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July 15, 1985

'85 JUL 22 P2:56

Dr. D. J. Brooks
Geotechnical Branch
Office of Nuclear Material
Safety and Safeguards
U.S. Nuclear Regulatory Commission
623-SS
Washington, D.C. 20555

WM Record File B0287 ORNL

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

Distribution:
Brooks
Starr
(Return to WM, 623-SS)
Joan-ticket
✓

Dear Dave:

Enclosed is the progress report for the month of June 1985 for B0287, "Technical Assistance in Geochemistry." Also enclosed are letter reports, LR-287-6, "Review of 'Critical Parameters for a High-Level Waste Repository, Volume I: Basalt,' by E. P. Binnall, H. A. Wollenberg, S. M. Benson, L. Tsao, O. Weres, A. L. Ramirez, and G. A. Armantrout, NUREG/CR-4161, May 1985," by A. D. Kelmers and G. K. Jacobs and LR-287-7, "Concerns Relative to the Applicability of the Yucca Mountain Radionuclide Sorption Information for Site Performance Assessment Purposes," by A. D. Kelmers.

Sincerely,

Susan

S. K. Whatley, Manager
Repository Licensing Analysis
and Support
Chemical Technology Division

SKW:bek

Enclosures:

1. Monthly Progress Report for June 1985
2. LR-287-6
3. LR-287-7

cc w/encl. 1: Office of the Director, NMSS (Attn: Program Support Branch)
Division Director, NMSS Division of Waste Management (2)
M. R. Knapp, Chief, Geotechnical Branch
K. C. Jackson, Geochemistry Section, Geotechnical Branch
Branch Chief, Waste Management Branch, RES
D. G. Brookins, University of New Mexico
W. D. Arnold
J. T. Bell
J. G. Blencoe
N. H. Cutshall
L. M. Ferris
J. R. Hightower
G. K. Jacobs
A. D. Kelmers
D. C. Kocher
A. P. Malinauskas
R. E. Meyer
R. G. Wymer
SKW File (2)

2230

Enclosure 1.

SKW
7/15/85

MONTHLY PROGRESS REPORT FOR JUNE 1985

PROJECT TITLE: Technical Assistance in Geochemistry

PROJECT MANAGER: S. K. Whatley

PROJECT STAFF: J. G. Blencoe, G. K. Jacobs, A. D. Kelmers, and R. E. Meyer

ACTIVITY NUMBER: ORNL #41 37 54 92 4 (FIN No. B0287)/NRC #50 19 03 01

TECHNICAL HIGHLIGHTS:

Task 1 - BWIP Geochemical Technical Assistance

As requested by the NRC Project Manager we reviewed the draft site technical position (STP) on "Use of Hydrazine to Experimentally Simulate Expected Site Redox Conditions and Reactions." Earlier work under our companion NRC/NMSS project (#B0290) provided the basis for this position.

Task 2 - NNWSI Geochemical Technical Assistance

The MS thesis of M. S. Henne (University of Nevada), "The Dissolution of Rainier Mesa Volcanic Tuffs, and Its Application to the Analysis of the Groundwater Environment," 1982, was reviewed (LR-287-4). The data obtained by Henne shows that some of the groundwaters that infiltrate Rainier Mesa may be capable of percolating downward very rapidly through the underlying unsaturated tuffaceous rocks.

Task 3 - Salt Site Geochemical Conditions

The draft topical report on "Brine Migration in Salt" by Walton Kelly was reviewed and comments furnished to the NRC Project Manager (LR-287-5).

Task 4 - Short-Term Geochemical Technical Assistance

No activity.

