PNL-5015-1
(FY 84 1st Qtr.)

Uranium Recovery Research Sponsored by the Nuclear Regulatory Commission at Pacific Northwest Laboratory

Quarterly Progress Report, October - December 1983

February 1984

Prepared for the U.S. Nuclear Regulatory Commission
under Contract DE-AC06-76RLO 1830
NRC FIN B2269, B2292, B2370, B2379

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

Battelle

PNL-5015-1

DISCLAIMER

PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

PNL-5015-1
(FY-84)

URANIUM RECOVERY RESEARCH SPONSORED BY THE NUCLEAR REGULATORY COMMISSION AT PACIFIC NORTHWEST LABORATORY

QUARTERLY PROGRESS REPORT
OCTOBER TO DECEMBER 1983

M. G. Foley
W. J. Deutsch
G. W. Gee
J. N. Hartley
D. R. Kalkwarf
D. W. Mayer
R. W. Nelson
B. E. Opitz
S. R. Peterson
R. J. Serne
V. W. Thomas
W. H. Walters
N. A. Wogman
T. W. Schrauf

February 1984

Prepared for the
U. S. Nuclear Regulatory Commission
under Contract DE-AC06-76RLO 1830
NRC FIN B2269, B2292, B2370, B2379

Pacific Northwest Laboratory
Richland, Washington 99352

EXECUTIVE SUMMARY

This report documents progress for four major research projects which include 9 discrete research tasks and a management task being conducted for the U.S. Nuclear Regulatory Commission (NRC), Office of Research, Waste Management Branch. The primary purpose of these tasks is to provide information to help the NRC license uranium recovery facilities. A truncated title of each task and a brief highlight summary are provided here.

- Long-Term Stabilization

Hydrologic modeling of the Slick Rock study site, including determination of the extent and velocity of flood impingement on the UMT pile and design of the riprap, was nearly completed. Design of riprap and cost estimates for several different design options and flood magnitudes at Grand Junction and Slick Rock were in progress for a topical report to be submitted in February, 1984.

The final draft of the report on vegetative covers was completed, and submitted to review. It will be submitted to clearance in January, 1984. Field and laboratory work were completed on the rock durability subtask, and preparation of the final report initiated. The literature review for settlement and consolidation was also completed, and a draft letter report submitted for project management review.

- Interim Stabilization of Mill Tailings Piles

Field-testing of commercially-available windscreens and additional chemical stabilizers continued. A monitoring trip was made to the Gas Hills, Wyoming test site.

- Tailings Dewatering Techniques

The lab apparatus for measuring soil properties has been modified to perform the necessary laboratory measurements. Saturated measurements of the required material properties (i.e., void ratio and hydraulic conductivity) as functions of the effective stress have been successfully completed for the sand and slime samples from the Grand Junction mill tailings pile. We are still in the process of measuring the conductivity of the sands. A mixture of the sand and slimes will be measured to obtain data that may be representative of the composite mill tailings pile. The unsaturated measurements are currently in progress and are planned to be completed by May, 1984.

During the measurement of the saturated slimes consolidation, it became apparent that time-dependent creep or secondary consolidation is a significant concern. Secondary consolidation is due to realignment or deformation of soil particles. The amount of tailings slimes settlement due to secondary consolidation may be of the same order or greater than the primary consolidation (the consolidation due to pore water dissipation). This is an important finding since the available consolidation analysis techniques ignore secondary consolidation.

The consolidation theory that is available in the variably saturated flow and consolidation model TRUST has been replaced by a new theory developed by Fredlund and Morgenstern. The new theory is based on a two stress-state description of the void ratio, saturation and hydraulic conductivity in the unsaturated zone. The new version of the model is currently called TRUST-II. Classical consolidation theory will still be used in the saturated zone.

Testing of the model solutions with and without consolidation has been completed for the saturated regime. Testing of the unsaturated consolidation results will be finished as soon as data from the Grand Junction slimes are obtained. The new theory as implemented in TRUSTI-II does not account for secondary consolidation. As noted earlier, this could be a serious shortcoming in certain situations.

- Tailings Neutralization and Other Alternatives in Immobilizing Toxic Materials in Tailings

Laboratory column tests with neutralizing barriers (compacted on-site sediments add-mixed with lime and used as part of a tailings pit liner) continued. The test columns continued to neutralize the acidic influent after 35 port volumes of contact simulating several years of sediment/solution interaction.

- Evaluation of Seepage and Leachate Leachate Transport From Tailings Disposal Facilities

A method to evaluate the environmental consequences of disposing uranium mill tailings in deep mine stopes below the water table has been completed, and a final report submitted for publication. The approach reduces data-input requirements and concentrates on considerations of the permeability contrasts between the tailings in the mine stope and the surrounding medium, and on the orientation of the stope relative to the local ground-water flow field. Chemical interactions will be included in the analyses, pending the outcome of coupled transport and chemical modeling to be done in FY-84.

- Effluent and Environmental Monitoring Methods and Equipment and Instrument Testing

Instrumentation was removed from the two houses in Edgemont, South Dakota, and field data were being reduce prior to preparing the status report on measurement techniques for radon daughter products. Work for subtasks on yellowcake monitoring, measurement techniques, well-logging techniques, temporal and spatial sampling strategies, surface and groundwater sampling techniques, and radon flux/radium concentration comparisons was concluded, and preparation of status reports was initiated.

- Attenuation of Radon Emissions

A handbook for determining radon attenuation through cover soils was completed and reviewed, as was a draft of a document in regulatory guide format describing the determination of radon attenuation by cover soils. A validation report on handbook techniques was initiated. All three reports will be submitted to NRC in March 1984 to close out the project.

- Assessment of Leachate Movement

The effects of the length and scaling (varying column dimensions but constant length-to-diameter ratio) of laboratory columns on leaching patterns were investigated. Differences in column lengths and residence times had no effect on the leaching curves. No effect on effluent concentrations of column lengths (residence time) or volumes (scaling) was noted.

Funding for this task in Uranium Recovery was eliminated for FY-84; however, the work is applicable to other waste forms and will be funded at a reduced level in FY-84 in Low-Level Waste.

- Methods of Minimizing Ground-Water Contamination in In-Situ Leach Leach Uranium Mining

Ground-water samples have been collected from a Wyoming roll-front uranium deposit. The ground water sampled from the ore zone aquifer at the North Platte pilot leach plant in Wyoming has sodium, bicarbonate, and sulfate as the dominant dissolved constituents. The total dissolved solids content of the waters sampled is less than 500 mg/L. The composition of the water does not vary appreciably across the roll front containing the uranium deposit; however, the redox potential does change from slightly positive for two of the upgradient wells to negative for the three wells sampled downgradient of the roll front. Dissolved uranium concentrations are uniformly low across the roll front. Comparison of the ground-water composition with that of the lixiviant used during pilot scale leaching shows that both chloride and total dissolved solids level (measured as electrical conductivity) would be effective excursion detection parameters at this site.

Column experiments simulating aquifer restoration by ground-water sweeping have been completed. Preliminary results show that uranium may be a difficult contaminant to restore to baseline levels if uranium minerals remain in the leach zone following mining. These minerals would be subject to dissolution by oxidizing ground water brought into the leach zone during sweeping. Several operators have experienced difficulties restoring the uranium concentration in the ground water using the sweeping technique, and this mechanism may explain why uranium concentration is sometimes difficult to restore. In these cases it may be necessary to use a combination of restoration techniques that include sweeping and recirculation with the addition of a reducing agent to immobilize the uranium.

CONTENTS

INTRODUCTION

Pacific Northwest Laboratory (PNL) is currently conducting research for the U.S. Nuclear Regulatory Commission (NRC) on uranium recovery process wastes for both active and inactive operations. The overall objective of this research is to provide NRC and their licensees with technical guidance on several issues related to management of wastes from uranium mills and *in situ* recovery operations. Principal issues addressed in these studies are: designs and performance of radon-suppression covers; the incentives and constraints for using protective covers, and designs for armoring tailings pile radon-suppression covers; short-term stabilization options for controlling windblown particles; leachate movement in soil; tailings dewatering and consolidation; disposal deliberately below the water table; neutralization incentives; contamination control and restoration in *in situ* uranium recovery; and environmental measurements, instrumentation, and protocols for assessing the radioactive contamination associated with uranium milling and mill tailings. Results of these studies will provide means to better evaluate the environmental impacts during and following the active life of a uranium recovery facility, and many will be used in developing regulatory guides.

The National Research Council Committee on Onshore Energy Minerals Management Research (COEMMR) stated:

> "The most significant unresolved (uranium) milling-related problem appears to be the safe disposal of radioactive and heavy metal-laden mill wastes. Potentially suitable tailings management techniques, using different approaches, have been adopted at several of the mills commissioned in the last few years. It is important that field performance of both old and new techniques be monitored and the data critically examined to determine the effectiveness of the different methods, and the nature of any required modifications."

NRC-sponsored uranium recovery research at PNL is focused on NRC regulatory responsibilities for uranium-recovery operations:

- license active milling and *in situ* extraction operations,
- concur on the acceptability of DOE remedial-action plans for inactive sites,
- license DOE to main inactive sites following remedial actions

PNL's program consists of four coordinated projects comprised of a program management task and nine research tasks that address the critical technical and safety issues for uranium recovery. Specifically, the projects endeavor

(a) Information available in Proceedings of the Workshop on Research and Information Needs for Management of Uranium Production from Leased Federal and Indian Land, held December 9-10, 1982, Albuquerque, New Mexico. In publication through the Committee on Onshore Energy Mineral

Management Research sponsored by the National Research Council, Washington, D. C.

to find and evaluate methods to:

- prevent erosion of tailings piles and prevent radon release from tailings piles
- evaluate the effectiveness of interim stabilization techniques to prevent wind erosion and transport of dry tailings from active piles
- estimate the dewatering and consolidation behavior of slurried tailings to promote early cover placement
- design a cover-protection system to prevent erosion of the cover by expected environmental stresses
- reduce seepage into ground water and prevent ground-water degradation
- control solution movement and reaction with groundwater in *in situ* extraction operations
- evaluate natural and induced restoration of groundwater in *in situ* extraction operations
- monitor releases to the environment from uranium recovery facilities.

This quarterly progress report for the uranium recovery research program at PNL covers the research performed for the NRC at PNL in the period October, 1983 through December, 1983. The following sections report the progress in uranium recovery research at PNL during the quarter.

This information is preliminary, and conclusions should be regarded as tentative. Further information will be contained in the topical reports published, or scheduled to be published throughout this research effort. The authors solicit comments and suggestions from readers of this progress report.

STABILIZATION, ENGINEERING, AND MONITORING ALTERNATIVES ASSESSMENT FOR IMPROVING REGULATION OF URANIUM RECOVERY OPERATIONS AND WASTE MANAGEMENT

Project Manager: M. G. Foley

FIN B-2370

OBJECTIVE

This research effort will address many of the technical issues related to providing and assessing methods for predicting, evaluating, and limiting the environmental effects of wastes from uranium milling operations. The principal objective of the project is to provide information essential in licensing actions to ensure that individuals and the public will be adequately protected during the active life of the mill and over an indefinite time period following shutdown. The scope of this investigation embraces seven tasks, each of which will be discussed separately in the report.

TASK 1. LONG-TERM STABILIZATION

Task Project Manager: W. H. Walters
Principal Investigator: W. H. Walters
Support Investigators: M. G. Foley
R. L. Skaggs
R. M. Ecker
P. A. Beedlow
C. S. Kimball

FIN B-2370 (Task 1)

OBJECTIVE

Through this task we will provide the Nuclear Regulatory Commission with an engineering handbook on the protection of decommissioned uranium tailings impoundments from long-term erosion by wind and water. The handbook will also include a technical/economic evaluation of riprap design procedures, an evaluation of watershed models for estimating potential surficial erosion around the tailings pile, and criteria to estimate embankment slope stability.

ACCOMPLISHMENTS DURING PAST QUARTER

Subtask A. Technical Feasibility Study

1. Grand Junction, Colorado Case Study

Work continued on the calculation of rock sizes using the Caltrans, Corps of Engineers, and Safety Factor methods for purposes of comparison. The calculations include rock size determinations for six potential flood events and also consider variations in embankment side slopes.

2. Slickrock, Colorado Case Study

Channel cross-sections and hydraulic data for the Dolores River were prepared for the hydraulic modeling (HEC-2) of the river reach in the vicinity of the tailings impoundment. Field survey data for the low water channel were tied into the topographic map contour maps developed from aerial photography. Channel and flood plain hydraulic roughness values (Manning's n were estimated using aerial photography and site inspection results. The probable maximum flood (PMF) discharge of 46,100 cfs at the site was determined based on a previous PMF study for an upstream reservoir. Preliminary results from the modeling effort indicate that the PMF would be about 10 ft deep along the tailings embankment.

Subtask B. Riprap Design for Overland Erosion and Local Scour

No work was performed on this subtask during this quarter. The literature review work has been completed.

Subtask C. Riprap Protection for Local Drainage Channels

No work was performed on this subtask during this quarter. The literature review work has been completed.

Subtask D. Vegetation Covers

The draft report for this task was submitted for review by the project and program managers and for peer review by Ecological Sciences personnel. Based on these reviews the draft report was being revised and will be submitted for clearance review in early January, 1984.

Subtask E. Economics of Riprap Design Procedures

Work commenced on the evaluation of the Slickrock, Colorado tailings site. The analysis will consider only one flood event of 46,100 cfs (PMF). Rock sizes and quantities will be determined for various side slope values and specific gravities of several rock sources.

Subtask F. Watershed Model Evaluation

Work is scheduled to commence during January, 1984.

Subtask G. Rock Selection and Durability

The field and laboratory work for this subtask were completed and preparation of the draft report initiated. The report will be submitted to review and clearance in February, 1984.

Subtask H. Impoundment Slope Stability and Settlement

The literature review for the settlement and consolidation section of the report was completed and a draft submitted for project management review. Work continued on the slope stability section.

TASK 2. INTERIM STABILIZATION OF TAILINGS

Task Project Manager: J. N. Hartley
Principal Investigator: M. R. Elmore

FIN B-2370 (Task 2)

OBJECTIVE

The overall objective of this task is to assess the effectiveness, durability, and practicability of interim stabilization techniques and strategies for the suppression of dust from exposed tailings surfaces, under a full range of site and environmental conditions.

ACCOMPLISHMENTS DURING PAST QUARTER

A field test was initiated at PNL to study the effectiveness of 3 types of windscreens in reducing fugitive dust emissions from open sources such as tailings piles. A tailings pile is simulated by a layer of fine sand placed behind the windscreens and on an unprotected control area. The effectiveness of these 3 windscreens, which represent the range of available types, will be determined by wind speed reduction, measured by arrays of anemometers placed upwind and downwind of the screens, and by suspended particle reduction, measured with particulate samplers downwind of the screens and on the control area.

A monitoring trip was made to the Gas Hill, Wyoming test site to assess the condition of the chemical stabilizer test plots and the windscreen test panels erected in September 1983. At that time repairs were made to one of the screens damaged during high winds. The damage occurred as a result of improperly constructed mounting posts supplied by the manufacturer.

