas simulated storage decreased. The factors affecting the reliability of the predictions with this model should be identified. Factors to consider should include the evaporative boundary condition, calculated versus actual unsaturated hydraulic properties, and hysteresis. It is likely that some of these factors will be identified in enhancements to UNSAT-H planned for the future. It should be kept in mind that the significance of the model results is limited because all observed data are derived from mixed and re-compacted soil which does not preserve the soil structure or stratification of the native soil profiles.

4.7 Hanford Site Performance Assessment Technology Program-Contaminant Release, by R.J. Serne and M.I. Wood

This topic is out of my area of expertise for the large part. As a general reviewer, my concern is that analyses will be limited

to standard laboratory tests that will not represent the combined and interactive effects of multiple process which occur under field conditions and at large time scales.

4.8 Hanford Site Performance Assessment Technology Program; Contaminant-Soil Interaction by R.J. Serne and M.I. Wood

Future recommended work for the single-shell tank experimental program should include the evaluation of pore liquids collected from the vadose zone and ground water near actual sources. Data from sampling of actual fluids released from tanks, when collected over time and/or along a travel path, could provide valuable information regarding chemical transport processes at the field scale. Additionally, analysis of field data could determine whether retardation factors or distribution coefficients obtained from the field are similar to those predicted in batch tests in the laboratory. If field data from native soils are not feasible, perhaps large scale chemical transport (sorption, solubility dispersion) tests of certain constituents could be run by modifying the caisson and deep lysimeter experiments described by Dr. Gee. Time scales for studying transport through soil may need to be on the order of a few years. The program identifies a great deal of potentially very valuable work to be accomplished in the future, such as the effects of partial saturation on transport properties.

4.9 Vadose and Saturated Zone Flow and Transport Modeling by B. Sagar

The presentation described the capabilities of PORFLO-3 and the general approach to use the code for uncertainty analysis. The efforts described later to apply PORFLO-3 to simulate actual transport from a leak at the T106 tank are most exciting. Site characterization and monitoring should be implemented to collect information required to expand this work to the model validation stage.

4.10 Verification and Benchmark Testing of UNSAT-H and PORFLO-3, by R.G. Baca

One-dimensional vertical infiltration simulations with UNSAT-H compared favorably with Philips analytic solution. As a benchmark test case vertical infiltration (constant flux) through horizontally layered surface sediments and basalt was simulated for 105 days using UNSAT-H, WORM and FLASH. Work appears to be still in progress, inasmuch as the handout material does not address all tasks and deliverables described in the Statement of Work (see Section 3.5). Only the summary work plan for verifying and benchmarking PORFLO-3 were presented. No further comment seems appropriate at this time.

4.11 RCRA/CERCLA Support by J. Sonnichsen

A two-dimensional analysis of ground water flow was described in the vicinity of the North Richland Well Field and waste sites in the 1100 area. Due the presence of recharge pits at the well field which could cause ground water mounds and drawdown due to well field pumping, vertical flow and contaminant transport could be very important. Only a two-dimensional horizontal flow model was applied to the problem. Future site characterization activities should evaluate importance of vertical flow components. A three-dimensional flow and transport code may be useful in this analysis.

4.12 Solid Low-Level and Radioactive Mixed Waste Burial Grounds Performance Assessment - Status and Flows by R.R. Seitz, R. Khaleel, T. Legore

Site characterization activities appear to be an important part of this effort. Much of the data will be obtained by analyzing core samples. In situ tests are recommended to compliment the laboratory tests on core samples.

4.13 Effects of Varying Recharge Rates on Radionuclide Flux Rates to Water Table

The analysis in the handout apparently shows travel times through the vadose zone in the 200 East Area as predicted by the VAM2D code. An explanation should be provided as to why another code (besides PORFLO-3) is used in performance assessment. Nevertheless, it is encouraging that the results are very similar to those presented earlier during the workshop by Dr. Gee and Dr. Kincade using simplified one-dimensional analyses. Seepage and transport from a solid waste burial trench are presented for chemical constituents subject to sorption and decay. Variability in parameters such as K_d should be considered.

Although the presentation was interesting and potentially very useful, it was not clear exactly where this effort fit in to the organization of the various performance assessment tasks.