Task 5 - Project Management

A recent document by Chapman, N. A., McKinley, I. G., and Smellie, J.A.T., "The Potential of Natural Analogues in Assessing Systems for Deep Disposal of High-Level Radioactive Waste," 1984, was reviewed by G. K. Jacobs (LR-287-3) in preparation for the proposed workshop on natural analogs. The subject document presents an excellent discussion of how natural analogs may be useful in helping to increase the level of confidence in models of performance for high-level radioactive waste repositories. The report emphasizes crystalline host rocks because the study was commissioned by the Swedish and Swiss repository programs. However, because of the nature of natural analog studies, much of the report is relevant to any host rock under consideration for repository development.

The report, written from the perspective of geologists directly involved in the repository development, provides excellent insight into many of the natural analogs and is supported by 166 references. Although the report, by necessity, skims over many important details, it is quite complete and accurate in its assessment of specific analogs.

Since the basis for Chapman et al. (1984) was the natural analog workshop held during the fall of 1984, another workshop on the same topic might not be timely for the spring of 1986. In addition there seems to be a general lack of interest by the DOE site projects in natural analogs (conversations with various site representatives suggest that the DOE sites see little quantitative application of natural analogs during the licensing process). It is likely that an expansion of the current subcontract work with Brookins, combined with the conclusions of Chapman et al. will provide an adequate basis for the NRC to establish a technical position on the use of natural analogs in the licensing process.

Therefore, we propose that we cancel and/or delay our plans for the workshop on natural analogs and consider a workshop on a subject more relevant to the licensing of a repository. There are two areas we think need to be addressed by both NRC and DOE: 1) sorption testing and modeling and 2) development of a source term for the waste package/disturbed zone. As discussed during the NRC visit this month, significant uncertainty and controversy remains with respect to establishing acceptable methodologies for the modeling and testing or sorption characteristics for the far field in any dense, fractured media. The second area recommended for a workshop, which could emphasize both modeling and experimental methods, would provide an opportunity for those involved in waste package testing and R&D to meet with geochemists and discuss common issues related to describing the source term.

We are interested in receiving NRC comments on these proposals.

MEETINGS AND TRIPS: None

REPORTS AND PUBLICATIONS:

G. K. Jacobs and S. K. Whatley, "Conference on the Application of Geochemical Models to High-Level Nuclear Waste Repository Assessment, held at Oak Ridge, Tennessee, October 2-5, 1984," NUREG/CP-0062 (ORNL/TM-9585), 1985.

Letter report, LR-287-3, "Review of 'The Potential of Natural Analogues in Assessing Systems for Deep Disposal of High-Level Radioactive Waste,' by N. A. Chapman, I. G. McKinley, and J.A.T. Smellie, IER-Bericht Nr. 545, 1984," by G. K. Jacobs, 1985.

Letter report, LR-287-4, "Review of 'The Dissolution of Rainier Mesa Volcanic Tuffs, and Its Application to the Analysis of the Groundwater Environment,' MS Thesis of M. S. Henne, University of Nevada, Reno, NV, 1982," by J. G. Blencoe, 1985.

Letter report, LR-287-5, "Review of 'Brine Migration in Salt,' by Walton Kelly, 1985," by G. K. Jacobs, 1985.

PROBLEM AREAS: None

COST/BUDGET REPORT:

Expenditures were $23.6K for June 1985 and $261.3K for FY 1985. A detailed cost/budget report will be sent under separate cover.

Enclosure 2.

R-287-6
7/15/85

LETTER REPORT

Title: Review of "Critical Parameters for a High-Level Waste Repository, Volume I: Basalt, by E. P. Binnall, H. A. Wollenberg, S. M. Benson, L. Tsao, O. Weres, A. L. Ramirez, and G. A. Armantrout, NUREG/CR-4161, May 1985.