PROJECTED WORK FOR NEXT QUARTER

Work will continue on the laboratory studies report and on monitoring and evaluation of the PNL windscreen field test. The next monitoring trip to the Wyoming test site will probably be postponed until next spring.

REPORTS ISSUED DURING THE QUARTER

The report, Field Testing of Fugitive Dust Control Techniques at a Uranium Mill Tailings Pile, 1982 Field Test, Gas Hills, Wyoming, NUREG/CR-3510 was sent to NRC for printing. A paper has been prepared for the annual mill tailings symposium in Fort Collins, Colorado during February, 1984 titled, "Fugitive Dust Control at Uranium Mill Tailings Piles". A draft of the laboratory studies report, Laboratory Testing of Chemical Stabilizers for Control of Fugitive Dust Emissions from Uranium Mill Tailings, is being prepared.

TASK 3. TAILINGS DEWATERING TECHNIQUES

Task Project Manager: D. W. Mayer
Principal Investigators: D. W. Mayer
T. W. Schrauf
S. W. Tyler
T. J. McKeon

FIN B-2370 (Task 3)

OBJECTIVE

In this task we determine the most effective approaches to dewatering uranium mill tailings that have been slurried into pits. Minimizing the release of contaminants to the environment by reducing the seepage into ground water and earlier placement of radon suppression covers is the primary objective. Special attention is given to evaluating the classical vertical consolidation theory as a worst-case estimator of settlement during the dewatering of tailings. Improved analysis techniques will be implemented and we will evaluate and test measurement techniques for obtaining the material properties i.e., void ratio, degree of saturation, and hydraulic conductivity) as funtions of the stress-state parameters. We will use this analysis capability to assess various disposal strategies.

ACCOMPLISHMENTS DURING PAST QUARTER

Subtask A. Evaluation of Linear Consolidation Theory

The work on this subtask was completed in FY82.

Subtask B. Measurement and Representation of Material Characteristics

The objective of this subtask is to obtain the necessary saturation, hydraulic conductivity, and void ratio data that will allow us to simulate the fluid flow and consolidation in uranium mill tailings piles. We will also develop methods for interpreting the lab data.

Preliminary measurements made with the triaxial device (used for the unsaturated measurements) revealed problems with using the apparatus for slurries. To solve this problem a Rowe consolidometer, (see Appendix A for a description and schematic of this piece of equipment) was modified for the unsaturated measurements. We are in the process of making the unsaturated measurements with the modified Rowe consolidometer. No significant problems have been experienced with the new equipment.

The measurements of saturated Grand Junction mill tailings slimes and sands has been completed. Some difficulties were encountered while measuring the hydraulic conductivity of the sands. This problem is currently being rectified.

The measurement of the consolidation of the slimes yielded unexpected results. Time-dependent strain (or secondary consolidation) may be as large or larger than primary consolidation. This is an important result since the available analysis techniques ignore secondary consolidation. Secondary consolidation for sands is much less than for slimes and is not considered of major importance. Studies will be performed to investigate primary consolidation and secondary consolidation on a sand/slimes mixture that may be representative of the consolidation that could be expected for the composite tailings pile.

Unsaturated measurements of mill tailings slimes are currently being performed. These measurements are planned to be completed by the end of February at which time the measurements of the sands will commence. Appendix A gives a detailed status report on this Subtask.

Subtask C. Computer Code Modification Testing and Documention

The objective of this subtask is to change the existing consolidation model in the TRUST code to the two stress-state model. This change primarily involves making void ratio, saturation, and hydraulic conductivity a function of both the load at a point in the tailings pile and of the local capillary pressure. This representation of the material properties will only be used in the partially-saturated region. The classical consolidation theory, with the soil properties handled as functions of effective stress (i.e., the load minus the pore-water pressure) will still be used in the saturated region. To meet this objective and to make the new technique available to others, the new version of TRUST (which will be designated TRUST-II) along with a pre- and post-processor utility package will be tested and documented.

During the last quarter the TRUST-II model is progressing on schedule. Example simulations have been completed and debugging of the code is essentially finished. Final debugging of the model awaits simulations using the unsaturated flow and consolidation measurements that will be obtained under Subtask B.

Subtask D. Evaluation of the Interactions Between Consolidation and Fluid Flow

No work on this subtask was scheduled for this report period.

Subtask E. Tailings Dewatering Test Cases

No work on this subtask was scheduled for this report period.

PROJECTED WORK FOR NEXT QUARTER

During the second quarter of FY84 the soil property data for sands and a sand/slimes mixture from the Grand Junction mill tailings pile will be obtained.

The soil properties for the slimes will be used in the comparison studies to be conducted under Subtask D. We expect the slimes to consolidate more than the other materials that will be measured (i.e., sands and sand/slimes mix); therefore, the effects of coupling and decoupling the flow and consolidation are expected to be most significant for the slimes.

Documentation of the variably saturated flow and consolidation computer model TRUST-II model will be continued to ensure that the new algorithm is working properly and does not adversely affect the accuracy of the model results. Once documented (scheduled for July, 1984) the model will be available for use by others to perform the simulation of flow and consolidation. It should be noted here that the utility package that was submitted in August, 1983 (NUREG/CR-3443) is compatible with the TRUST-II version of TRUST. The testing and documentation of TRUST-II is a doubly important goal for FY84. First, the modeling capability provides a state-of-the-art analysis of the dewatering and consolidation of uranium mill tailings piles. Second, the utility package is not compatible with the version of TRUST documented in NUREG/CR-2360. The decision to make the utility package compatible with TRUST-II was made to eliminate the need for redocumentation of the utility package once the TRUST-II model has been released.

REPORTS ISSUED DURING QUARTER

Schrauf, T.W. 1983. Status of Sampling and Measurement of Uranium Mill Tailings Consolidation Characteristics. Letter report (see Appendix A).

TASK 4. TAILINGS NEUTRALIZATION AND OTHER ALTERNATIVES FOR IMMOBILIZING TOXIC MATERIALS IN TAILINGS

Task Project Manager: B. E. Opitz
Principal Investigators: B. E. Opitz
R. J. Serne
Support Investigators: M. E. Dodson
R. L. Erikson
M. J. Mason
D. R. Sherwood

FIN B-2370 (Task 4)

OBJECTIVE

In this task we assess the effectiveness, benefits, and costs of treating acidic tailings and tailings solution to reduce the potential leaching of toxic elements, radionuclides and macro ions from a tailings impoundment.

ACCOMPLISHMENTS DURING THE PAST QUARTER

Subtask A. Neutralization Methods Selection

This subtask was completed in FY83 when we completed and submitted the literature review on amelioration techniques. However, throughout the remainder of the project we will make an effort to keep abreast of recent developments in applicable treatment techniques.

Subtask B. Laboratory Analysis

Laboratory experiments, started during the previous quarter to investigate a possible alternative to neutralizing the acidic tailings solution in an entire tailings impoundment, continue to be monitored. The "neutralizing barrier" studies, using flow-through permeability columns, involved add-mixing up to 5% (by weight) lime with onsite sediments from two Wyoming mills. The barrier, when placed below the existing tailings pond bottom, neutralizes (treats) only the solution which escapes from the tailings impoundment.

Results from these experiments have shown dramatic decreases in permeability (values approaching 10^{-10} cm/s) as contact with acidic (pH 2.0 or less) tailings solution continues. Untreated sediments (sediments with no lime) display permeabilities two or three orders of magnitude larger than those of treated sediments after periods of equal acid solution contact.

The pressurized flow-through columns used in the neutralizing barrier studies represent accelerated testing of treated and untreated mill site sediments. Currently, the treated sediments (sediments with lime), continue to neutralize the acidic influent tailings solution after 35 pore volumes of contact simulating several years of sediment/solution interaction.

Single-reagent neutralization studies were initiated to investigate contaminant/carbonate complexation in uranium mill tailings solutions previously neutralized with either calcium hydroxide or calcium carbonate. Of special interest are the contaminant solubility effects resulting from carbonate containing neutralizing reagent, contaminant removal at elevated (alkaline) solution pH's, and contaminant sorption on colloidal size particles. Contaminant complexation with carbonate containing regents may account for elevated solution concentrations of several constituents, notably, U, Ra, Se, Mo, Co, and Mn, once neutralization is complete. In previous studies similar trends were not evident with noncarbonate-containing neutralizing reagents.

The results of this study will be compared with previous acid-solution neutralization data and as input for geochemical models used in the Leachate Assessment Project (B2292).

Subtask C. Field Tests

A field demonstration plan entitled, "Field Demonstration Plan for Verification of Uranium Mill Tailings Neutralization Techniques," was submitted during the second quarter of FY83. The plan outlines three alternatives for field testing the most promising and cost-effective current neutralization technique.

PROJECTED WORK FOR NEXT QUARTER

We will continue to monitor the neutralizing barrier studies for long-term contaminant attenuation and acid pH breakthrough. In addition, the carbonate-contaminant complexation studies will be completed.

REPORTS ISSUED DURING THE QUARTER

None.

TASK 5. EVALUATION OF SEEPAGE AND LEACHATE TRANSPORT FROM TAILINGS DISPOSAL FACILITIES

Task Project Manager: R. W. Nelson
Assistant Task Manager: T. J. McKeon
Principal Investigators: A. E. Reisenauer
T. J. Bander

FIN B-2370 (Task 5)

OBJECTIVE

In this task we evaluate the environmental consequences that may result from the disposal of uranium mill tailings below the water table. Two methods for the disposal of tailings below the water table are examined. The first involves disposal in excavated pits where some or all of the tailings are in contact with the regional ground-water flow and subject to leaching by the ground water. The second method examined is the disposal of tailings in deep underground mine stopes below the water table.

ACCOMPLISHMENTS DURING PAST QUARTER

A method for evaluating the environmental consequences resulting from the disposal of uranium mill tailings in deep underground mine stopes has been developed. This evaluation method is described in NUREG/CR-3560, entitled, Evaluation Methods for the Consequences of Below Water Table Mine Disposal of Uranium Mill Tailings. A camera ready copy of this document was sent to NRC for printing.

The method we have developed uses analytical expressions for the velocity field and examines the convective transport of tailings liquor and leachate downgradient from the mine stope. The quasi-analytical model of the flow system is easy to use and appropriate when a limited data are available. The final results of the analysis include the arrival distribuion of contaminants (mass flux versus time) and the concentration of particular contaminants in the water pumped from a downgradient well as a function of time.

Our evaluation method consists of two basic parts, transport analysis and consequence analysis. The model used for the transport analysis calculates the travel paths and travel times for the water- coincident contaminants from the tailings-filled stope to the water supply well. The consequence analysis used the results of the transport analysis in conjunction with the geochemical leaching characteristics of the tailings and ground water to calculate the rate at which contaminants arrive at the water supply well.

The three dimensional model developed for the transport analysis examines only the convective transport of contaminants; no dispersion is considered.

In analyzing the flow system, one of the most important considerations is the permeability contrast between the tailings in the mine stope and the surrounding medium. The contrast in permeability not only controls the relative amount of ground water flowing into and through tailings, but also causes the pathlines of the ground water to be refracted when they cross through an area of different permeability.

The orientation of the mine stope with respect to the regional ground-water gradient is another important parameter in defining the extent of the potential contamination problem. The regional ground water gradient may intercept the stope at any angle from 0° to 90° with the longitudinal axis of the mine stope. The angle at which the regional gradient intersects the stope or tunnel is important because the size and duration of the downgradient contaminant plume change significantly as the angle varies from 0° to 90°. For example, at 90° (when the regional gradient is perpendicular to the stope) the ground water moves directly across the stope so less water makes contact with tailings for leaching. This kind of direct seepage results in a downgradient leachate plume that is short but very wide (i.e., the plume is essentially as wide as the tailings-filled stope is long).

If the gradient is oriented at 45° to the tunnel length, the ground-water flow paths are diagonal through the tailings, which gives a longer flow path and a longer leachate plume. This results in a longer time period in which peak concentrations enter the pumped well downgradient from the tailings disposal tunnel. At the 45° orientation, the leachate plume is narrower, with a width about seven-tenths that of the tunnel length (i.e., approximately the projected tunnel length normal to the regional gradient).

The different lengths of the leachate plume and corresponding shorter or longer times for the plume to move past the downgradient well can significantly change the leachate concentration reaching the biosphere. The reduction in contaminant concentrations in the water pumped from the well depends both on the plume length and the flow pattern of the fluid into the well.

Contaminants at the front of the leachate plume arrive at the well earlier because they travel along the shorter more direct pathlines into the well. These contaminants are diluted as the contaminated water is mixed with clean water during pumping. The uncontaminated water preceding the leachate front, but traveling along the longer more indirect pathlines dilutes the contaminated water in the well that arrived along the shorter pathlines. Significant dilution occurs if the length of the leachate plume is less than the difference in length of the longest and shortest pathlines entering the well.

The model developed for the consequence analysis evaluates the spatially and time dependent concentration of the fluid entering the water supply well. Assuming the fluid is completely mixed by the pumping, the concentration of contaminants in the well is calculated.

Currently, the consequence analysis incorporates only one of two geochemical interactions, the leaching of the tailings by ground water. The other, interactions between the leachate and the porous medium of the aquifer after the leachate has left the mine stope, are ignored. The model developed for the consequence analysis is structured such that it may easily be coupled with the results of a geochemical code evaluating the interactions between the leachate and the porous medium.

Laboratory experiments studying the leaching of tailings by natural ground waters and the interactions of acidic leachate with natural aquifer materials are being conducted as part of Task 4 of this research, B-2370, and also under the NRC-sponsored project B-2292. Results from the leaching studies of Exxon Mill tailings have been summarized and are ready for incorporation into the model used to predict the consequences of tailings disposal in mine stopes.

The leachate breakthrough data from experimental columns of coarser aquifer material conducted during the last year by other cooperating researchers have been assembled and are being used to plan the first tests of the initial geochemical coupled-transport simulation model. Specifically, the tailings solution concentrations input to the experimental columns along with the characteristics of the coarser aquifer material in the columns will be used to calculate the expected leachate breakthrough curve. The comparison of the calculated and experimentally measured breakthrough curves will provide initial verification of the coupled code modeling capability.

PROJECTED WORK FOR NEXT QUARTER

The major work for the next quarter will be to attempt to identify the "worst case" scenarios by parametrically varying the parameters used to characterize the problem. The parameters that need to be studied are: The contrast in conductivities between the tailings and the aquifer; the pumping rate of the well; the orientation of the mine stope with respect to the regional gradient; the magnitude of the regional gradient; the location of the pumping well; and the ratio of the length of the mine stope to its diameter.

During the next quarter the first test runs of the coupled geochemical and transport code will be completed and compared with the measured laboratory column results. If the agreement is satisfactory, the geochemical modeling results will be incorporated into the extensive evaluation of mine stope disposal of uranium tailings.

REPORTS ISSUED DURING THE QUARTER

McKeon, T.J. and R. W. Nelson. 1983. Evaluation Methods for the Consequences of Below Water Table Mine Disposal of Uranium Mill Tailings. NUREG/CR-3560, Nuclear Regulatory Commission, Washington, D.C.