4.14 T106 Tank Leak Modeling Investigation by J. Smoot and B. Sagar

This is certainly one of the most relevant technology development activities presented. This type of work can lend substantial credibility to subsequent performance assessments using PORFLO-3.

Hydraulic properties for the model were not obtained on-site, but rather were derived from data in the 200 East Area. This

investigation could be strengthened by collecting additional on-site data such as: re-logging the boreholes with geophysical tools, obtaining pore liquid samples, soil sampling from on-site borings to describe physical and hydraulic properties, and possibly conducting in situ tests for hydraulic properties. These site characterization activities will extend by at least 11 years the data base for radionuclide distributions that could be used for model calibration or validation. Modeling results showed that the leakage rate controlled early time infiltration behavior and that recharge effects were not significant. The longer term data and simulations could show a greater significance of recharge on transport. Additional characterization data should be collected on-site in representative units and in areas where model performance is poor. The model hydraulic parameters adjusted during calibration should be compared to values obtained in situ or from laboratory analyses of cores.

It will be important to recognize the spatial averaging that occurs in the simulations when grid block size is large. The minimum size used in the model was about 0.5 m vertically and 2 m horizontally. This dimension is large compared to the air-entry pressure head, and large changes in hydraulic conductivity occur over small changes in water content.

More of this type of modeling activity should be encouraged. Efforts should continue to identify important flow and transport mechanisms at the field scale. However, as it appears now, this is only a calibration exercise. A calibrated model cannot in

itself be used to provide much assurance that we have confidence in predictions at larger distances and much greater time scales.

4.15 Stabilization and Isolation of Liquid Waste Disposal Structures by S.J. Phillips and T.W. Gilbert

This activity is out of my area of expertise, but as a general reviewer the grout injection plan seems very appropriate. What studies have been done to confirm the long-term integrity of the grout? Will liquids and sludges currently in these engineered facilities be removed prior to emplacement of grout, or will the grout displace the residue into the formation? Care should be taken that grouting does not introduce additional contaminants into the subsurface. Collapsed soil above timbered cribs should also be stabilized to prevent channeling of runoff or snowmelt deep into the subsurface. The waste fluids that already have leaked from the cribs could be displaced by infiltration through large macropores created by the soil collapse.

4.16 Hanford Grout Disposal Program - Introduction and Overview by Theresa B. Bergman

Monitoring at these sites appears to be only the leachate collection system beneath each grouted waste disposal vault. The design should comply with RCRA; however, if no leachate is collected one cannot determine whether no seepage has occurred or

whether the collection system has failed. A vadose zone monitoring system could be valuable in the long-term. One type of monitoring to consider would be with a neutron probe in deep wells constructed between the vaults. The deep wells could be used for both determining in situ soil moisture or deep seepage and for sampling ground water. Collecting baseline data on the deep subsurface conditions is recommended prior to emplacement of the vaults.

4.17 Regulatory Framework by Gary McNair

No comments.

4.18 System Description and Design G.W. McNair

The design of the grouted waste disposal vaults relies upon capillary properties to create barriers to infiltration of water into the grout waste. Long-term experiments should be conducted to demonstrate the effectiveness of the gravel diffusion barrier. Capillary properties, e.g. wettability and interfacial tensions of different fluids in contact with the asphalt-coated gravel and other barrier materials, should be quantified in the laboratory.

The long-term stability of this barrier system (gravel, interim and protective barriers) should be evaluated for unexpected events such as consolidation, differential settlement and glaciation, if periods of interest are 10,000 years. Unexpected

events could lead to desiccation and cracking of the clay cover, warping of the interim barrier, and decomposition of the grout. Although the design appears very solid, additional long-term investigations are suggested, and a comprehensive uncertainty analysis should be completed. As mentioned in the comment in section 4.16 a vadose zone monitoring system is recommended to complement the leachate collection system for long term impact assessments.

The grout leaching tests appear to be very thorough. Pore liquids leaching the grout could have a composition different than either Hanford ground water or deionized water, owing to the presence of carbon dioxide in the soil. Samples of soil should be collected to estimate the chemical composition of liquids most likely to encounter the grout. Over a 10,000 year period, identify what climatic or atmospheric changes (e.g. humid climate; organic acids in soil; acid rain) could occur that would change significantly lower the pH of the infiltrating water and accelerate the rate of release of chemicals from the grout.