AUTHOR: A. D. Kelmers and G. K. Jacobs

PROJECT TITLE: Technical Assistance in Geochemistry

PROJECT MANAGER: S. K. Whatley

ACTIVITY NUMBER: ORNL #41 37 54 92 4 (189 #B0287)/NRC #50 19 03 01

SUMMARY

The report is, in general, a superficial and sometimes not totally rigorous treatment of obvious issues that have been addressed by the DOE site projects and the NRC in the past. The report provides little new guidance and would seem to be approximately five years too late. Some portions of the sections of the report dealing with radionuclide sorption and solubility (Sections 3.4.3 and 3.4.4) are technically incorrect and could be interpreted to be inconsistent with the published NRC technical position on solubility, as well as the technical position on sorption currently being prepared. We are concerned that dissemination of this information could compromise the NRC/NMSS interaction with DOE site projects.

SPECIFIC CONCERNS

The introduction of the subject report indicates that the project is directed toward considering the adequacy and reliability of instrumentation that may be used by the DOE repository projects. This report covers many geotechnical topics and identifies important processes and parameters that may require instrumental measurement. Much of the information in Section 3.4, Geochemical Parameters, appears to be a superficial and not totally rigorous treatment of the obvious. The discussions show little appreciation for the importance of geochemistry to the licensing of a repository and provide no new useful information. We wish to comment particularly on the sections concerning radionuclide sorption (Section 3.4.3, Sorptive Capacity of the Fracture Lining Material) and solubility (Section 3.4.4, Solubility of Radionuclides of Interest). These sections seem particularly germane to the radionuclide sorption and solubility work that we have underway for the NRC/NMSS. We feel compelled to comment on these sections because of the potential inconsistency with the NRC technical position on solubility that may be construed from the discussions pertaining to the calculation of sorption and solubility parameters.

On p. 68 the statement is made: "Several computer codes have been developed which can be used or adapted to make predictions of sorption behavior. These include WATEQ, developed by the U.S. Geological Survey, and EQ3/EQ6 developed al LLNL." This statement is technically incorrect. WATEQ and EQ3/6 do not currently have the capability to model sorption reactions. EQ3/6 is curently being modified to include sorption processes (Isherwood and Wolery 1984). The original version of WATEQ has been modified several times with some versions having the capability to model sorption (see Nordstrom et al. 1979; Jenne 1981). However, even with these modifications, the application of thermodynamic models for predicting sorption reactions is not practical, except for systems involving simple ion exchange on well-described clay minerals. Although an admirable scientific goal, models of sorption behavior from basic principles for radionuclide migration relevant for a HLW repository will probably not be incorporated into a successful performance assesment model in a timely manner for repository licensing. All the DOE site projects currently measure sorption by one or more experimental methodologies. It is likely that the NRC technical position on sorption, which is now in preparation, will require some combination of empirical data and a qualitative understanding of the sorption mechanisms controlling the experimental results. It is not anticipated that the technical position will give much credence to sorption behavior predicted from thermodynamic principles without laboratory and field analyses to validate the model. We are concerned that dissemination of the position in this report, without further clarification and caveats supplied, could compromise the NRC/NMSS technical position.

On p. 70 the statement is made: "Radionuclide solubility can be determined by calculation rather than in situ measurement.*" This statement is diametrically opposed to the NRC technical position on solubility which downplays the use of any calculational methodology for solubility, except to aid in the planning and interpretation of laboratory studies, not vice versa as implied by the footnote on page 70 of the subject report. The available thermodynamic data is generally inadequate to permit reliable solubility/speciation calculations for many of the important radionuclides. The technical position of the NRC states that measured solubilities are expected to be utilized in performance assessment modeling. We wish to suggest that a few in situ measurements to confirm laboratory test results may be desireable with calculations only used to complement these activities. We are concerned that the statement on solubility contained in this report, without further clarification and caveats supplied, compromises the NRC technical position.

REFERENCES

Isherwood, D. and T. J. Wolery, EQ3/6 Geochemical Modeling Task Plan for Nevada Nuclear Waste Storage Investigations (NNWSI), UCID-20069, Lawrence Livermore National Laboratory, Livermore, CA, 1984.