TASK 6. EFFLUENT AND ENVIRONMENTAL MONITORING METHODS AND EQUIPMENT AND INSTRUMENT TESTING

Task Manager: N. A. Wogman
Principal Investigators: P. O. Jackson
E. A. Lepel
K. B. Olsen
V. W. Thomas
W. C. Weimer
J. A. Young

FIN B-2370 (Task 6)

OBJECTIVE

In this task we assess measuring devices, techniques, and procedures for verifying if site and structure decontamination is acceptable. We develop needed monitoring methods and equipment, including methods to assess the release of radioactive and toxic materials from various facility components. From these assessments, we can provide guidance on monitoring requirements and strategies to evaluate compliance with uranium mill and tailings standards (e.g., PL-95-604, 40 CFR 192, 40 CFR 190). The work in this task is distributed among several subtasks identified below.

ACCOMPLISHMENTS DURING PAST QUARTER

Subtask A. Field Comparison of Radon Progeny Measurement Techniques and Critical Evaluation of Long-Term Radon-Daughter Measurements and Needed Improvements

Objective

In this subtask we ascertain whether a satisfactory short-term measurement technique is available for the determination of annual-average radon-daughter concentrations in buildings. We are to determine which, if any, of the available long-term radon and radon-daughter measuring devices is the most accurate and cost-effective.

Accomplishments During Past Quarter

Data were collected in the occupied and vacant houses in Edgemont, South Dakota, over a period of about two and one-half months. The parameters measured were described in detail in last quarter's report. Briefly, a weather station measured temperature, pressure, wind speed and direction. Radon-daughter concentrations were measured in both the vacant and the occupied houses. Average radon-daughter concentrations were measured weekly at the same locations using Radon Progeny Integrating Sampling Units and long-term average radon and radon-daughter concentrations were also measured using Track Etch® techniques. Average radon concentrations were also measured in the houses as were condensation nuclei. Average temperature was measured in the occupied house and the time periods that circulating fans or exhaust fans were in operation was recorded. The rate of exchange between inside and outside areas in both the occupied and vacant houses were measured. Due to funding shortages, these measurements (originally planned to be continued for six months to a year) were truncated early in December. All instrumentation has been removed from the two houses in Edgemont, South Dakota and the subcontracts with their owners have been allowed to lapse. Simple correlations between these parameters in this data base are now being investigated. Writing of the status report, "Critical Evaluation of Short- and Long-Term Radon-Daughter Measurement Techniques and Recommended Procedures", has commenced.

Projected Work for Next Quarter

Data analysis and the status report mentioned above will be completed during the quarter.

Subtask B. Yellowcake Emission From Ventilation Exhausts

Objective

In this subtask we are to evaluate current methods for monitoring yellowcake and to recommend a new, revised, or improved method for monitoring yellowcake emissions from ventilation exhausts at uranium mill sites.

Accomplishments During Past Quarter

A ^{57}Co source was evaluated for use as the excitation source for x-ray fluorescence analysis of uranium in yellowcake. The first draft of the status report, "Laboratory Evaluation of Instrumental Methods for the Measurement of Yellowcake Emission," was finished. It appears that a preferred method of continuously monitoring yellowcake ventilation exhausts with current technology is the use of continuous automatic isokinetic stack sampler to collect particulates on a filter substrate. Three samples per day per stack would be collected at each mill and the filter samples would be analyzed using ^{57}Co to excite the K x-rays of the uranium nucleus for isotopic excitation x-ray fluorescence.

Projected Work for Next Quarter

The status report will be completed and issued during the quarter.

Subtask D. Critical Evaluation of Measurement Techniques for Uranium ^{226}Ra, ^{230}Th, and ^{210}Pb in Effluents and Environmental Materials and Recommended Improvements

Objective

In this subtask we compare the sensitivity of existing analytical procedures for quantifying U, ^{226}Ra, ^{230}Th, and ^{210}Pb in effluents and environmental materials. The individual sensitivities will be compared with regulatory standards. Where improvements are required, existing techniques will be extended, if possible, or new techniques will be developed to produce methods which are sensitive enough to address the regulatory standards. The final report for this subtask will be a set of analysis methods to be used to measure the radioisotopes of interest in both effluents and environmental materials.

Accomplishments During Past Quarter

We have completed our analysis of the effects of anti-coincidence shielding on the limits of detection of large-surface-area planar, intrinsic-germanium-detector systems. The use of this type of shielding has lowered the limit of determination by a factor of approximately 2. Other work at PNL has demonstrated that an additional significant improvement in sensitivity could be achieved through a slight modification in detector construction. Although funds were not available to perform this modification on the intrinsic detectors which we were evaluating, we think that such modification could be very helpful in achieving the detector sensitivities necessary to meet the NRC regulatory standards.

Projected Work for Next Quarter

A status report, "Measurement Techniques for Uranium, ^{226}Ra, ^{230}Th, and ^{210}Pb in Effluents and Environmental Materials Associated with Uranium Recovery," will be issued. This report will present: 1) a comparison of the sensitivities of existing analytical procedures, 2) a discussion of possible improvements in these analytical methods, and 3) a recommendation for field and laboratory measurement procedures.

Subtask E. Review Well-Logging Techniques

Objective

In this subtask we are to 1) evaluate and compare well-logging techniques with core-sample analytical results for the measurement of uranium and its progeny in uranium tailings, 2) determine the effects of interfaces (high natural concentrations of uranium decay-chain products and variations of ^{40}K concentrations) on the response of the well-logging instruments, and 3) recommend an acceptable procedure which can be applied to present and future uranium mill tailings remedial-action programs.

Accomplishments During Past Quarter

Data on the Edgemont and Grand Junction field trips have been reduced. The first draft copy of the report, "Borehole Logging During Engineering Assessment for Remedial Action--Recommended Procedures and Equipment," has been written.

Projected Work for Next Quarter

We will complete the report mentioned above and submit it to NRC.

Subtask F. Evaluate and Recommend Sampling Strategies for Temporal and Spatial Evaluation of Contamination

Objective

In this subtask we are to develop guidelines to help detect and evaluate the windborne-radioactive contamination that has been spread from uranium tailings piles and which may extend up to several kilometers. Our guidelines will define the number, distribution, and timing of samples necessary to detect the spread of contamination with reasonable certainty, while keeping the cost and size of the detection effort at a minimum.

Accomplishments During Past Quarter

Continuing efforts on this subtask were interrupted last quarter after the issuance of the topical report, Recommended Sampling Strategies for Spatial Evaluation of Contamination Around Uranium Tailings Piles, NUREG/CR-3479 (PNL-4830).

Projected Work for Next Quarter

None.

Subtask G. Sampling Techniques for Detecting Contamination of Surface and Ground Water by Tailings Leachate

Objective

In this subtask we are to evaluate the existing standard techniques for measuring levels of contaminants in natural waters to determine their applicability at uranium recovery sites. Known dissolved contaminants that are potential hazards to water quality will be considered in this study. These include some of the radioactive uranium-daughter products (in particular thorium and radium) and stable elements Se, As, Sb, Zn, Ni, Cr, and Cu. An additional objective is to propose a spatially-oriented monitoring protocol for ground water that will be generally useful for uranium recovery sites.

Accomplishments During Past Quarter

A subset of the ^{3}H data in the Hanford ground water data set was selected to evaluate a number of sampling strategies. During the statistical analysis of this data subset, funds to perform this task were truncated, prohibiting the completion of this important statistical evaluation.

Projected Work for Next Quarter

None.

Subtask I. Radon Flux Comparisons with ^{226}Ra Concentrations in Surface and Subsurface Soils

Objective

We will examine the degree of correlation that exists between radon fluxes and ^{226}Ra concentrations in surface and subsurface soil to determine whether average radon fluxes can be predicted from measurements of ^{226}Ra concentrations in soil and whether detection and delineation of subsurface deposits of ^{226}Ra can be enhanced by the use of radon-flux measurements at the soil surface.

Accomplishments During Past Quarter

Correlations between radon-flux measurements, gamma-exposure-rate measurements, and ^{226}Ra concentration measurements in soil made in Edgemont, South Dakota have been completed. The first-draft copy of the status report, Comparison of Radon Fluxes with Gamma-Ray-Exposure Rates and Soil ^{226}Ra Concentrations, has been completed. Conclusions presented in the report include the following: correlations between fluxes and ^{226}Ra concentrations measured in shallow boreholes were lower than those between fluxes and exposure rates, indicating that exposure rates are better than ^{226}Ra measurements for detecting elevated radon fluxes from near-surface deposits. Measurements made on one property at two different times indicated that if the average flux were determined from a large number (40) of measurements at one time, the average flux at a later time could be estimated from a few estimates using the assumption that the change in the flux at individual locations will be equal to the change in the average flux.

Projected Work for Next Quarter

The status report mentioned above will be completed and submitted to the NRC.

REPORTS ISSUED DURING THE QUARTER

None.

TASK 7. TECHNICAL PROGRAM MANAGEMENT

Project Manager: M. G. Foley
Principal Investigators: M. G. Foley
G. W. Gee

FIN B-2370 (Task 7)

OBJECTIVE

This task provides the program management function of all the uranium recovery waste management studies contracted to PNL from the Waste Management Branch, NRC-RES. The principal functions of Program Management are to coordinate the efforts of scientists and engineers assigned to tasks, prepare and issue quarterly technical and administrative reports, maintain an awareness of uranium waste research by others, schedule and arrange local and external research reviews, and carry out related management functions.

ACCOMPLISHMENTS DURING THE PAST QUARTER

The program manager is the principal point of contact between the PNL technical team and NRC-RES project and task managers, and must ensure that PNL work addresses the research needs of the NRC; that NRC is kept informed of PNL progress as well as final products; and that all deliverables provided to NRC have been properly reviewed. Specific activities over the past quarter to accomplish this task are listed below.

- Submitted a revised 189 for FY-84 for B-2370 in November, based on NRC comments and changes in program direction and scope.

- Submitted a revised 189 for project B-2379 (Methods for Minimizing Ground-Water Contamination In *In Situ* Leach Uranium Mining).

- Assisted in transfer of project B-2292 (Leachate Assessment) to support by LLW for FY84.

- Arranged and participated in an NRC review of the uranium recovery research program at PNL in October.

- Reviewed the drafts and final documents of the reports produced by the uranium recovery program (listed elsewhere in this report).

- Prepared and submitted 3 monthly administrative reports.

International Activities

Canadian Mill Tailings Program

G. W. Gee met with Dr. John Cherry (U. of Waterloo) and exchanged reports on Uranium Mill Tailings research. A draft of Dr. Cherry's report on sampling uranium mill tailings was reviewed and will be useful for the Leachate Assessment (B2292) field effort and also helpful in planning the Neutralization (Task 4) field study. Plans also have been made to visit with Mr. Vic Haw, director of the Canadian National Uranium Tailings Program, prior to or during the February, 1984 Uranium Mill Tailings Symposium in Fort Collins, Colorado, as a follow-up to our visit with him in Ottawa in September.

IAEA Participation

Travel plans have been approved for G. W. Gee to be the U.S. representative and to attend the Coordinated Research Program meeting of the International Atomic Energy Agency (IAEA) in Brazil in February, 1984. The IAEA is covering the travel costs for Dr. Gee to attend this meeting. The NRC has a no cost-research agreement with the IAEA, allowing information exchange on research related to contaminant migration from uranium mill tailings. The workshop type meeting will allow exchange of current research from Argentina, Australia, Brazil, Canada, Czechoslovakia, India, Japan, and the U.S.

NEA-Monograph

The Nuclear Energy Agency (NEA) has requested that PNL participate in preparing a monograph in the Geochemistry of Uranium Mill Tailings; Dr. A. B. Muller (Paris) is coordinating the effort. A meeting was held in Golden, Colorado November 20-21, 1983 to outline the monograph and set a production schedule. Dr. J. Evans (Australia), Dr. J. Cherry (Canada), Dr. D. Longmuir (USA) and Dr. G. Gee (USA) along with Dr. Muller will be the major contributors. Scheduled completion of the monograph will be December, 1984.

PROJECTED WORK FOR NEXT QUARTER

In addition to managing the technical and budgetary schedules, and submitting periodic administrative and technical progress reports, the program manager will ensure that:

- The status of uranium recovery waste technology will be addresed, and short-term and long-term research needs determined so that the PNL program properly meets the needs of NRC-RES or addresses the impact of changing regulatory requirements on research needs if beyond the scope of the present program.

- Continuing reviews of PNL work by internal and external peer reviewers and by NRC will be arranged and conducted.

REPORTS ISSUED DURING THE QUARTER

Foley, M. G. et al. 1983. Uranium Recovery Research Sponsored by the Nuclear Regulatory Commission at Pacific Northwest Laboratory: Annual Progress Report, June 1983 to September 1983. (PNL-4608-3), Pacific Northwest Laboratory, Richland, Washington.

ATTENUATION OF RADON EMISSION FROM URANIUM MILL TAILINGS

Project Manager: N. A. Wogman
Principal Investigator: D. R. Kalkwarf
Support Investigators: V. C. Rogers and K. K. Nielson (Rogers and Associates Engineering Corporation) RAE

FIN B-2269

OBJECTIVE

In this project we will define uniform methods for determining the thickness of soil cover material needed to meet radon flux limits (as specified in connection with the final GEIS on uranium milling), and design methods for measuring the effectiveness of the soil cover after it is emplaced. These methods will be used to develop a NRC regulatory guide.

ACCOMPLISHMENTS DURING PAST QUARTER

Task 8. Prepare a Handbook for Determining Radon Attenuation Cover Soils (RAE)

Objective

We are to prepare a handbook to guide engineers in the covering of uranium mill tailings piles with soil in order to reduce radon emission to prescribed levels.

Accomplishments During Report Period

An updated version of a A Handbook for the Determination of Radon Attenuation Through Cover Soils, NUREG/CR-2340, was prepared and retitled, Radon Attenuation Handbook for Uranium Mill Tailings Cover Design, NUREG/CR-3533. A draft of this document is currently undergoing peer and NRC review. A number of modifications have been suggested and are being incorporated.

Task. 10. Validate Calculated Radon Attenuation Values for Soils Covering Large Areas of Tailings

Objective

We are to validate radon attenuation values, calculated by methods described in the revised engineering handbook, for large areas of tailings.

Accomplishments During Report Period

Methods described in the current draft of "the Handbook" were found to generate conservative estimates for the thickness of earthen covers needed to attenuate radon flux to prescribed levels at the UMPTRAP site, Grand Junction, Colorado. A document describing these results will be completed after final versions of "the handbook methods" are established.

Task 12. Prepare a Regulatory Guide for Determining Radon Attenuation by Cover Soils (RAE)

Objective

We are to prepare a document in the format of an NRC Regulatory Guide which specifies acceptable methods for covering uranium-mill tailings with soil to reduce radon flux to within prescribed limits.

Accomplishments During Report Period

A draft of this document is currently undergoing peer and NRC review.

PROJECTED WORK FOR NEXT QUARTER

This project was scheduled for completion in CY-83. The following products will be delivered to NRC as soon as agreement is reached on their scope.

1) A camera-ready copy of Radon Attenuation Handbook for Uranium Mill Tailings Cover Design.

2) A camera-ready copy of a topical report describing tests of the validity of handbook methods using data collected at the Grand Junction site.

3) A camera-ready copy of a draft regulatory guide for determining radon attenuation by cover soils.