4.19 Experimental Determination of Diffusion Coefficients in Gravel Under Unsaturated Conditions by J.C. Conca

In the centrifuge technique, the importance of consolidation of the sample and rearrangement of pore structures during centrifuging should be investigated, especially if the technique is extended to materials finer than medium sand.

This research appears to be a very good contribution to the technology development program. Continued work is recommended, especially in using the centrifuge method to characterize the unsaturated hydraulic properties of native soil and barrier materials in the low moisture regime.

4.20 System Identification - Soil Hydraulic Properties by G.W. Gee

Hydraulic properties of soil were obtained from disturbed and undisturbed core samples. During sampling and coring, pore structures and cements can easily be disturbed, even in intact cores. In situ methods are generally best for collecting representative data at a large scale. Several borehole methods exist for determining saturated hydraulic conductivity in situ. However, there are virtually no proven methods to readily obtain unsaturated hydraulic conductivity or moisture retention data in situ at depths below about 2 meters. This area is one that is ripe for technology development, and this reviewer has submitted research proposals to accomplish this.

Limitations to our ability to characterize the hydraulic properties of a site should be recognized, especially in the vadose zone. The data collection program does not include measurements of anisotropy in saturated hydraulic conductivity, anisotropy in unsaturated hydraulic conductivity, or hysteresis in the moisture retention curve. Unsaturated hydraulic conductivity has been shown

during the workshop to be a key parameter for performance assessment modeling.

Unsaturated hydraulic conductivity was calculated from moisture retention data. Work should continue to demonstrate that the calculation approach is valid for a range of native and engineered materials, especially in the dry moisture regime. Matching factors, including K_s and one or more other measured values of unsaturated hydraulic conductivity, should be considered if necessary to improve predictions of unsaturated hydraulic conductivity from moisture retention curves. The applicability of the approach to calculate relative permeability to non-water wet systems should be demonstrated.

Spatial variability in hydraulic properties is an important element of site characterization and performance assessment that has not received much attention at the workshop.

4.21 Subsurface Models - Selection and Applications in Grout Performance Assessment by R.W. Nelson

The presentation indicated that the hydrologic system will be identified by evaluating a) physical and chemical processes involved, b) appropriate descriptions of processes, and c) measurements of properties and characteristics. This sounds comprehensive and the activity certainly is necessary, but from the workshop it was not clear how, when, or where hydrologic system

identification would be accomplished and what the scope of such activity would be.

TRACR3D has been selected to model flow in the vadose zone. Previous and on-going work discussed at the workshop centered on codes such as UNSAT-H and PORFLO-3, and VAM2D was used as well. The duplication of effort suggests that there is a lack of coordination between the technology development and applications programs.

I am not familiar with Dr. Strack's "Shallow Unconfined Flow" definition. More information should be provided on the ground water models, (SLAEM and MLAEM), and the limiting assumptions should be clearly identified. There appears to be ground-water chemistry data available at different times which could be used to compute ground-water travel times and contaminant fluxes. If this has not already been done, the data could be used to calibrate the model and possibly to validate it as well. The predictive power of the flow and transport model should be clearly demonstrated by application to field experiments at Hanford and elsewhere (e.g. Chalk River, Waterloo, Mississippi).

This presentation is part of the performance assessment on the grouted double-shell tank waste (McNair et al., 1989). From Appendix E in McNair et al. (1989) the vertical flow beneath grout sites will be limited to the upper 20 cm of the aquifer. This seems unrealistic and uncharacteristic of most contaminant plumes. That appendix also indicates that in the ground-water flow simulation "overall recharge...has not been simulated in this analysis because extensive model development and calibration

efforts would have been required. Current results do not appear sensitive to this omission..." A much more detailed discussion of the significance of this assumption should be presented, especially in light of the technology development directed by Dr. Gee.

4.22 Grout Performance Assessment Results to Date by G.W. McNair

This presentation is a summary of the performance assessment work on the grouted double-shell tank waste by McNair et al. (1989). A number of comments on this document are presented in section 3.2 and will not be repeated here.