Jenne, E. A., Geochemical Modeling: A Review. PNL-3574, Pacific Northwest Laboratory, Richland, WA, 1981.

Nordstrom, D. K., L. N. Plummer, T. M. L. Wigley, T. J. Wolery, J. W. Ball, E. A. Jenne, et al., "Comparison of Computerized Chemical Models for Equilibrium Calculations in Aqueous Systems," in Chemical Modeling in Aqueous Systems, ed. E. A. Jenne, p. 815-35, Am. Chem. Soc. Symp. Series 93, 1979.

LETTER REPORT

TITLE: Concerns Relative to the Applicability of the Yucca Mountain Radionuclide Sorption Information for Site Performance Assessment Purposes

AUTHOR: A. D. Kelmers

PROJECT TITLE: Technical Assistance in Geochemistry

PROJECT MANAGER: S. K. Whatley

ACTIVITY NUMBER: ORNL #41 37 54 92 4 (189 #B0287)/NRC #50 19 03 01

SUMMARY

We are concerned that the information on radionuclide sorption and retardation available for the Yucca Mountain candidate repository site may prove to be inappropriate or inadequate for utilization in site characterization and repository licensing activities due to the use of potentially nonconservative or inaccurate experimental methodology, and that application of the sorption information may not meet the regulatory criteria of reasonable assurance. We suggest that it could be productive to address some of the specific concerns listed below through interaction between the Nuclear Regulatory Commission/Office of Nuclear Material Safety & Safeguards (NRC/NMSS), Oak Ridge National Laboratory (ORNL), Nevada Nuclear Waste Storage Investigations (NNWSI), and Los Alamos National Laboratory (LANL).

1. PURPOSE

The purpose of this letter report is to document some of our concerns relative to the radionuclide sorption information that has been developed by LANL for the NNWSI project. We have assumed that the NNWSI plans to use this information in performance assessment calculations both during characterization of the Yucca Mountain candidate repository site and in a repository license application. Our concerns have evolved both from an extended review, conducted on this NRC/NMSS project, of the sorption information published by LANL and from some initial results of our experimental evaluation of the LANL sorption methodology which we have recently started under a companion NRC/NMSS project (#B0290).

2. SPECIFIC CONCERNS

2.1 Lack of Sorption Information Compilation and Synthesis

The LANL has been conducting extensive experimental measurements of various radionuclide sorption values relative to the Yucca Mountain site since about 1979. The results of this work have been described in detail (see Section 3) in progress reports, topical reports, summary reports, and papers at Department of Energy (DOE) contractor meetings, Materials Research Society meetings, and other

meetings. This reportage represents over 1000 pages of text and contains several thousand individual sorption values. Unfortunately, we have been unable to find any single report or paper that attempts to compile and synthesize this mass of data to yield a coherent and consistent understanding of radionuclide sorption and retardation in either the engineered facility or the site far field at Yucca Mountain. Much of the reporting has been limited to a description of the experimental methods employed and documentation of the values measured without further explanation of the potential relevance or application of the values in performance assessment calculations. We do not understand how NNWSI plans to model sorption for the Yucca Mountain site. Also, we can not tell which of the many published values are the key or important ones that may be utilized in the site characterization and repository licensing process. Therefore, it is difficult for us to assess questions such as the applicability, relevance, or completeness of the published sorption information with respect to regulatory requirements for the Yucca Mountain candidate site.

2.2 Timeliness of Reporting

In order for the NRC and its contractors to evaluate information in a timely manner consistent with regulatory schedules, it is desirable that the NRC remain current with the conceptual approach and the experimental or calculational results being conducted at the DOE projects. Unfortunately, in the case of the Yucca Mountain sorption information, most reports available to us are over a year behind the LANL activities. The most recent report received in the ORNL library is LA-10154-PR, the quarterly progress report for January-March 1984 of all the NNWSI activities at LANL. In our meeting with LANL staff at the USGS Core Library at Mercury, Nevada, in February 1985, we heard interesting topics peripherally discussed that have not yet appeared in publications available to us. Of particular interest to the subject of this letter report were comments that LANL had not been able to correlate measured sorption values and experimental parameters for many radionuclides, and that a computer regression program was being written to attempt to establish such correlations. We suggest that it could be beneficial to the NRC/NMSS goals if some means of more rapid and frequent interaction could be established between ORNL and LANL to facilitate information transfer.