REPORTS ISSUED THIS QUARTER

None.

ASSESSMENT OF LEACHATE MOVEMENT FROM URANIUM MILL TAILINGS

Project Manager: S. R. Peterson
Principal Investigators: R. J. Serne
W. J. Martin
S. R. Peterson
M. E. Dodson
Support Investigators: M. J. Mason
G. W. Gee
B. E. Opitz
R. L. Erikson

FIN B-2292

OBJECTIVE

Within this program we will develop experimental and computer modeling tools to assess the long-term environmental impact of leachate movement from uranium mill tailings and commercial low level waste.

ACCOMPLISHMENTS DURING PAST QUARTER

Task 1. Project Management

S. R. Peterson was invited to participate in and present a paper at the annual NRC geochemistry review in Reston, Virginia. The presentation was entitled "Geochemical Modeling: A Case Study." This paper dealt with the methodology we have developed for investigating the chemical interactions of acidic solutions with sediments.

A paper was also prepared for future inclusion in a NUREG document. This paper illustrated how geochemical modeling can be used, in parallel with characterization data for sediments from field and laboratory experiments, to derive a composite description of the solution/sediment interactions. The paper had the same title as the presentation described above and was mailed to the NRC in early December.

A new proposal was written for studying low-level waste sites because funding for this project was transferred from the Uranium Recovery to the Low-Level Program at NRC. The experimental and geochemical modeling tools that we are developing are considered applicable to other forms of waste and it is hoped that these tools will be utilized under the Low-Level Waste program.

A presentation was made to the Japanese Atomic Energy Research Institute on the modeling of radionuclide mobility.

Task 2. Laboratory Analysis and Experiments

The use of column experiments has been an integral part of research in the field of leaching hazardous waste materials. Through the course of time and numerous studies, many questions have developed concerning the validity of the results produced from column experiments. Some of these questions are: 1) How do the results of column experiments compare to those of batch experiments? 2) What is the appropriate column length to diameter ratio? 3) What effect does increasing solution contact time with the compacted column material have on effluent solution composition? 4) Can the trends resulting from smaller, laboratory scale column experiments be extrapolated to a field situation? We have designed experiments to try to answer some of these questions.

Leaching experiments were designed with various lengths and diameters. Leachate flow through the columns was from bottom to top to ensure complete column saturation. Synthetic ground water was used as a leachate. Two of the columns had the same length to diameter ratio (1 to 1) so that the only factor varying between the two columns was the volume. Other columns were constructed that had the same diameters but different lengths. The synthetic ground water was then passed through these columns after packing them with uranium mill tailings.

We will begin by discussing those leaching columns that had the same diameters but different lengths. Because the influent flow rate was the same for each of these columns the amount of time (residence time) the solution phase had to interact with the solid phase varied. Based upon the normalized effluent data, where concentration was plotted versus pore volumes of effluent, the columns of varying length and residence time show similar leach curves for macro cations. The similarity in the leach curves suggests that any readily soluble salts rapidly dissolve and reach equilibrium in time periods less than the shortest residence time used. Important trace metals such as arsenic (As), molybdenum (Mo), and selenium (Se) also show no differences in leach rates in the different columns. Furthermore, there were no differences in anions such as chloride and sulfate nor in the radionuclides measured.

Using total dissolved solids (TDS) as an overall parameter demonstrated that there was no significant difference in leaching rates. Therefore, the differences in column length and residence times had no effect on the leaching curves for the cations, anions, or radionuclides.

Next, we will discuss some preliminary results from the scaling experiments. For purposes of this report, the definition of scaling is considered to be the maintenance of a constant length-to-diameter ratio while increasing the overall size (volume) of the column. These columns were packed with uranium mill tailings and leached with synthetic ground water. The larger of the two columns studied had a pore volume approximately 4.6 times greater than the smaller column. For comparative purposes the flow rate was adjusted so that one pore volume of ground water passed through each column in the same amount of time.

The effluent concentrations between 0 and 1.5 pore volumes showed no differences in leaching patterns between the two sizes of columns for any of the solution constituents. There is a slight fluctuation in the column data sets between 1.5 and 4 pore volumes in all columns. We think that this small difference is a result of inconsistent mixing related to dead end pores or stagnant fluid. As the column effluent concentrations decrease in relation to the first effluent concentrations, the inconsistent contributions (mixing) from these dead end pores can significantly affect the effluent concentration curves. The variation in column packing could cause a difference in the number of dead end pores from column to column. After the fourth pore volume, the effluent concentrations of the various constituents are tailing off and begin approaching influent concentrations. Again, using total dissolved solids as a general parameter, the leaching trends followed the same general pattern for both columns indicating no significant effect on the leaching of constituents due to scaling.

There appears to be no effect on the effluent concentrations of the leaching columns due to differences in column lengths (residence time) or column volumes (scaling) caused by different diameter to length ratios. The results of these experiments provide a foundation for using column experiments as a valid technique in leaching uranium mill tailings and using those results in predicting long- and short-term movement of contaminants from tailings impoundments because of leaching due to migrating ground waters or rainfall.

Task 3. Geochemical Modeling

Ion-speciation and solid-phase solubility calculations have been extensively used to gain a better understanding of the geochemical processes controlling the chemical composition of natural waters. Several computer codes have been used to perform these calculations. Some of the more recent programs include MINEQL (Westall et al. 1976), PHREEQE (Parkhurst et al. 1980), WATEQ3 (Ball et al. 1981), and MINTEQ (Felmy et al. 1983). Several such computer programs have been successfully used to evaluate possible solid-phase controls on solution composition (Nordstrom et al. 1979, Gang and Langmuir 1974, Peterson and Krupka 1981, Peterson et al. 1982, and Deutsch et al. 1982). Geochemical modeling involving ion-speciation and solubility calculations (Peterson and Krupka 1981; Peterson et al. 1982) was used to verify if precipitation of solid phases in laboratory permeability columns was thermodynamically possible, and if so, what solids would be expected to precipitate. The results of the modeling efforts were then compared to mineralogical characterization studies performed on laboratory and field samples.

Little work, however, has been done in using geochemical computer codes to predict the aqueous phase compositions of solutions resulting from interaction with an assemblage of solid phases in a flow-through system. During such chemical interactions, one or more solid phases may dissolve and thermodynamically more stable solid phases precipitate as the solution composition changes. The new assemblage of solid phases can then be reacted with a new volume of influent solution and the process repeated.

A hypothesized assemblage of solid phases can be used to represent heterogeneous geologic materials, which are permitted to dissolve or precipitate in response to changes in the aqueous media. This conceptual model, in conjunction with the MINTEQ geochemical code, is then used to simulate the contact of a specified solution with these geologic materials. The resultant compositions of the aqueous phase and the change in mass of each solid phase in the assemblage are calculated as successive pore volumes of solution interact with the solid phase assemblage.

Aqueous/sediment interactions are extremely complex. Predictive geochemical modeling was effective in unraveling some of the predominant mechanisms controlling the concentrations of certain dissolved constituents. The geochemical modeling can be used to quantitatively evaluate: 1) the accuracy of theorized chemical models of complex aqueous/sediment interactions, and 2) the predominant reactions affecting the composition of the aqueous phase.

The precipitation/dissolution reactions considered in the conceptual model were capable of predicting the column effluent concentrations of several major constituents in the tailings solutions (e.g., SO_4, Ca, Al, Mn, and Fe; Peterson et al. 1983). Sulfate concentrations in the column effluents were generally one to two orders of magnitude above the secondary drinking water standards established by the U.S. Environmental Protection Agency. The conceptual model was able to predict these elevated concentrations. No solubility controls, however, were identified for the majority of the trace constituents. Many trace constituents appear to be controlled by adsorption on and/or coprecipitation with ferric oxyhydroxide solids (Serne et al. 1983). More work, namely incorporation of trace metal adsorption reactions, is necessary to predict the migration of other contaminants from uranium mill tailings solutions. The geochemical modeling approach coupled with laboratory and field studies should be applicable to a variety of waste disposal problems, including low level waste.

Task 4. Field Study

Additional data were collected from the Federal American Partners mine in Gas Hills, Wyoming. Analyses were completed on the data collected in the July, 1983 sampling trip.

Speciation and solubility modeling was begun on the available well data. Data were available from seventeen wells. As the solubility and speciation modeling are completed on specific wells these data are being compiled in tables to facilitate determination of possible solubility controls and important mechanisms controlling contaminant migration.

PROJECTED WORK FOR NEXT QUARTER

Continued analysis of the data obtained from the scaling and residence time experiments will continue. Additionally, the concentrations of contaminants in the effluent solutions from permeability cells packed with coarse overburden materials and leached with acidic tailings solution will be determined. These data will be modeled and compared to modeling results obtained when clay materials were leached with the same acidic solutions.

Additional characterization of sediments using techniques such as electron microprobe analysis, x-ray fluorescence and scanning electron microscopy will be performed on the field samples that were collected at the Pathfinder (Lucky Mc) evaporation pond. The additional characterization techniques would: 1) allow trace element profiles to be identified, and 2) provide insight into how and with what minerals and solid phases the trace elements tend to be associated.

Speciation and solubility modeling will also be continued on the field site. The results from the speciation and solubility modeling will be used to form conceptual chemical models. We will begin to narrow down these models by using the BALANCE computer code (Parkhurst, D. L., 1982) to narrow down the possible conceptual models.

REFERENCES

Ball, J.W., E.A. Jenne, and M.W. Cantrell. 1981. WATEQ3: A Geochemical Model with Uranium Added. U.S. Geol. Survey, Open File Report 81-1183.

Deutsch, W.J., E.A. Jenne, and K.M. Krupka. 1982. "Solubility Equilibria in Basalt Aquifers: The Columbia Plateau, Eastern Washington, U.S.A." Chemical Geology 36:15-34.

Felmy, A.R., D.C. Girvin, and E.A. Jenne. 1983. MINTEQ: A Computer Program for Calculating Aqueous Geochemical Equilibria, EPA-68-03-3089 (Draft).

Gang, M.W., and D. Langmuir. 1974. "Controls on Heavy Metals in Surface and Ground Waters Affected by Coal Mine Drainage: Clarion River-Redbank Creek Watershed, Pennsylvania." In Proceedings of Fifth Symposium on Mine Drainage Research, pp. 3963. Coal and the Environment Technical Conference, October 22-24, 1974.

Nordstrom, D.K., E.A. Jenne, and J.W. Ball. 1979. "Redox Equilibria of Iron in Acid Mine Waters." In Chemical Modeling In Aqueous Systems. E.A. Jenne (Ed.), ACS Symposium Series No. 93:51-79.

Parkhurst, D.L., D.C. Thorstenson, and L.N. Plummer. 1980. PHREEQE - A Computer Program for Geochemical Calculations. U.S. Geological Survey, Water Resources Investigations 80-96, 210 pp.

Parkhurst, D.L., L.N. Plummer, and D.C. Thorstenson. 1982. BALANCE - A Computer Program For Calculating Mass Transfer for Geochemical Reactions in Ground Water. U.S. Geological Survey, Water Resources Investigations, 82-14, 29 pp.

Peterson. S.R., and K.M. Krupka. 1981. "Contact of Clay Liner Materials with Acidic Tailings Solution. II. Geochemical Modeling." In Uranium Mill Tailings Management, Proceedings of the Fourth Symposium on Uranium Mill Tailings Management, Colorado State University, Fort Collins, Colorado, pp. 609-626, October 26-27.

Peterson, S.R., R.L. Erikson, and G.W. Gee. 1982. The Long-Term Stability of Earthen Materials in Contact with Acidic Tailings Solutions. NUREG/CR-2946 Nuclear Regulatory Commission, Washington, D. C.

Peterson, S.R., A.R. Felmy, R.J. Serne, and G.W. Gee. 1983. Predictive Geochemical Modeling of Interactions Between Uranium Mill Tailings Solutions and Sediments in a Flow-Through System. NUREG/CR-3404, Nuclear Regulatory Commission, Washington, D. C.

Serne, R.J., S.R. Peterson, and G.W. Gee. 1983. Laboratory Measurements of Contaminant Attenuation of Uranium Mill Tailings Leachates by Sediments and Clay Liners. NUREG/CR-3124, Nuclear Regulatory Commission, Washington, D. C.

Westall, J.C., J.L. Zachary, and F.M.M. Morel. 1976. MINEQL: A Computer Program for the Calculation of Chemical Equilibrium Composition of Aqueous Systems. Tech. Note 18, Dept. Civil Eng., Massachusetts Institute of Technology, Cambridge, Massachusetts.

METHODS OF MINIMIZING GROUND-WATER CONTAMINATION FROM IN-SITU LEACH URANIUM MINING

Project Manager: W. J. Deutsch
Principal Investigators: W. J. Deutsch
R. J. Serne
Support Investigators: W. J. Martin
D. R. Sherwood

FIN B-2379

OBJECTIVE

In this study we evaluate in-situ uranium mining operations and restoration procedures and provide information to help NRC establish regulatory guidelines for the environmentally sound operation and abandonment of these mines. We evaluate existing production/restoration procedures and assess the potential for deleterious hydrogeochemical alterations resulting from lixiviant excursions and ore-zone mining.

ACCOMPLISHMENTS DURING PAST QUARTER

Task 1. Project Management

During the past quarter a letter progress report (PNL-4924) describing the recent field work and laboratory experiments was written and submitted to NRC. Portions of the work completed during the first quarter of FY84 are summarized in this quarterly report.

The document, Ground Water Restoration Requirements, Techniques, and Practices at In-Situ Leach Uranium Mines, NUREG/CR-3104, PNL 4583) has been revised and retitled to reflect the changes made in the report. The document has been returned to NRC for publication under the title, Aquifer Restoration Techniques for In-Situ Leach Uranium Mines.

Task 2. Site Characterization

In October, 1983, we returned to the North Platte, Wyoming ISL facility operated by Uranium Resources, Inc. (URI) to obtain ground-water samples. These ground-water samples were necessary to complete our characterization of the Wyoming roll-front deposit from which we had obtained core samples in August, 1983.

In order to properly sample the wells, we constructed a flow-through pumping system that allowed us to monitor certain solution parameters (pH, Eh, temperature, and electrical conductivity) that would indicate to us when ground water representative of the aquifer was being pumped from a well and a sample could be taken for analysis. Initially, we had planned to use a pump/packer system to isolate the screened interval in the well from the water standing in the well bore above the screen. This system would have allowed us to take a representative sample of the ground water entering the resin, and is, in turn, added to the lixiviant as the pregnant solution flows through the exchange columns and uranium carbonate complexes exchange for chloride on the resin. As can be seen in Table 1, this process has enhanced the chloride concentration in the lixiviant by 23 times compared to the amount in typical ground water from the Wyoming ore zone aquifer. Chloride is not normally removed from solution by water/sediment interactions and should be an excellent indicator of an excursion in this system. The sulfate concentration increases less than twice due to the leaching operation and would probably not be a good excursion indicator at this site. Alkalinity increases by about 4 times but is subject to various water/sediment interactions that might affect its concentration making it less desirable as a detection parameter. The difference in total dissolved solids (TDS) level between the ground water and lixiviant is also about 4 times. Although precipitation/dissolution of solids as the lixiviant reacts with sediments of the aquifer would affect the TDS, the TDS level in the lixiviant should remain significantly different from that in the ground water for an appreciable distance away from the leach zone. The TDS level can be easily monitored by measuring the electrical conductivity of the solution, and this parameter is recommended, along with chloride concentration, as an excursion indicator at the North Platte mine site.