The chemical diffusion coefficient for gravel is one of the key controls on whether drinking water standards for elements such as iodine and technetium will be exceeded. If the gravel diffusion coefficient is less than about $10^{-9}cm^2/s$, the predicted impact will be such that the existing apportioned drinking water standards will not be exceeded. This diffusion coefficient is very sensitive to moisture content. As Dr. Conca showed, if the moisture content increases by less than 0.5%, the diffusion coefficient could increase tenfold from about 10^{-9} to $10^{-8}cm^2/s$. McNair et al. (1988) indicate that the apportioned amount is 20% of the existing drinking water standard, in order to account for the compounding effects from other waste sources. Although the apportioned limit affords a good factor of safety, there are sources of uncertainty in the engineered barriers that could lead to increases in moisture

content and diffusion coefficient within the gravel. The on-going studies should address the consequences of these uncertainties.

4.23 Areas of Uncertainty by D.H. Mitchell

The proposed studies pertaining to uncertainty analysis appear to address very valid concerns. The uncertainty analysis could be expanded to include a worst case scenario such as complete failure of the interim or gravel barriers, and disintegration or thorough fissuring of the grout due to chemical effects or structural damage from glacial ice and river erosion. Although these worst-case scenarios are highly improbable, the public will ask such questions, and work should be completed in anticipation of this.

5.0 GENERAL COMMENTS AND RECOMMENDATIONS

The performance assessment process must not lose site of the importance of adequate site characterization. Site characterization is very clearly shown by information provided during this workshop to be at the heart of the performance assessment process (e.g. Case and Otis, 1988). Yet, very little effort seems to be devoted to site characterization to date, and if additional site characterization is contemplated, it must be completed in time for other components in the performance assessment process to be influenced by site characterization.

Included with site characterization should be a stage called "process identification". Possibly this may fall within conceptual model development as well. A number of processes have not been considered fully based on the presentations, and efforts should be made to investigate at the field scale under field conditions the processes relevant to flow and transport in the vadose zone and ground water:

- instability of the wetting front in layered media
- moisture dependent anisotropy
- hysteresis in moisture characteristics
- the mobility and leachability of pore liquids (organics, radionuclides) held near residual saturation.

- anisotropy of hydrodynamic dispersion (dispersivity, diffusion) in stratified soil
- subsurface air convection
- lateral moisture flow (e.g. during the tour seepage into the large pit used for the grout project was stated to occur at the 60 to 80 ft depth. The origin of the seep was stated to be cribs 800 feet away)
- capillary effects (contact angle, wettability)

The past history of waste disposal and waste movement must be characterized so that a data base is available for model calibration and/or validation as well as "process identification". Recommended activities could include:

- reconstructing or predict existing ground water plumes (^3H, NO_3)
- modeling and site characterization at site of Rockwell's vadose zone injection experiment (previously intended for validation ca. 1983)
- vadose zone characterization and modeling of spills and leaks in both time and space (T106 is a great start and seems very promising)
- using in situ distributions of radionuclides where possible to compute field sorption properties (K_d, R_d)
- mapping existing zones of seepage in excavations and pits in detail to identify source areas, geologic controls on

transport and flow, influence of natural recharge and seasonal/climatic variability on the occurrence of vadose zone (perched?) discharges.

At present, the hydrogeologic framework is incompletely established, at least based on limited data presented during the workshop. The contaminant plume paths are inconsistent with the hydraulic head data, especially in the southern part of the site. Time series data of water levels should be collected continuously for analysis of system responses to recharge, seepage, river stage, etc. The hydrologic significance of features such as clastic dikes should be identified, and the three-dimensional effects of flow on transport must be recognized. Unsaturated hydraulic properties of soil are best determined using a combination of field and laboratory tests (in situ moisture, texture, conductivity, moisture retention). However, new technology is needed to obtain unsaturated hydraulic properties in situ.