2.3 Absence of a Performance Assessment Strategy for Sorption Modeling

The NNWSI or LANL has not revealed the performance assessment strategy to be employed for the Yucca Mountain site, therefore, we are unable to evaluate the relevance to site assessment activities of the sorption methodology employed or the values measured. The NNWSI has not indicated how, or even if, credit for sorption and retardation will be taken at Yucca Mountain in the performance assessment of the engineered facility and/or the site far field. Thus, we cannot evaluate their position on sorption since it is unknown. We suggest that it may be desirable for the NRC to attempt to explore the strategy planned by NNWSI for Yucca Mountain; at least qualitative knowledge of the performance assessment strategy is essential in order for the NRC to evaluate many types of information including sorption information.

The release pathway for groundwater from emplaced waste to the accessible environment and the important sorptive minerals along the pathway have not been completely identified for the Yucca Mountain repository. Much of the thrust of the LANL sorption information effort (for example, LA-9328-MS and LA-9846-PR) has been aimed at correlating radionuclide sorption with tuff sample mineralogy. Good correlations were only obtained for Sr, Cs, and Ba sorption onto clinoptilolite [LA-9328-MS]. However, until the release pathway mineralogy is defined, the completeness or applicability of the measured sorption value/tuff mineralogy correlation for even these few radionuclides must be considered unknown.

Many of the sorption values reported by LANL for Yucca Mountain are for fission product radionuclides such as Sr, Cs, Ba, etc. Some of these have relatively short half-lives and might be expected to decay prior to canister failure and availability for migration. Release scenarios that could make migration of these radionuclides to the accessible environment a potential problem have not been published, thus we are uncertain as to the relevance of the short-lived fission product sorption information to the repository assessment modeling. It is desirable to determine whether NNWSI plans to explore other key radionuclides, and which ones.

2.4 Uncertain Applicability of Distribution Coefficient Values Measured with Crushed Rock Samples to Model Fracture-Flow Geologic Systems

Sorption ratios measured in batch contact tests are often assumed, as NNWSI has done [DOE (1984)], to be equivalent to distribution coefficients and used to calculate retardation factors for solutes such as radionuclides in groundwater. This calculation assumes that the radionuclides in groundwater will exhibit conventional ion exchange chromatographic behavior during migration through the geologic media. This assumption is valid only if: (1) the sorption and desorption reactions are rapid and reversible, (2) the bulk of the geologic media is available for sorption, and (3) saturated conditions exist. These conditions are often, but not necessarily, met for migration of trace metal contaminants in soil, but can not be satisfied for radionuclide migration in fractured impermeable media. These constraints on the application of batch contact methodology were recognized in the earliest LANL publication [LA-7216-MS], but seem not to have been addressed in more recent reports.

A good discussion of the problems involved in calculating the retardation of radionuclides due to sorption in a fractured dense host rock is given in Neretnieks (1980) or McKinley and Hadermann (1984). The simplifying approach inherent in the treatment reported by NNWSI [DOE (1984)] assumes that the entire bulk of the host rock is available for sorption. Neretnieks (1980) shows that the calculated retardation factors obtained by this method are both inaccurate and non-conservative because the rate of diffusion of radionuclides into the rock is slow compared to the groundwater migration rate. Neretnieks (1980) develops sound arguments for determining the accessibility of the rock matrix to the radionuclides and using this information in transport equations to estimate retardation due to sorption. We suggest that such an approach to retardation in the Topopah Spring tuff could yield more defensible retardation factor values than those obtained using the simplified non-conservative assumptions in DOE (1984).