Task 3. Natural Restoration Processes

The results of the batch experiment in which leached ore and reduced sediment from the Benavides leach mine were reacted with lixiviant were described in detail in the November letter progress report. The conclusions of the report are summarized in the following two paragraphs.

The objective of the batch experiment was to determine the impact on solution composition of storing lixiviant in contact with aquifer sediments for a relatively long period of time (up to 3 months). It was shown that chemical reactions between the lixiviant and the sediment would lead to temporary increases in the calcium, sulfate, and iron concentrations of the solution, but that over the period of a month the iron concentration would decrease due to reduction of ferric iron to ferrous iron and precipitation of less soluble ferrous iron sulfides. The calcium and sulfate solution concentrations would decreased due to ion exchange and possibly by dilution on mixing with ground water outside the leach zone. The gypsum precipitate would dissolve and be removed as new ground water moved into the leached ore zone. Sorption would cause an initial decrease in the uranium concentration, which would be lowered further as reducing conditions were reestablished in the aquifer and relatively insoluble U(IV) minerals precipitated from solution.

The batch experiment may adequately simulate what would happen if residual lixiviant were left in the spent ore zone after leaching. However, column experiments conducted previously with reduced sediment probably more closely simulate the situation where lixiviant moves naturally out of the ore zone in response to the hydrologic gradient. The lixiviant encounters sediments containing reduced minerals (principally sulfides) that react with the solution removing oxygen, lowering the pE, and producing metallic oxyhydroxides. The uranium would be strongly adsorbed by the oxyhydroxides. and

	Benavides, TX Ore Zone Aquifer Ground Water[a]	North Platte, WY Ore Zone Aquifer Ground Water[b]	North Platte, WY Lixiviant Composition Well P-1[c]	Ratio of Lixiviant to Mean Ore Zone Ground Water Composition at North Platte, WY Site
Ca	25.9	17	138	8.1
Mg	9.6	6.5	42	6.5
Na	486	89	365	4.1
K	15.2	4	12	3.0
Cl	677	6.1	140	23
SO_4	71.1	126	229	1.8
Alk (as $CaCO_3$)	142	152	620	4.1
Si	8.4	4.2	11.5	2.7
pH, std units	8.53	8.47	6.7	0.8
U	0.17	0.004	18.2	4,550
TDS	1435	439	1713	3.9

(a) From Table 7 and 8 of Deutsch et al. 1983.
(b) Mean values computed for wells M-1 through M-6 of Deutsch et al. 1983.
(c) Table 10, Uranium Resources Inc., North Platte Technical Report. Volume II: Restoration and Stage II Forecast, April 1983.

TABLE 1. Mean Composition of Ground Waters and Lixiviant Samples at Texas and Wyoming ISL Uranium Mines. (All concentration units are mg/L.)

ultimately reduced to U(IV) and incorporated in a secondary mineral. A new, smaller or weaker ore zone would form downgradient from the initial one in response to the same types of processes that produced the original roll front. Considering primarily the redox-sensitive ground-water constituents, the aquifer can probably restore itself as a result of interactions between the lixiviant and the sediments.

A column experiment designed to evaluate the potential for natural restoration at the North Platte, Wyoming mine site was started during December, 1983. In the experiment synthetic lixiviant is pumped through columns of reduced sediment obtained by coring downgradient from the roll in the ore zone aquifer. Synthetic lixiviant is used because actual process solution is not available (the pilot plant is not operating at this time). The composition of the synthetic lixiviant is very similar to that of the solution pumped from the production well at North Platte during operation of the plant. The results from this experiment should be available by February, 1984.

Task 4. Induced Restoration Techniques

During the past quarter, the effects of ground-water sweeping on aquifer restoration have been evaluated with a set of column experiments. In these experiments, columns containing leached ore from the Benavides, Texas mine were saturated with weak lixiviant (U = 3 ppm) that was spiked with the common leach-generated contaminants arsenic (4.8 ppm), selenium (4.1 ppm), and molybdenum (5.0 ppm). Spiked lixiviant was pumped through each column until more than 2 pore volumes had contacted the sediment. The column influent solution was then changed from lixiviant to ground water collected at the Texas site. The ground water was pumped through the columns to simulate sweep-induced restoration of the aquifer. The entire experiment was conducted in an anoxic chamber to approximate the reduced oxygen fugacities of the ore-zone environment.

Effluent samples from each column were analyzed for macro-cations, anions, alkalinity, pH, Eh, arsenic, selenium, molybdenum, and uranium. The sediment samples were analyzed by x-ray diffraction for mineralogy and x-ray fluorescence for bulk chemistry.

Initial results of these analyses indicate that a variety of mechanisms control the migration of chemical constituents during ground-water sweeping. The effluent samples collected during lixiviant contact have more than three times the total dissolved solids concentration of the influent solution. Sulfate, calcium, carbonate, and uranium are the primary constituents elevated in concentration in the effluent relative to the influent solution. Oxidation and dissolution of pyrite may account for the high sulfate concentration in the effluent, while dissolution of calcite would increase both the calcium and carbonate concentrations. Both pyrite and calcite have been identified as minor constituents of the sediment used in the experiment. After seven pore volumes of ground water had been pumped through the leached ore sediment, the concentrations of sulfate, calcium, and carbonate approach influent values, whereas the uranium concentration remained high. Uranium continued to elute from the leached ore through the twelfth pore volume. Peak uranium concentrations in the effluent exceeded 100 ppm during the first pore volume of lixiviant contact. During sweeping with ground water, uranium concentration was reduced from 40 ppm to 3.4 ppm by the twelfth pore volume. This response of uranium concentration to ground-water sweeping is probably due to leaching of residual uranium minerals in the sediment.

Arsenic, selenium, and molybdenum exhibited considerably different mobilities during ground-water sweeping of the leached ore. The arsenic concentration in the spiked lixiviant was 4.8 ppm; however, the amount in the effluents from both columns was always below detection limits (0.015 ppm). The concentration of selenium in the effluent never approached the influent concentration (4.1 ppm) of the spiked lixiviant. Initial selenium concentrations in the effluents were below our detection limit of 0.020 ppm, but the selenium concentration did increase somewhat after ground-water sweeping had begun. The peak selenium concentration (0.15 ppm) eluted after ten pore volumes of ground water contact and the concentration remained in excess of 0.14 ppm until the end of the experiment at twelve pore volumes. Molybdenum appeared to be the most mobile of the three contaminants added to the lixiviant. The concentration of molybdenum in the lixiviant was 5.0 ppm and its effluent concentration reached 3.5 ppm during lixiviant contact. The amount of molybdenum in the effluents was reduced to background (0.2 ppm) after 10 pore volumes of ground-water sweeping.

The preliminary results of our experiments on ground-water sweeping have shown that, if residual uranium ore is present in the leached zone at the completion of mining, restoration of the aquifer for uranium may be inhibited due to slow, long-term oxidation of the uranium minerals during ground-water sweeping. The mobility of other redox-sensitive contaminants such as arsenic, selenium, and molybdenum may be reduced significantly due to water/sediment interactions and this will enhance restoration for these elements.

The experimental study evaluating chemical reductants as an aid to aquifer restoration was curtailed during the last quarter to allow us to complete sampling at the Wyoming mine site and perform the initial natural restoration experiments with the Wyoming materials. The work on chemical reductants will be the prime focus of laboratory work for the remainder of this fiscal year.

PROJECTED WORK FOR NEXT QUARTER

Additional characterization work will be completed on the sediments collected at the Wyoming roll front deposit. This will include separation and the identification of the minerals with a density greater and less than 2.9 gm/cc in the sediment, and the determination of the amount of ferric oxides and pyrite in the sediment. We hope to determine which phase(s) the uranium is associated with in the sediment. Additionally, we will continue laboratory studies of chemical reductants as aids to aquifer restoration. We will concentrate on the two reductants sodium sulfide and sodium sulfite. A survey of mine operators who have used surface treatment restoration techniques such as reverse osmosis and electrodialysis will commence next quarter.

REPORTS ISSUED DURING QUARTER

Duetsch, W. J., W. J. Martin, B. M. Sass, and R. J. Serne. 1983. Status of Field Work and Laboratory Experiments on Aquifer Restoration Following In Situ Leach Uranium Mining, letter progress report, PNL-4924, Pacific Northwest Laboratory, Richland, Washington.

REFERENCE

Deutsch, W. J., R. J. Serne, N. E. Bell, and W. J. Martin. 1983. Aquifer Restoration at In Situ Leach Uranium Mines: Evidence for Natural Restoration Processes NUREG/CR-3136 (PNL-4506) U. S. Nuclear Regulatory Commission, Washington, D.C.

APPENDIX A

STATUS OF MEASUREMENTS OF URANIUM MILL TAILINGS CONSOLIDATION CHARACTERISTICS

STATUS OF MEASUREMENTS OF URANIUM MILL TAILINGS CONSOLIDATION CHARACTERISTICS

T. W. Schrauf

INTRODUCTION

Laboratory measurements are currently in progress to measure the consolidation characteristics of slurried uranium mill tailings. The laboratory equipment and test procedures used to make these measurements are discussed here. Additionally, preliminary results of the measurements made to date are presented and discussed.

OBJECTIVES

The principal objective of the experiments discussed is to provide input data for use in computer modeling of uranium mill tailings consolidation. In addition to providing realistic input parameters for computer modeling efforts, the ability of the model to duplicate the measured sample consolidation behavior can be evaluated. The need to generate experimental data on uranium mill tailings results from the currently limited data base existing for these materials, particularly with regard to unsaturated conditions. Use of existing data is also complicated by certain contradictions and lack of detail in published results.

For saturated consolidation studies, both void ratio and permeability of the soil are measured as functions of effective stress. The dimensionless void ratio, defined as the ratio of the void volume (pore space) to the solid (soil particle) volume within a representative elementary volume of soil, is used to determine the soil volume at a given effective stress. The soil permeability is used to determine the time rate at which excess pore water pressure dissipates and hence effective stress increases following application of a given total stress. Soil permeability can either be measured directly or calculated from the observed time rate of soil consolidation. It is important to note that for many soils void ratio is not strictly a function of effective stress but also a result of time-dependent strain behavior. Such time-dependent behavior is often referred to as secondary consolidation, which increases both the amount of and time required to reach total consolidation.

For unsaturated conditions, void ratio and saturation of the soil are measured as functions of the stress state variables $(\sigma - p_a)$ and $(p_a - p_w)$ where σ is the total stress, p_a is the pore air pressure, and p_w is the pore water pressure. Unique void ratio and saturation surfaces can be defined in terms of these two stress-state variables provided the stress path is such that saturation increases or decreases monotonically from initial conditions (Matyas and Radhakrishna, 1968; Fredlund and Morgenstern, 1976). The dimensionless sample saturation is defined as the ratio of water-filled void volume to total void volume. The tests discussed here are conducted under conditions of decreasing saturation. As for the saturated consolidation studies, void ratio is used to determine the soil volume for given values of the stress-state variables. Sample saturation is used to calculate the sample permeability and hence to determine the time rate of unsaturated consolidation. Due to the relatively slow rates of sample desaturation, time-dependent strain behavior is generally of lesser consequence than for saturated consolidation studies.

LABORATORY PROCEDURES

Two separate types of consolidometers were used for the saturated and unsaturated consolidation tests. Because of the differences in both the equipment and methodology, the saturated and unsaturated consolidation tests are given separate discussions.

Saturated Consolidation Tests

Saturated consolidation tests have been conducted for several decades and hence test equipment and procedures are well standardized and documented in nearly any soil mechanics text. The tests discussed herein were conducted with a fixed-ring consolidometer, as shown in Figure 1.

Description of Device

The fixed-ring consolidometer consists of a sample base and two rings and holds a cylindrical sample. The inner ring provides lateral confinement (zero radial strain) to the sample, while the outer ring forms a reservoir submerging the sample to maintain saturation. The base provides two outlets that are hydraulically connected to the sample base. One outlet is connected to a falling head permeameter for direct-sample permeability measurements while a second is connected to an overflow reservoir. Two porous stones butt against the loaded faces of the sample, permitting free pore drainage during consolidation. While the lower surface is fixed, the upper porous stone, backed by a rigid loading plate, moves downward under load to compress or consolidate the sample. Samples are 11.3 cm in diameter and up to 3.8 cm in height.

Loads are applied to the sample using a system of weights and levers. This loading system provides a very constant load pressure over a long period of time, although it is sensitive to vibrations in the laboratory. While such vibrations cannot be controlled, they are generally of minor importance.

Changes in sample height are measured to determine the sample volume under applied loads. Two methods are employed. First, the sample height is measured indirectly by measuring the height of the upper loading plate surface above the inner ring. To account for tilting of the loading plate during the test, two measurements are made 180° apart on the edge of the plate and averaged to determine the true mean sample height. This direct measurement is added to the height of the upper ring to determine the sample height

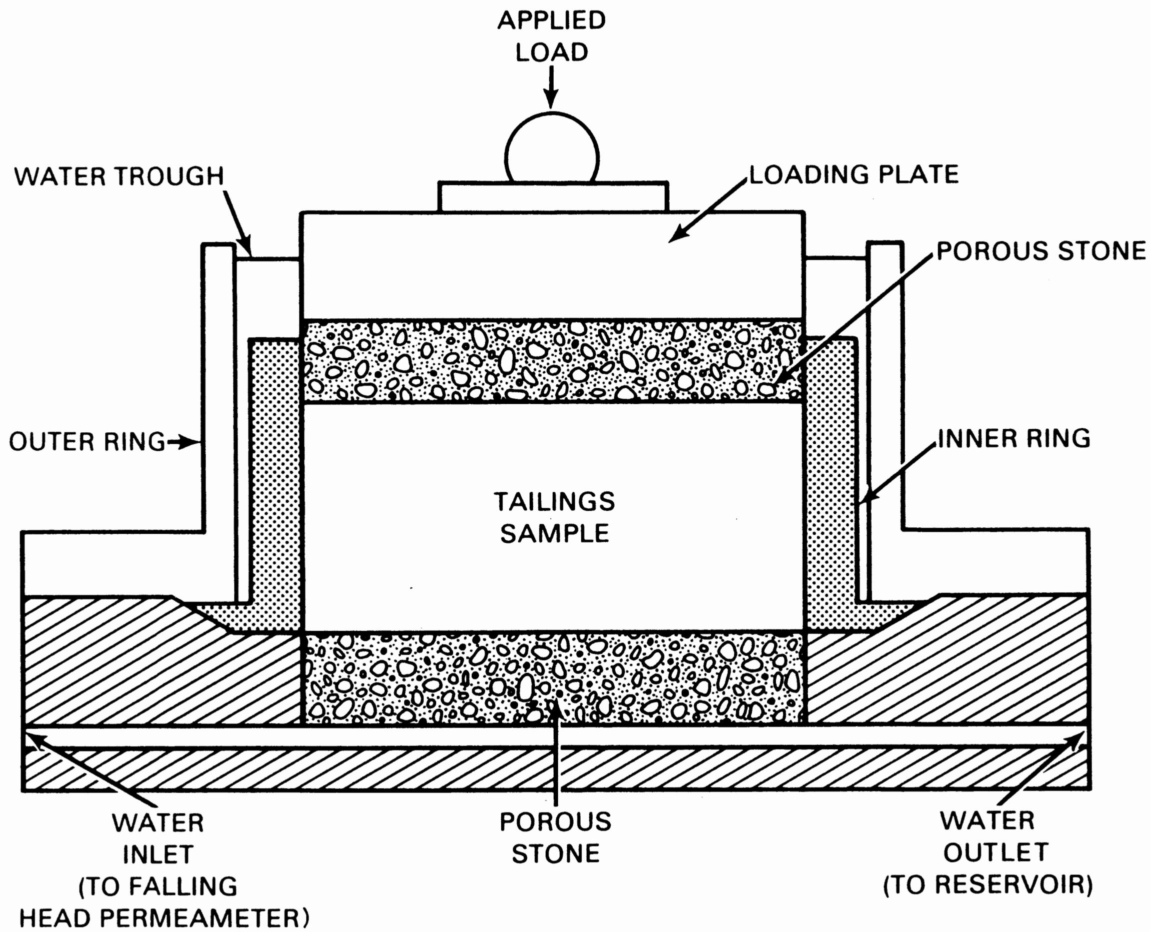

FIGURE 1. Fixed-Ring Consolidometer

plus the combined thickness of the upper porous stone and loading plate. Subtracting the latter yields the true sample height. Changes in sample height can also be measured directly from a dial gage mounted over the center of the upper loading plate and attached to the consolidometer base. While the dial gage has a greater precision (2.5 μm or 0.0025 mm) than the direct measurement (25 μm or 0.025 mm), both are employed as a check.