Recharge studies by Gee et al. should be expanded. Recommended related projects to consider include:

- mapping areas at Hanford into zones of expected recharge potential;
- evaluating topographic effects: micro-scale, local scale (lysimeters do not account for moisture accumulation in low lands due to multi-dimensional flow in the vadose zone);

- using tritium, ^{36}Cl, ^{18}O, and deuterium isotopes from the vadose zone to evaluate soil-water movement and recharge in undisturbed soil. The chloride mass-balance method should be considered too;
- scaling-up barrier lab experiment and conduct long-term investigations to analyze in detail moisture movement in the gravel layer by tomography or CAT-Scan.
- developing a reliable method to obtain unsaturated conductivity in the dry range. Continue centrifuge work; show van Genuchten model is accurate in the range of field moisture; and
- monitoring moisture movement near dune covered gravel. This affords an opportunity to analyze a natural analog to the barrier concept. In situ instrumentation and geochemical sampling may be useful.

Conceptual models should be based upon important processes likely to control the release of liquids. The importance of site characteristics cannot be neglected. Field and laboratory studies, as well as applied research using models, should guide the development of the conceptual framework of the system to be modeled in the performance assessment.

The performance assessment presented in the past three days has emphasized the application of mathematical models. Conventionally, a predictive model is verified against an analytical solution, calibrated against some known record, then run

to validate its predictive capability. The calibration and validation stages seem to have been only touched upon so far. the models must be shown capable of simulating previous leaks at Hanford, or controlled field experiments at one or more of several sites where model validation projects are on-going in both the saturated and unsaturated zones. When site characterization data are available, then revisions to the models should be considered. A single code should be verified, benchmarked and applied to all relevant problems to avoid costly duplication of codes and to provide a DOE-standard code or set of codes, that all can agree upon and use for all performance assessments.

There is an unquantifiable uncertainty in predicting 10,000 years into the future. There are likely to be unexpected processes and events that could significantly impact human health and the environment. The public should squarely face this fact. Best engineering judgement is essentially being used to conduct the performance assessment and design remedial action programs. With a carefully designed subsurface monitoring system, errors in the design or the consequences of the unexpected processes and events can be detected long before substantial and possibly irreversible impacts occur. A post emplacement monitoring program could be considered as one method of reducing uncertainty. If detected early, re-remedial action plans can be implemented most cost-effectively. However, there was very little discussion about monitoring the performance of a system. Performance assessment as defined throughout most of the workshop stopped short of considering a comprehensive assessment of the actual performance

of the engineered system. In the technology development program efforts should be considered to evaluate current monitoring techniques and develop new techniques where appropriate.

Substantial efforts are on-going which comprise various performance activities. Although an organization and management structure was provided at the beginning of the workshop, the presentations seemed a bit disjointed. There did not seem to be a strong sense of cooperation and mutual understanding among the various groups; however, from the brief workshop this may be an incorrect impression. With the impending massive influx of funds for CERCLA and RCRA compliance activity, it appears that there will be a great expansion in the level of activity by subcontractors. The interaction between working groups should be encouraged and carefully coordinated.

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ATTACHMENT 1

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DANIEL B. STEPHENS & ASSOCIATES, INC.
CONSULTANTS IN GROUND-WATER HYDROLOGY

• GROUND-WATER CONTAMINATION • UNSATURATED ZONE INVESTIGATIONS • WATER SUPPLY DEVELOPMENT •

July 7, 1989

Mr. Doug Dennison
Advanced Sciences, Inc.
1835 Terminal Drive, Suite 200
Richland, WA 99352

Subject: Preliminary Written Comments on DOE-RL Third Party Review of WHC Performance Assessment

Dear Mr. Dennison:

I have briefly reviewed all of the documents you sent to me. I anticipate that my comments will be revised after the meeting and site visit in Washington later this month. On the whole, the program appears to be thorough and carefully developed. I have a few minor comments which I prefer to address in my report on the final comments; however, there are two points which I do want to mention here regarding performance assessment.

First, the program as outlined seems to emphasize model verification and benchmarking as means to gain confidence in the performance assessment. There is a need to include a model validation stage as well, in my opinion. There are a few sets of data available to conduct a model validation exercise; in fact, I recall that several years ago Buck Sission at Rockwell was involved in an injection test in the vadose zone somewhere near the Hanford Site. The models must be shown to accurately simulate field-scale behavior.