A limited amount of work has been reported by LANL to compare radionuclide retardation measured by column chromatographic techniques with the retardation factors calculated from batch contact distribution coefficient values [LA-9329-MS]. Poor agreement resulted in some cases; plutonium behavior was different in flow-through column tests vs batch contact tests and the batch contact values proved to be nonconservative [LA-9793-PR]. This disagreement suggests that some experimental parameter(s) for the batch contact tests is(are) not representative of dynamic systems. In any case, this column work still involved the use of crushed rock material. A few experiments to measure radionuclide sorption by tuff rock wafers have also been described [LA-9577-PR], but this information apparently was not utilized in the performance assessment in DOE (1984).

We suggest that interaction with NNWSI and LANL on this fundamental concern relative to sorption methodology may be particulary desirable since every indication is that LANL is continuing to give emphasis to batch contact experiments employing crushed rock material. If this concern should be upheld after additional scrutiny, then most of the radionuclide sorption information for the Yucca Mountain site may be unacceptable for licensing purposes.

2.5 Unevaluated Batch Contact Methodology Test Protocol and Parameters

The batch contact methodology employed with crushed tuff to measure sorption and desorption ratios appears to have been established by LANL in 1977 for experimental work with Yucca Flat soils [LA-7216-MS], and then used without substantial alteration of the test protocol or parameters in subsequent work with argillite [LA-7455-MS], granite [LA-7456-MS], and finally in the extensive tuff work from 1979 through the present time.

None of the reports describe how the protocol or parameters were selected or optimized for the material under investigation. We were surprized to see that geologic materials as dissimilar as soil, shale, granite, and tuff were treated identically in experiments. A discussion of the sensitivity of the measured sorption or desorption values to the methodology is not generally included in the reports. This deficiency may render questionable the precision, accuracy, and, therefore, the applicability of the reported values for modeling purposes.

A careful description of the batch contact methodology is given in LA-9328-MS. This methodology is very similar to that given in LA-7216-MS and LA-7455-MS, or the sorption methodology handout given to us at the meeting in February, 1985 (Bayhurst, et al., unpublished). No justification or optimization of the important parameters used such as crushed rock/groundwater ratio, rock particle size, contact temperature, contact time, method of recovering groundwater after contact, etc., is given. We are concerned that the protocol and parameters used may not be optimized and that the information obtained could be biased or inaccurate.

2.6 Groundwater Instability During Experiments

Most of the sorption and desorption experiments conducted by LANL, and the resulting tables of sorption ratio values [LA-9328-MS, LA-9846-PR, DOE (1984)], have been carried out with radionuclide-traced water from well J-13, which is

adjacent to Yucca Mountain. The natural pH of this groundwater is 6.7 to 7.0. This pH has been extensively documented in LANL reports (for example, LA-9328-MS). We have recently received two samples of J-13 well water and have measured similar pH values. On standing with exposure to air, we have observed that the pH rises to considerably higher values, probably due to loss of dissolved CO_2. In most of the LANL batch contact experiments, the final pH after contact was reported to be from 8 to 9 when the test atmosphere was air. In tests involving an inert atmosphere of nitrogen, the final pH was even higher. We are concerned that pH changes of this magnitude during the sorption experiments could result in changes in both the rock/groundwater system and the measured sorption ratios to conditions or values which would not be representative of repository conditions. Many fission product and actinide radionuclides exhibit speciation changes with increases of pH from near neutral to pH 8 to 10 and the concomitant changes in bicarbonate/carbonate concentrations. Reactive minerals present in the tuff samples might also be altered by such pH changes. We are concerned that the Yucca Mountain sorption information obtained under test conditions that allowed the pH to range so far from the natural system pH may be of questionable relevance to the repository. We know the LANL staff are now aware of this concern about CO_2 loss and pH change since we heard some discussion of this point during the February meeting at Mercury, Nevada. However, the new LANL work under a CO_2/air atmosphere has not yet appeared in published reports available to us. We suggest that it may be important to pursue this concern with LANL because the bulk of the sorption ratio information was measured under experimental conditions that allowed this pH increase and, therefore, may be of uncertain applicability for the repository analysis activities.