Sample Preparation

To simulate field conditions of tailing emplacement by sedimentation, the sample is emplaced in a very loose initial state. For tailings slimes, this is achieved by creating a liquid slurry consisting of two parts tailings to three parts distilled water by weight. The mixture is dispersed in a high-speed blender and then poured into the inner ring of the consolidometer. The sample is then left to stand for 24 hours to allow for sedimentation. Due to their rapid rate of sedimentation, tailings sands are emplaced differently. The inner ring of the consolidometer is filled with water and the sands added slowly in a dry state until a suitable sample height is attained.

Test Procedure

Following sample emplacement, the consolidometer is capped with the upper porous stone and loading plate and installed in the loading frame. An initial sample height is then measured and a load increment applied. Changes in the sample height, as read from the dial gage, are recorded versus elapsed time with time between readings increasing with elapsed time. As displacement varies approximately as the square root of time, initially, readings are typically taken at 0.09, 0.25, 0.49, 1.0, 2.25, 4.0, 6.25, 9.0, 16.0, 25.0, 36.0 minutes, etc., following each load application. This process is continued until the rate of displacement decreases drastically. Tailings slimes were generally observed closely for about 2 hours, while tailings sands required only about 30 minutes. A few additional readings are taken thereafter for a minimum period of about 24 hours. Some tests were run for 48 to 72 hours to better evaluate secondary consolidation effects while others were run for several days due to interruptions of the testing schedule. The test is then repeated by doubling the existing applied load pressure. The smallest applied load pressure is 0.1 kg/cm^2 and the largest 12.8 kg/cm^2.

Sample permeability is occasionally measured at the end of a load increment test using the falling head permeameter.

Upon completion of the last load increment test, the sample is removed from the consolidometer, weighed, oven dried for 24 hours, and reweighed. Approximately 10 g of the sample are then used to determine particle density. These data are necessary to determine the void ratio and final saturation from the measured sample volume change data.

Unsaturated Consolidation Test

In contrast to saturated tests, unsaturated tests have been conducted by only a few experimenters. The majority of such tests have been conducted using a modified triaxial test apparatus. Triaxial tests have the advantage of permitting three-dimensional deformation since the zero radial strain boundary is replaced by a constant radial stress boundary. For a slurried sample, however, a rigid radial boundary is necessary to support the sample owing to its lack of structure. A Rowe consolidometer (Rowe and Barden, 1966) was modified to conduct the unsaturated tests discussed here. This device is similar to the device used previously by Sherry (1982) to measure unsaturated consolidation of uranium mill tailings.

Description of Device

A diagram of the modified Rowe consolidometer used for these tests is shown in Figure 2. As with the fixed-ring consolidometer, a cylindrical sample is loaded axially with lateral confinement. Sample diameter is 25 cm and sample height is from 4 to 8 cm. The principal of operation is the same as for the fixed-ring consolidometer with the following differences. The vertical load is applied to the upper loading plate via a pressurized rubber diaphragm. As a consequence, the upper portion of the consolidometer is sealed off from the atmosphere. To permit free drainage of pore water through the upper porous plate, a connecting tube is provided. This tube also provides a convenient means of measuring sample displacement and height in a similar manner to that previously described for the fixed-ring consolidometer.

Further modifications of the Rowe consolidometer were required to adapt the device to unsaturated consolidation measurements. Foremost was the connection of a pore air pressure line. Positive pore air pressure is introduced through the central connecting tube to drive capillary water out through the consolidometer base. To facilitate drainage, a high air entry porous stone is place in the consolidometer base. A spiral groove connected to a central and peripheral outlet is used to remove air bubbles that diffuse through the porous stone.

External connections to the Rowe consolidometer are shown schematically in Figure 3. A pressurized air supply is connected to a pressure regulating manifold, which controls both the axial load and pore air pressures via regulators R_1 and R_2, respectively. When applying pore air pressure, one of the differential pressure regulators (D_1 or D_2) is employed. These regulators automatically increase the load pressure to compensate for the increasing pore air pressure and maintain a constant effective load pressure, $(\sigma - p_a)$.

A drainage loop connects to the Rowe consolidometer's grooved base and acts both to measure changes in sample water content and purge air from the loop. A peristaltic pump is used to circulate water through the loop without entrapping air bubbles to the system. The graduated pipette indicates changes in the system volume, traps air bubbles within the system, and vents

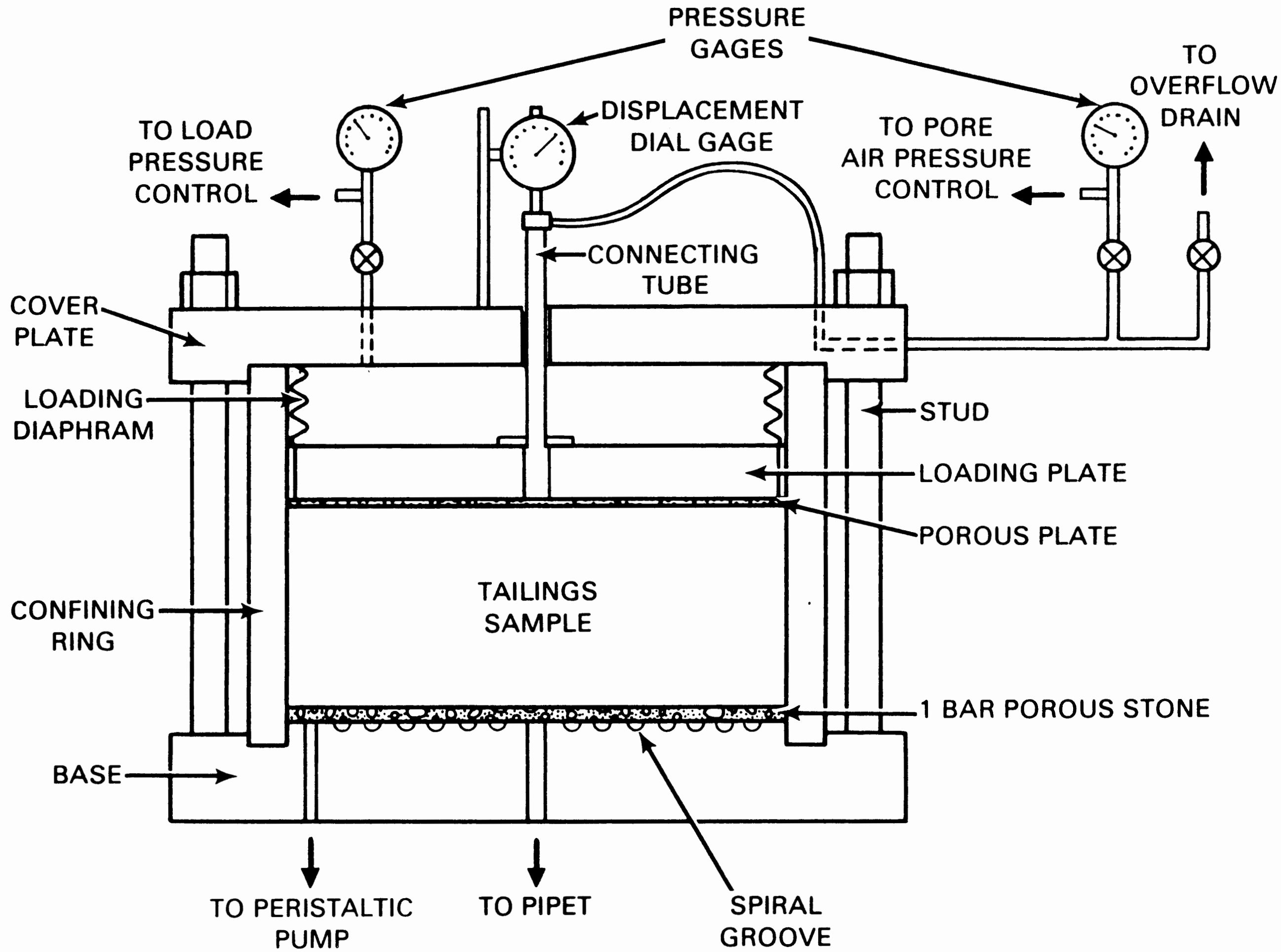

FIGURE 2. Modified Rowe Consolidometer

them. Excess water in the loop is bled off periodically to the overflow reservoir.

Sample Preparation

Sample preparation for the Rowe consolidometer is identical to that described previously for the fixed-ring consolidometer.

Test Procedure

Following sample emplacement, the sample height is measured directly, the upper piston and porous plate installed, and the loading diaphragm and cover plate bolted in place. One of the differential pressure regulators is then set to the maximum desired effective load pressure (σ-p_a). Regulator R_1 is subsequently used to control the load pressure, σ, under saturated conditions (p_a=0). A small seating pressure of about 0.2 kg/cm^2 is then applied to expand the loading diaphragm and seat the loading plate.

Once the system stabilizes, the initial height of the connecting tube, as referenced to the cover plate surface, is measured and the dial gage zeroed. A load increment is applied and dial gage readings are recorded in a similar fashion as described for the fixed-ring consolidometer. This process is repeated until the maximum effective load pressure is reached, at which point the differential regulator takes over control of the load pressure.

Time is allowed for the sample to fully consolidate at the maximum load pressure before desaturating. The peristaltic pump is also turned on at this time to purge air from the drainage loop. Initial readings are then recorded as before including the graduated pipette level. Desaturation is begun by increasing the pore air pressure via regulator R_2. The load pressure is automatically increased simultaneously to maintain a constant effective load pressure. Changes in sample height and pipette level are subsequently monitored until they stabilize. To accommodate water outflow and maintain a constant back pressure in the drainage loop, the pipette level is periodically lowered by releasing water to the overflow reservoir. Following stabilization, the pore air pressure is incremented and the process repeated. When the equilibration at the maximum applied pore air pressure is completed, the sample is removed and a new sample loaded.

In order to map out the void ratio surface as a function of the state variables (σ-p_a) and (p_a-p_w), each sample is consolidated under saturated conditions (p_a=p_w=0) to a different desired effective load pressure, (σ-p_a), and then desaturated. Values of the stress state variables (p_a-p_w) and (σ-p_a) for which void ratio values are to be determined are shown in Figure 4.