The second item is that hydrologists are coming to recognize that there are physical processes which are not accounted for adequately in most analytical and numerical models. In dry layered media, it is likely that fluid movement may occur in preferential paths. This process will tend to cause fingering in the advancing wetting front. The occurrence of macropores is a separate issue. Another process is anisotropy of unsaturated soil. In finely stratified soil anisotropy tends to increase with decreasing saturation. Consequently, the advancing wetting front and solutes can have a significant horizontal component. Additional work is needed in evaluating the importance of these physical processes in the performance assessment, and if the processes are important, then a methodology must be developed to obtain the relevant field data to account for these processes. Then, the models must be revised and validated.

I look forward to the meeting and hope these preliminary comments are helpful.

Yours sincerely,

Daniel B. Stephens & Associates, Inc.

Daniel B. Stephens

Daniel B. Stephens, Ph.D.
President

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APPENDIX G

COMMENTS OF EDWIN P. WEEKS

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Detailed technical comments by E. P. Weeks
regarding third-party review of shallow-burial
waste activities at Hanford, Washington

Although this report emphasizes my detailed technical comments regarding shallow-burial waste management activities, I reiterate one general comment included in the consensus report that is the basis for most of my detailed comments. Overall, my feeling is that the greatest need for viable performance assessment that I perceive as not being addressed is for a longterm programmatic commitment to a well-thought-out staged data collection program in support of sitewide system understanding. Such a program would require a five- to ten-year commitment to the philosophy that this is a major need that cannot be met on a piecemeal basis. As part of a coherent data collection program, greater communication is needed between modelers, hydrologists, and field people. The impression was given that people responsible for data collection are not privy to hypotheses to be tested or actual data needs of modelers. This appears to be an institutional problem, and is almost certain to be exacerbated by descent on Hanford of numerous contractors involved in operable unit cleanup.

In regard to the data collection program for site-wide understanding, a great many needs or opportunities come to mind. Some selected topics include:

More accurate water-table maps

Isotope sampling

Plume mapping

Continuous water-level monitoring

Calibrated sitewide model

Some of these are elaborated on below.

More accurate water-table maps.--The water table maps shown in the handouts for 1985 and 1988 are quite general, show large areas between contours for the 10-foot interval, and some seem strange. Scuttlebutt has it that altitude control on wells is presently inadequate to provide better potentiometer maps. This needs to be rectified.

Isotopic sampling. A major hypothesis concerning recharge through upland areas is that it is almost nil, and that UZ travel times are on the order of 100-1000 years. If this is true, environmental tracers, particularly chlorine-36 at post-bomb activities, should not be present at depths of more than a few meters. Confirmation of this through sampling and isotope analysis of water extracted from core or soil samples would do much to strengthen the viability of the hypothesis. This suggestion is based on the presumption that there are no site sources for chlorine 36.

Plume mapping-saturated zone.--Maps of selected chemical constituents were shown that demonstrated very substantial movement of nitrate and tritium in the saturated zone. From the water table maps supplied, and without some geologic explanation not presented, the observed chemical distributions are not adequately explained. Those distributions also do not appear to be explained by results of the modeling studies that were presented during the review. However, the movement appears to be very fast. Based on the hypothesis that the nearest tritium plume to the 200-East area represents the restart of the Purex plant 2 1/2 years ago, saturated zone travel time is on the order of one mile a year. This rapid movement suggests vertical stratification or movement within a fairly thin zone. Thus, the profiles with depth of selected chemical constituents need to be determined.

Plume mapping-unsaturated zone--A good presentation was made regarding the use of data developed on a plume of leachate from a leaky storage tank to validate a transport code. However, the collected data apparently

represents only two snapshots in time of tracer and water content. Perhaps additional data can be collected at this site to provide additional model validation. Also, of the 146 single-lined tanks containing radioactive waste, a substantial percentage have leaked. One has to wonder whether other excellent opportunities do not exist for model validation. Finally, substantial lateral UZ transport has occurred in the vicinity of some of the liquid waste disposal cribs. Sampling at points along the path of this movement could provide insight on UZ transport processes, on field-scale distribution coefficients for selected ions, and possibly additional information on unsaturated zone travel times. Although, for given crib installations, flow in certain horizons occurred laterally during the period that saturation in the crib was in use, vertical or near-vertical flow should occur at conditions of low saturation. Thus, the chemical species would be translated downward with time after their initial emplacement. The extent of this downward translation would provide a check on the hypothesis that travel times in the unsaturated zone are on the order of no more than a few decimeters a year.