A second aspect of groundwater instability during the tests involves the recent discovery by LANL that the well water contains microorganisms which grow when exposed to light [LA-10006-PR, LA-10032-PR]. LANL has reported that bacterial growth is occurring in the batch contact tests and that the presence of bacteria increased the measured plutonium sorption ratio values [LA-10154-PR]. We have not seen results from tests that explore the effect of bacterial growth on the sorption information for the other radionuclides. Bacteria might be expected to scavenge a number of the transition elements and actinides from solution. We have confirmed that microorganisms grow in the J-13 well water on exposure to light. This recent discovery by LANL brings into question all their previous sorption work with this water. We can only assume that similar growth occurred in all previous LANL experiments with J-13 well water involving all radionuclides. This previously unrecognized biological activity brings into question the validity of much of the published Yucca Mountain sorption information for use in repository performance assessment calculations. As with the pH changes discussed in the previous paragraph, we suggest that this subject should be a topic for NRC interaction with NNWSI and LANL.

3. SORPTION INFORMATION REPORTS

The reports published by LANL that contain sorption methodology descriptions or sorption information related to Yucca Mountain are given below in chronological order. Additional papers presented at DOE contractors meetings, Material Research Society meetings, or other meetings in general repeated the information contained in these LANL reports and are not listed.

LA-7216-MS, K. Wolfsberg, Sorption-Desorption Studies of Nevada Test Site Alluvium and Leaching Studies of Nuclear Test Debris, April 1978.

LA-7455-MS, B. R. Erdal, R. D. Aguilar, B. P. Bayhurst, P. Q. Oliver, and K. Wolfsberg, Sorption-Desorption Studies on Argillite: I. Initial Studies of Strontium, Technetium, Cesium, Barium, Cerium, and Europium, March 1979.

LA-7456-MS, B. R. Erdal, R. D. Aguilar, B. P. Bayhurst, W. R. Daniels, C. J. Duffy, F. O. Lawrence, S. Maestas, P. Q. Oliver, and K. Wolfsberg, Sorption-Desorption Studies on Granite: I. Initial Studies of Strontium, Technetium, Cesium, Barium, Cerium, Europium, Uranium, Plutonium, and Americium, February 1979.

LA-7480-MS, K. Wolfsberg, B. P. Bayhurst, B. M. Crowe, W. R. Daniels, B. P. Erdal, F. O. Lawrence, A. E. Norris, and J. R. Smyth, Sorption-Desorption Studies on Tuff: I. Initial Studies with Samples from the J-13 Drill Site, Jackass Flats, Nevada, April 1979.

LA-8110-MS, E. N. Vine, R. D. Aguilar, B. P. Bayhurst, W. R. Daniels, S. J. DeVilliers, B. R. Erdal, F. O. Lawrence, S. Maestas, P. Q. Oliver, J. L. Thompson, and K. Wolfsberg, Sorption-Desorption Studies on Tuff II. A Continuation of Studies with Samples from Jackass Flats, Nevada, and Initial Studies with Samples from Yucca Mountain, Nevada, January 1980.

LA-8747-MS, K. Wolfsberg, R. D. Aguilar, B. P. Bayhurst, W. R. Daniels, S. J. DeVilliers, B. P. Erdal, F. O. Lawrence, S. Maestas, A. J. Mitchel, P. Q. Oliver, N. A. Raybold, R. S. Rundberg, J. L. Thompson, and E. N. Vine, Sorption-Desorption Studies on Tuff: III. A Continuation of Studies with Samples from Jackass Flats and Yucca Mountain, Nevada, May 1981.