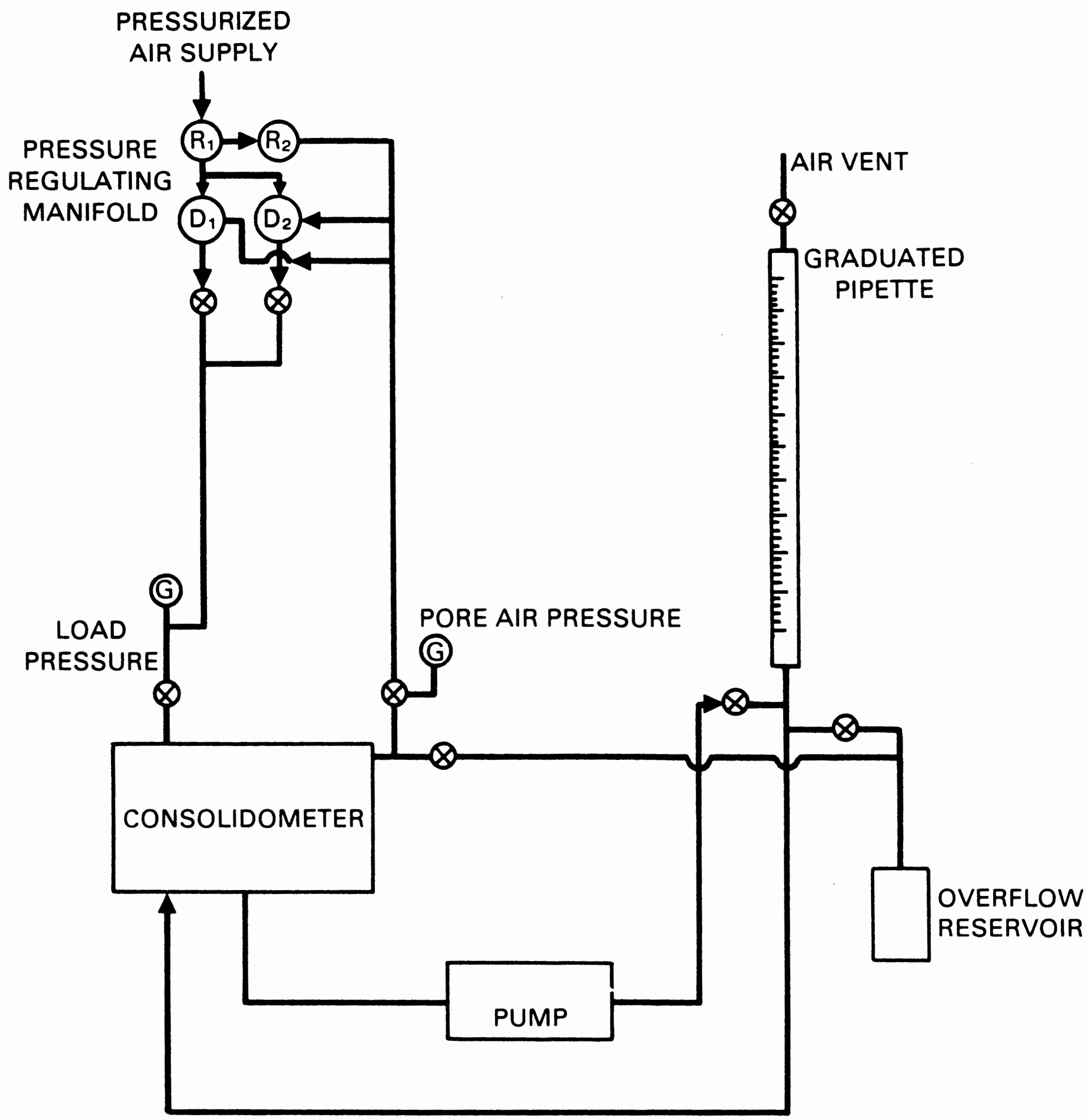

FIGURE 3. Schematic of External Components of the Modified Rowe Consolidometer

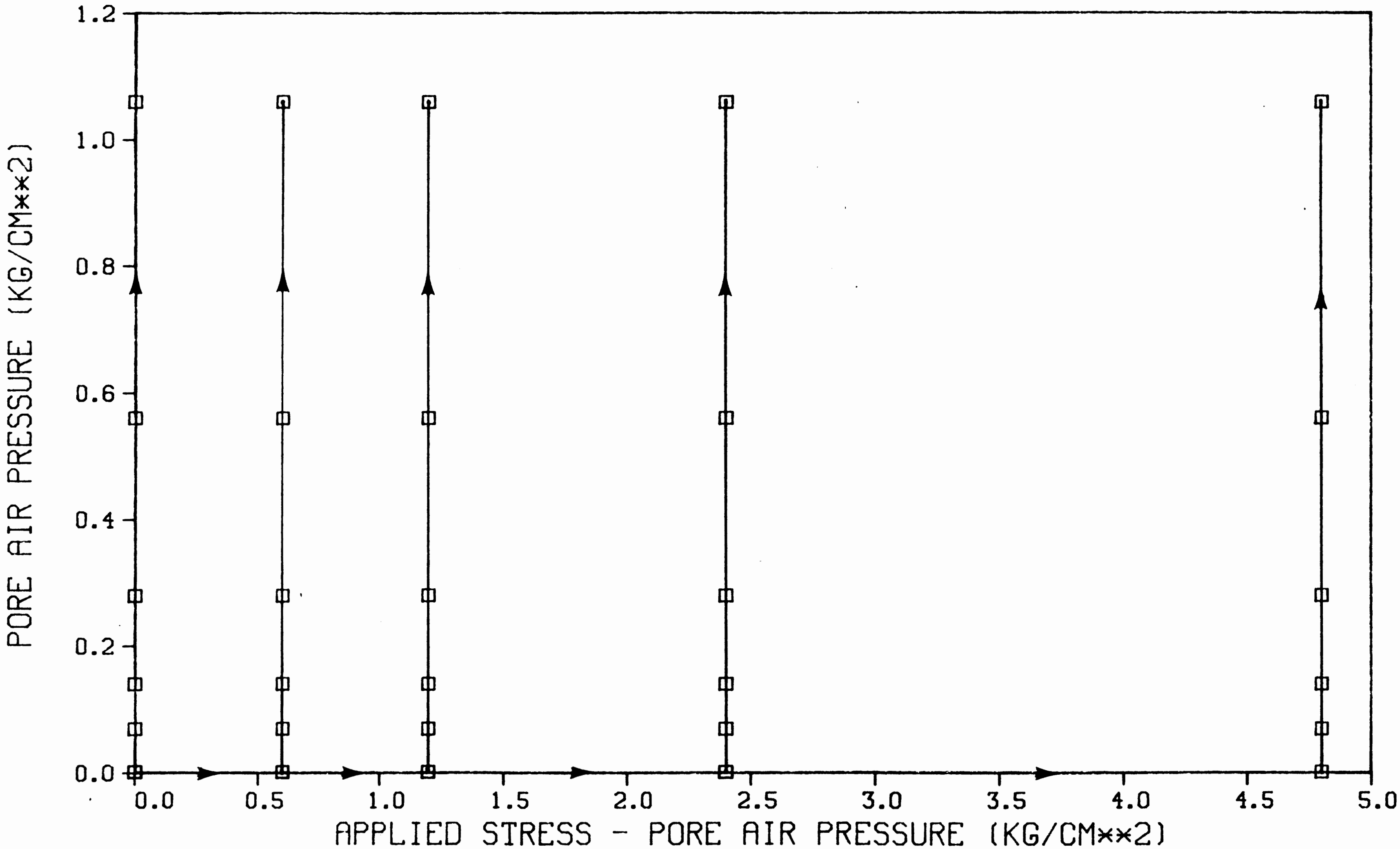

FIGURE 4. Stress Paths for Unsaturated Consolidation Tests

RESULTS

Saturated Consolidation Tests

A total of eight saturated consolidation tests, four on tailings slimes and four on tailings sands, have been completed. All tests were conducted using uranium mill tailings samples obtained from an inactive tailings site in Grand Junction, Colorado. The results presented were obtained using the laboratory procedures and equipment described previously. While space does not permit inclusion of all results obtained to date, representative results are presented for purposes of illustration. Notable differences were not observed for different samples of the same tailings type.

Test results for slimes sample number SL-3 are shown in Figure 5. Displacement is shown as a function of the square root of elapsed time for each load increment. The following observations are of note:

- The initial load increment results in the largest observed total displacement. This results from the lack of distinct soil structure while in the initial slurried state.

- All curves indicate an initial large displacement upon loading. This initial displacement probably results from the compressibility of small amounts of air trapped within the soil pores (Lowe et al., 1964). The magnitude of this initial displacement is seen to increase with increasing pressure increments.

- Following the initial large displacement, the curves are approximately linear with the linear portion increasing in length for larger-applied pressures. This linear portion corresponds to theoretical predictions for primary consolidation (Taylor, 1948; McNabb, 1960), that is, the portion of the consolidation curve corresponding to dissipation of excess pore water pressure. At larger-applied pressures, soil permeability is significantly reduced, lengthening the time period required for primary consolidation.

- Departure from linearity further along the curve is theoretically attributable, at least in part, to the finite sample height (McNabb, 1960). As excess pore pressure at the sample midplane begins to dissipate appreciably from the initial applied load increment, consolidation begins to proceed at a reduced rate. A sample of infinite height would continue to consolidate in inverse proportion with the square root of elapsed time.

- The continued consolidation of the sample, even after periods exceeding one day, indicates that time-dependent strain (secondary consolidation) is an important contribution to total consolidation. Both measured and calculated sample permeabilities as well as direct measurements of pore pressure dissipation indicate that primary consolidation is completed after a few hours. The large magnitude of the observed secondary

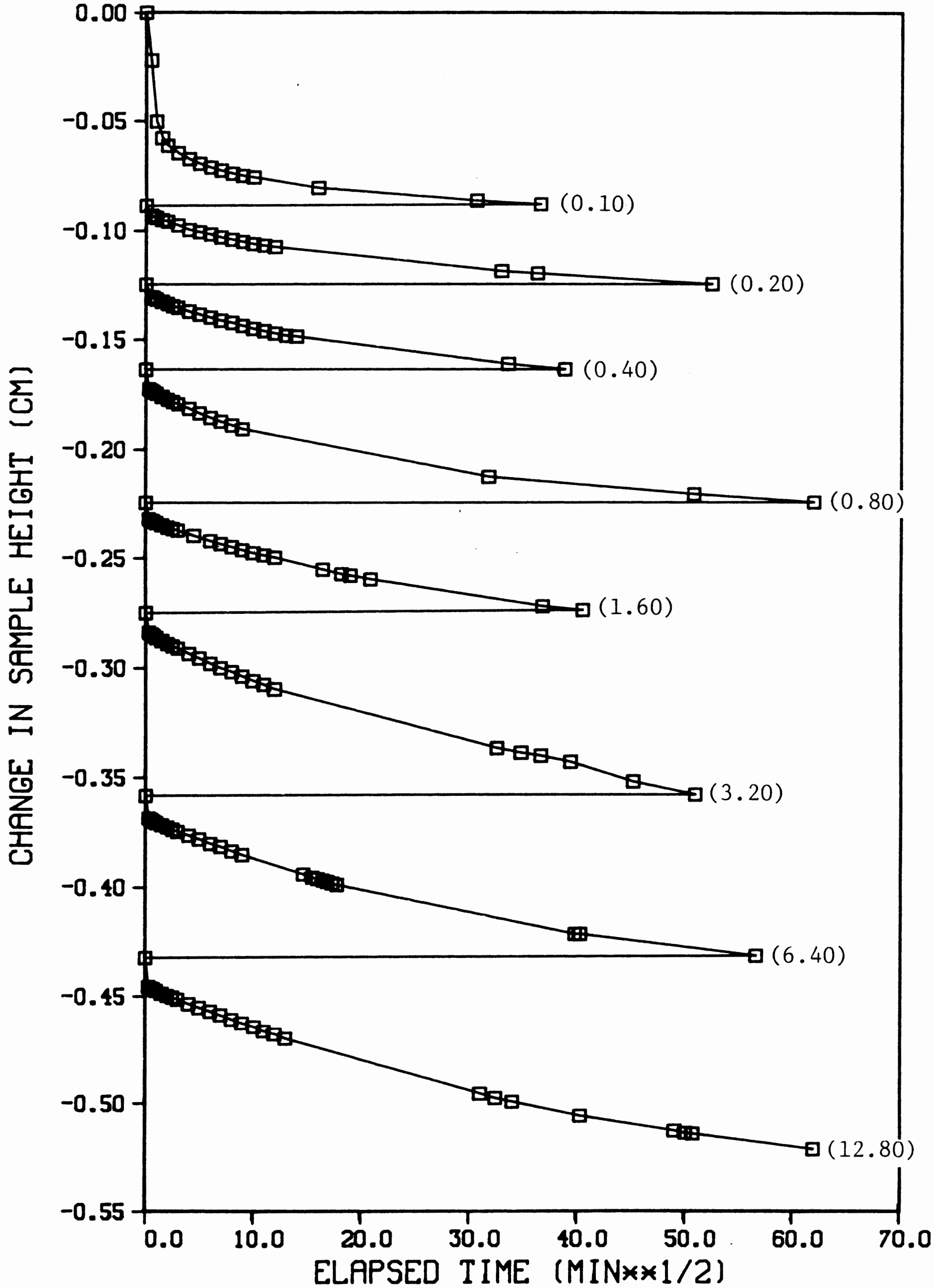

FIGURE 5. Change in Sample Height Versus Elapsed Time Following Each Load Increment, Sample No. SL-3. Total applied load (in kg/cm^2) indicated in parentheses for each curve.

consolidation is likely a result of the loose structure of the tailings slimes. Similar behavior has been observed for highly sensitive clays (Lo, 1961; Walker, 1969) as well as a variety of other silts and clays (Mesri, 1973) with very high natural water contents. The depositional environment of these soils is often quite similar to that of tailings. The degree of secondary consolidation increases with the size of the applied pressure increment.

Direct measurements of sample permeabilities are compared with those calculated from the observed consolidation behavior (Figure 6). Although the two values agree initially, the calculated values show a considerably greater decrease with effective stress. Direct measurements of excess pore pressure dissipation with time suggest that the true sample permeability lies closer to the values calculated from the observed sample consolidation. Two possibilities may help explain the discrepancy:

- Direct measurements of sample permeability may yield higher values as a result of piping between the sample sides and the consolidometer ring.
- Secondary consolidation may be sufficiently large so as to increase the apparent primary consolidation time by delaying the consolidation rate.

It is hoped that future modeling of the observed sample consolidation behavior will further clarify the permeability results.

Test results for sands sample number SA-3 are shown in Figure 7, in the same manner as for the slimes sample. The following observations are of note:

- The initial load increment does not create a large displacement as the sands have considerably more initial structure.
- Following the large initial displacement, very little further displacement occurs. The relatively high permeability of the sands combined with the small height of the sample allows primary consolidation to occur almost instantaneously.
- Although some secondary consolidation occurs, its magnitude is considerably smaller than for the slimes and hence is not considered of major importance.

Void ratios were computed for each sample following each loading increment. These results are presented in Figures 8 and 9 for the tailings sands and slimes respectively. Following standard convention, we have plotted void ratio versus the log of effective stress (or total applied load at the end of each loading increment). Many soils are characterized by a linear relationship, at least at effective stresses exceeding any preconsolidation pressure applied to the sample, between void ratio and log effective stress. When such a linear relationship is observed, the slope of the line is called the compression index. While most standard settlement calculations assume a

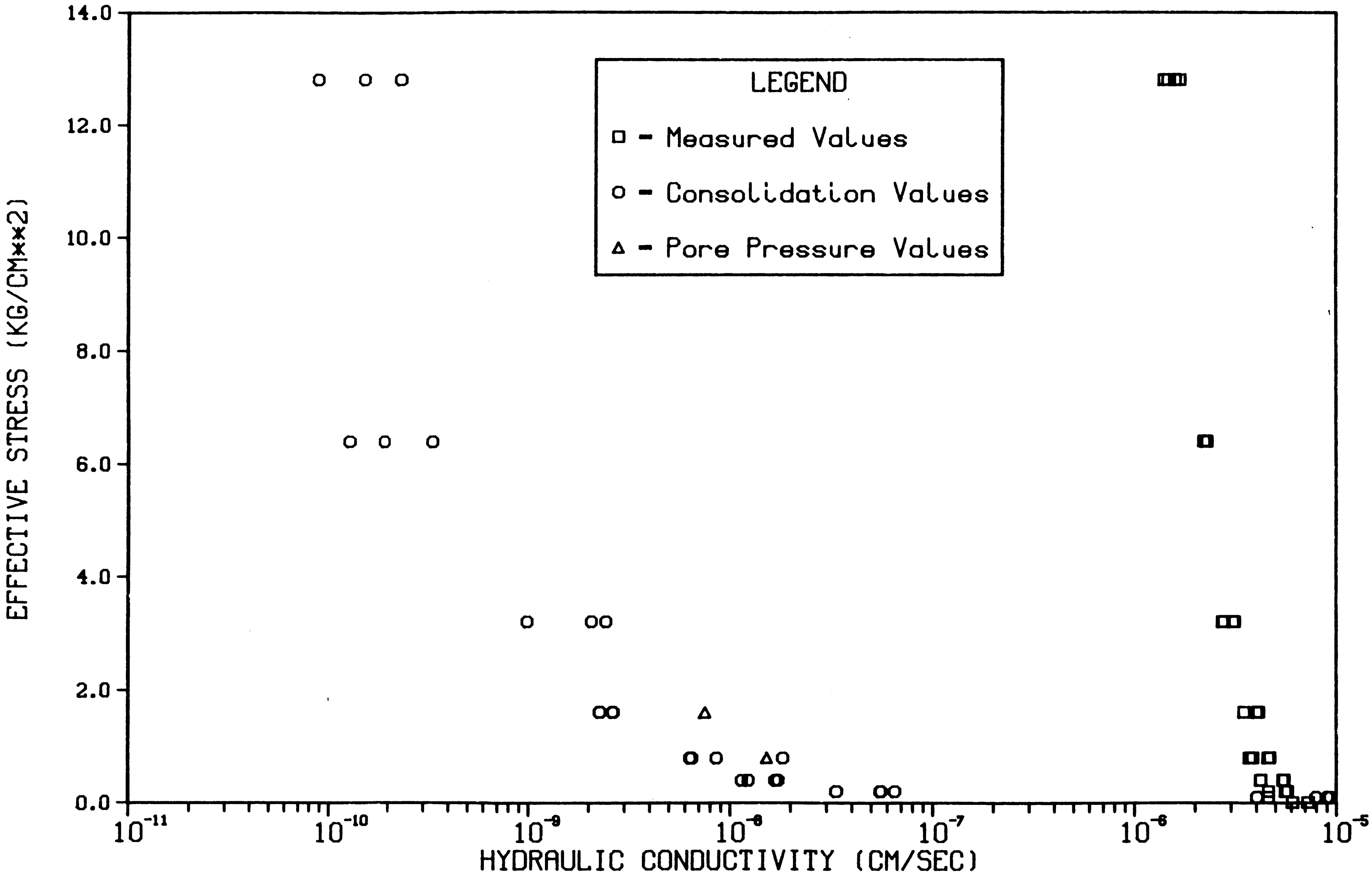

FIGURE 6. Measured and Computed Hydraulic Conductivities Versus Effective Stress for G. J. Tailings Slimes. Measured values calculated from falling head permeameter tests, consolidation values computed from the coefficient of consolidation as determined using Taylor's (1948) emperical method; pore pressure values computed from the measured time for 90% excess pore pressure dissipation.