Continuous monitoring of water levels. Relatively short time series data on water levels at selected sites can provide useful data for system understanding. For example, responses of water levels in wells near the Columbia River to river-stage change may provide information on aquifer properties and on the degree of hydraulic connection between the river and aquifer that might not be readily obtained from calibration of a flow model to match the potentiometric water table surface, even if a good map of that surface were available. Seasonal fluctuations or their lack in internal regions could help in testing the no-areal-recharge hypothesis.

Water level fluctuations in wells near Cold Creek and Dry Creek could provide a means for quantifying recharge from ephemeral flow in those channels.

Calibrated sitewide flow and transport model. Much understanding of the hydrologic system, including subtle effects of geology on flow patterns, potentially overlooked sources of recharge, and other currently unrecognized factors likely would be identified. Moreover, the calibration process could lead to identification of data needs.

During the presentations, strong emphasis was made on the use of empirical approaches to develop data for use in the computer codes. In some cases, these empirical approaches ignore relevant physical and/or chemical processes that may have a major control on transport and radionuclide release. Examples of these processes, each of which will be discussed in more detail below, are:

A. Vapor and gas transport

B. Diffusion coefficients developed from immersion in beakers to represent release to the unsaturated zone

C. Grout disintegration over time

A. Vapor and gas transport. More attention is due the fact that the thermally hot grout will drive moisture away, then cool and allow its recondensation in the vicinity of the grout block. Such effects may have a substantial effect on leaching of radioactive species that is not considered by currently planned modeling or experimental studies. I understand that a plan for a vapor transport study has been submitted for funding consideration by PNL personnel.

B. Diffusion studies--Studies of chemical species release by immersion of grout in Hanford ground water are inadequate by themselves to provide useful predictive data. Such releases are extremely sensitive to the conditions of the experiment, as evidenced by the radical differences shown between the effects in distilled versus ground water. To me at

least, these differences are minor compared to those between grout immersed in liquid and heat-producing grout emplaced in partly saturated porous media containing soil gas with CO_2 content elevated above atmospheric. For this actual case, several phenomena will be competing to affect the overall release rate. The grout temperature will be driving moisture from the grout-media interface by anisothermal vapor transport, but the deliquescent nature of salts in the grout will attract it. Soil CO_2 will diffuse toward the high-pH environment at the interface to either combine with the cement or to enhance the solubility, and hence retard, the precipitation of calcium carbonate. Depending on the relative efficiencies of these competitions, the grout could be wet or dry and encased in a calcite cocoon or totally free of calcite. In view of the above physics, experiments involving grout release by immersion seem irrelevant. Model predictions based on parameters derived from nonrelevant experiments will lack credibility to many more than the third-party reviewers.

C. Grout disintegration--Although many of the modeling assumptions are conservative, others are not. The claim appeared to be made that the as-yet unpoured grout monoliths would remain intact for 10,000 years. However, photographs of small samples of cracked grout were shown, and a statement was made during the field trip that the recipe for the grout to be formed using the DSST wastes is as yet undeveloped. Thus, it appears that we don't yet know how to make the grout, but we do know that once it is made, it will not crack or crumble during the next 10,000 years. A model that at least tested the effects on release rate of steadily crumbling grout needs to be made.

In conclusion, I feel that most, if not all, the technical talent is currently available on site to follow through on the above suggestions. The Hanford facility and PNL staff appear to have the capability to do a very credible sitewide hydrologic investigation. Many of the suggestions have been previously proposed by PNL or Westinghouse investigators and/or have been submitted by others for funding by DOE. At present, the missing element for a highly successful performance assessment effort appears to be a lack of programmatic commitment to a multifaceted sitewide hydrologic study and a commitment to pursue studies of physico-chemical phenomena relevant to waste burial that are conducted in parallel with the empirical studies.

In closing, I want to express appreciation for the major effort expended by the various investigators in making their presentations. I hope that the above suggestions can lead to improvements in the program that justify that effort.

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