LA-9327-PR, Compiled by W. R. Daniels, B. R. Erdal, D. T. Vaniman, and K. Wolfsberg, Research and Development Related to the Nevada Nuclear Waste Storage Investigations, January 1-March 31, 1982, October 1982.

LA-9328-MS, W. R. Daniels, K. Wolfsberg, R. S. Rundberg, A. E. Ogard, J. F. Kerrisk, C. J. Duffy, T. W. Newton, J. L. Thompson, B. P. Bayhurst, D. L. Bish, J. D. Blacic, B. M. Crowe, B. R. Erdal, J. F. Griffith, S. D. Knight, F. O. Lawrence, V. L. Rundberg, M. L. Skyes, G. M. Thompson, B. J. Travis, E. N. Treher, R. J. Vidale, G. R. Walter, R. D. Aguilar, M. R. Cisneros, S. Maestas, A. J. Mitchell, P. Q. Oliver, N. A. Raybold, and P. L. Wanek, Summary Report on the Geochemistry of Yucca Mountain and Environs, December 1982.

LA-9329-MS, E. N. Treher and N. A. Raybold, The Elution of Radionuclides Through Columns of Crushed Rock from the Nevada Test Site, October 1982.

LA-9484-PR, Compiled by K. Wolfsberg, W. R. Daniels, B. R. Erdal, and D. T. Vaniman, Research and Development Related to the Nevada Nuclear Waste Storage Investigations, April 1-June 30, 1982, October 1982.

LA-9577-PR, Compiled by W. R. Daniels, B. P. Erdal, and D. T. Vaniman, Research and Development Related to the Nevada Nuclear Waste Storage Investigations, July 1-September 30, 1982, March 1983.

LA-9666-PR, Compiled by A. E. Ogard, W. R. Daniels, and D. T. Vaniman, Research and Development Related to the Nevada Nuclear Waste Storage Investigations, October 1-December 31, 1982, May 1983.

LA-9691-PR, Compiled by W. R. Daniels, Laboratory and Field Studies Related to the Radionuclide Migration Project, October 1, 1981-September 30, 1982, May 1983.

LA-9793-PR, Compiled by K. Wolfsberg, D. T. Vaniman, and A. E. Ogard, Research and Development Related to the Nevada Nuclear Waste Storage Investigations, January 1-March 31, 1983, June 1983.

LA-9846-PR, Compiled by A. E. Ogard, K. Wolfsberg, and D. T. Vaniman, Research and Development Related to the Nevada Nuclear Waste Storage Investigations, April 1-June 30, 1983, December 1983.

LA-10006-PR, Compiled by E. A. Bryant amd D. T. Vaniman, Research and Development Related to the Nevada Nuclear Waste Storage Investigations, July 1-September 30, 1983, July 1984.

LA-10032-PR, Compiled by K. Wolfsberg and D. T. Vaniman, Research and Development Related to the Nevada Nuclear Waste Storage Investigations, October 1-December 31, 1983, August 1984.

LA-10154-PR, Compiled by B. M. Crowe and D. T. Vaniman, Research and Development Related to the Nevada Nuclear Wsate Storage Investigations, January 1-March 31, 1984, February 1985.

4. ADDITIONAL REFERENCES

The following references were also cited in the text:

B. P. Bayhurst, W. R. Daniels, S. D. Knight, B. R. Erdal, F. O. Lawrence, E. N. Treher, and K. Wolfsberg, A Batch Method for Determination of Sorption Ratios for the Partition of Radionuclides Between Groundwaters and Geologic Materials, unpublished LANL document, personal communication from K. W. Thomas, February 1985.

DOE (1984), Department of Energy, Draft Environmental Assessment; Yucca Mountain Site, Nevada Research and Development Area, Nevada, DOE/RL-0012, December 1984.

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