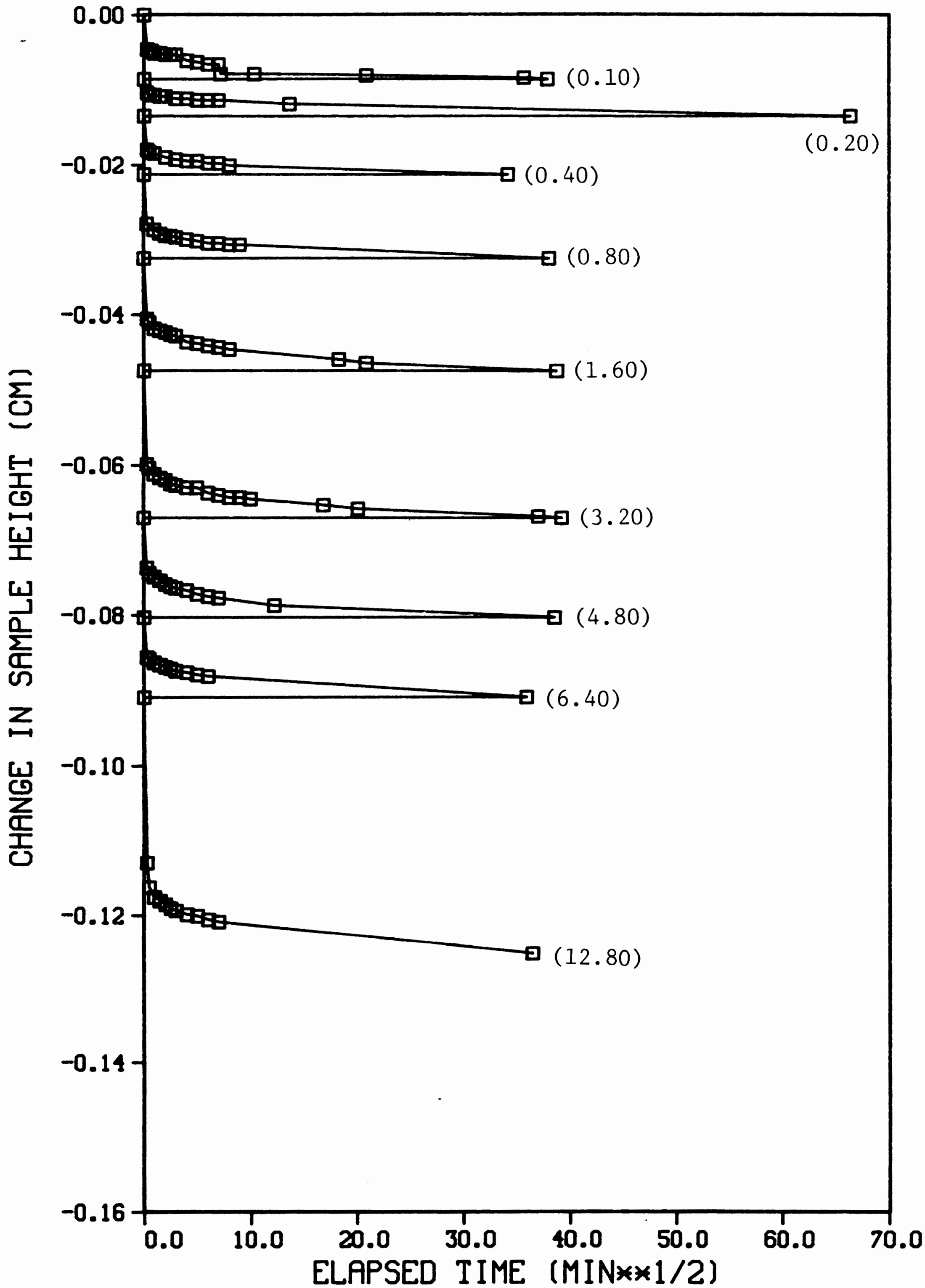

FIGURE 7. Change in Sample Height Versus Elapsed Time Following Each Load Increment, Sample No. SA-3. Total applied load (in kg/cm^2) indicated in parenthese for each curve.

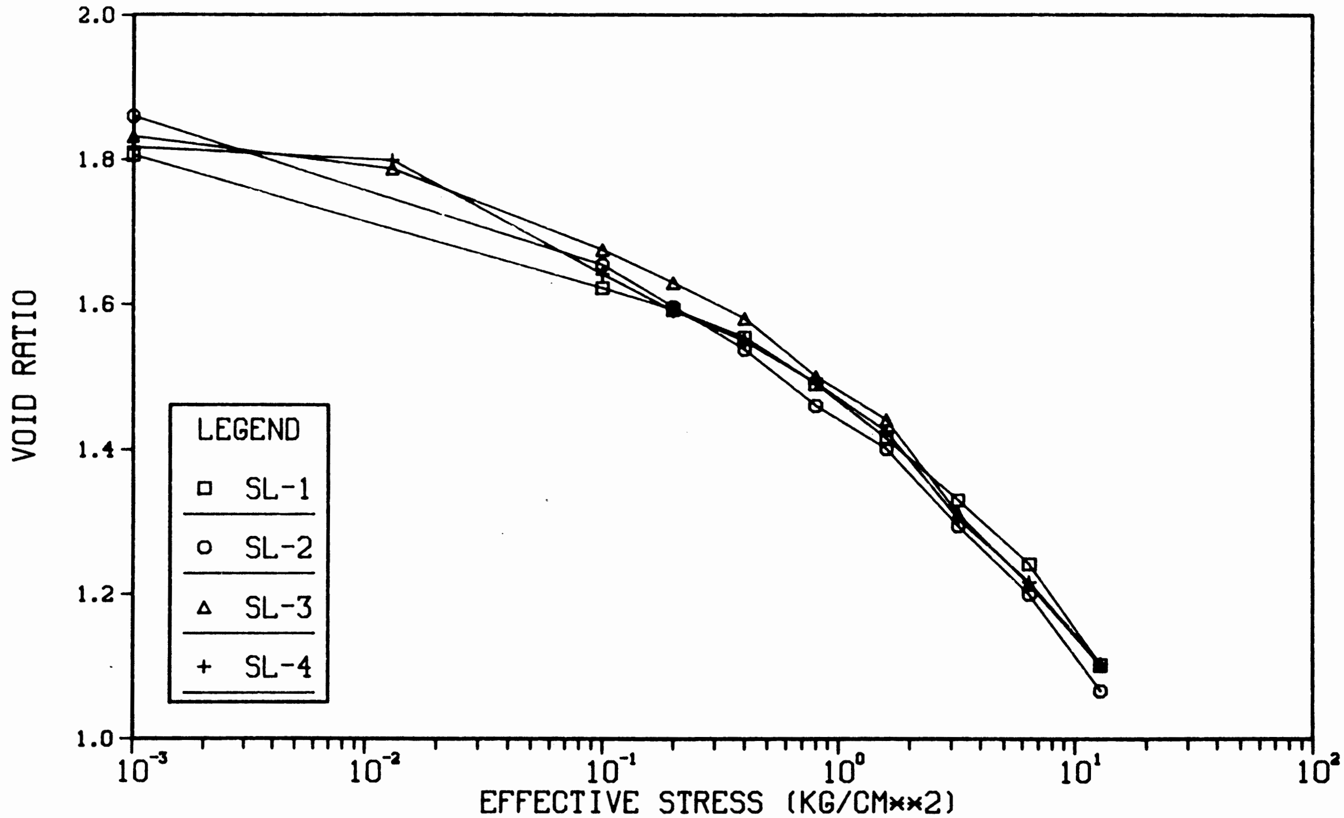

FIGURE 8. Void Ratio Versus Effective Stress - G.J. Tailings Slimes

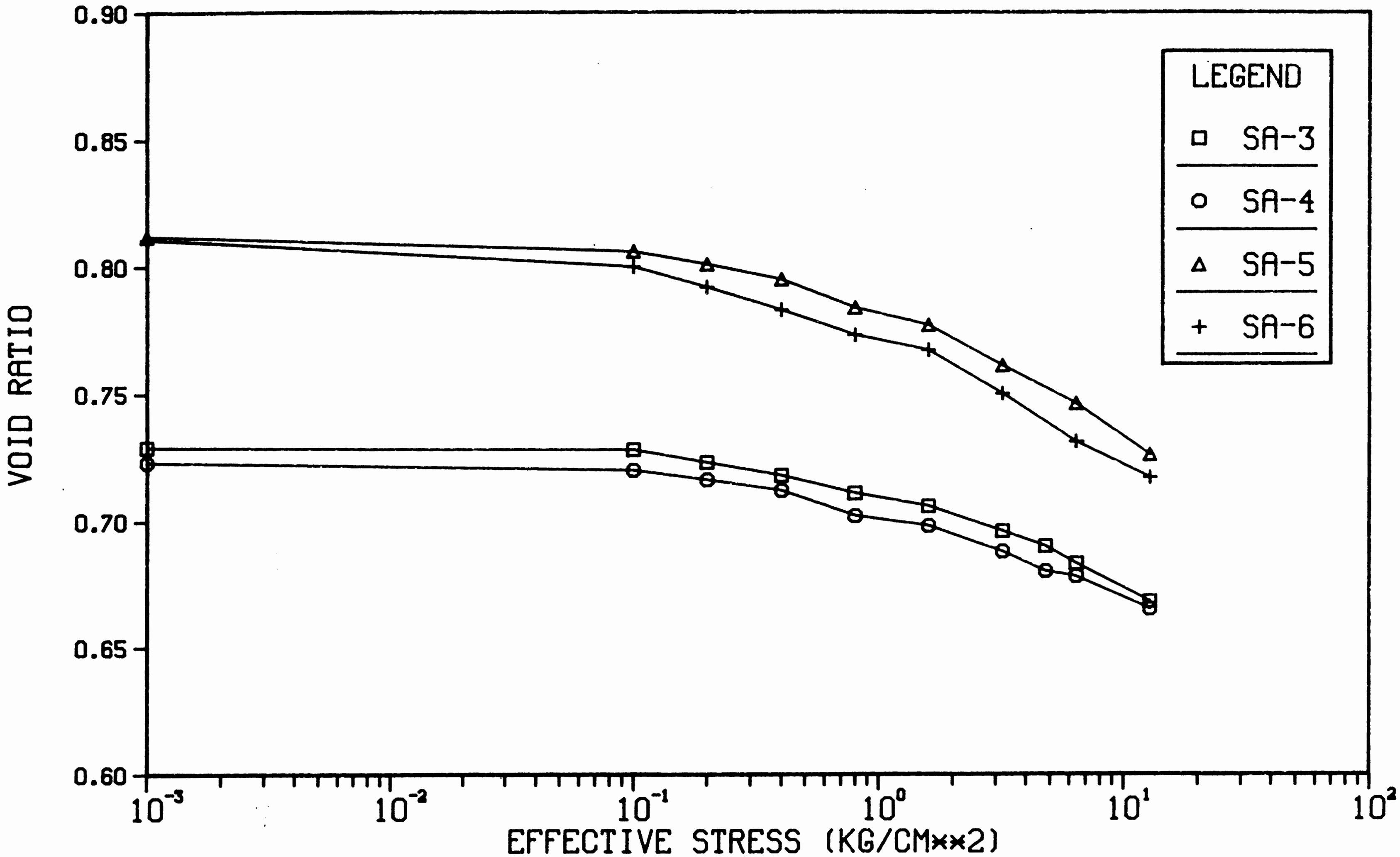

FIGURE 9. Void Ratio Versus Effective Stress - G.J. Tailing Sands

constant compression index, clearly this is not the case for the tailings material tested here. Similar results were obtained by Nelson et al. (1983) for tests on uranium tailings from Shiprock, New Mexico.

Although good agreement was found between all four tailing slimes samples tested, differences between the two batches of tailings sands tested (SA-3 and SA-4 versus SA-5 and SA-6) are observed. These differences are attributable to slight differences in sample preparation resulting in different initial void ratios. While both batches were prepared in the manner described previously, samples SA-3 and SA-4 were initially wetted before emplacement in the consolidometer. Samples SA-5 and SA-6 were air dried before emplacement. Differences between the void ratios measured for the two batches are exaggerated by the relative flatness of the void ratio curves with the largest difference amounting to only a 3% difference in total sample porosity.

Reasonable agreement is found between the tailings slimes data of Figure 8 and that reported previously by Nelson et al. (1983) for Shiprock slimes. The chief difference observed was a consistently higher void ratio for the Shiprock data.

Lesser agreement is found between the tailings sands data of Figure 9 and those reported for tailings sands previously by Nelson et al. (1983). Both a consistently higher void ratio and greater compressibility were observed for the Shiprock tailings sands than for the Grand Junction tailings sands. This is attributed to the greater uniformity and higher sand content of the Grand Junction sands.

Unsaturated Consolidation Tests

One unsaturated consolidation test has been conducted to date using Grand Junction tailing slimes. The sample was loaded under saturated conditions to an effective stress of 4.8 kg/cm^2 and allowed to equilibrate before desaturation. Results of the desaturation portion of the test are shown in Figures 10 and 11. Change in sample height versus time is shown in Figure 10 for applied pore air pressures of 0.5, 2.0, and 4.0 psi (0.035, 0.14, and 0.28 kg/cm^2). From this graph it is apparent that the largest unsaturated consolidation occurs following the initial sample desaturation. Based on the larger size of the unsaturated sample, the degree of consolidation due to desaturation appears to be considerably less than that due to sample loading. This is expected based on previous unsaturated tailings consolidation tests as reported by Sherry (1982).

Cumulative water outflow volumes are shown in Figure 11 for the three pore air pressure increments. The total outflow volumes correspond approximately to the magnitudes of observed sample displacement. However, the rate of desaturation is extremely rapid when compared to the corresponding displacement rate. Reasons for this are not fully understood as yet. It is noted that the undulation in the first outflow curve (p_a = 0.5 psi) is a result of difficulties in stabilizing the applied pore air pressure at such a

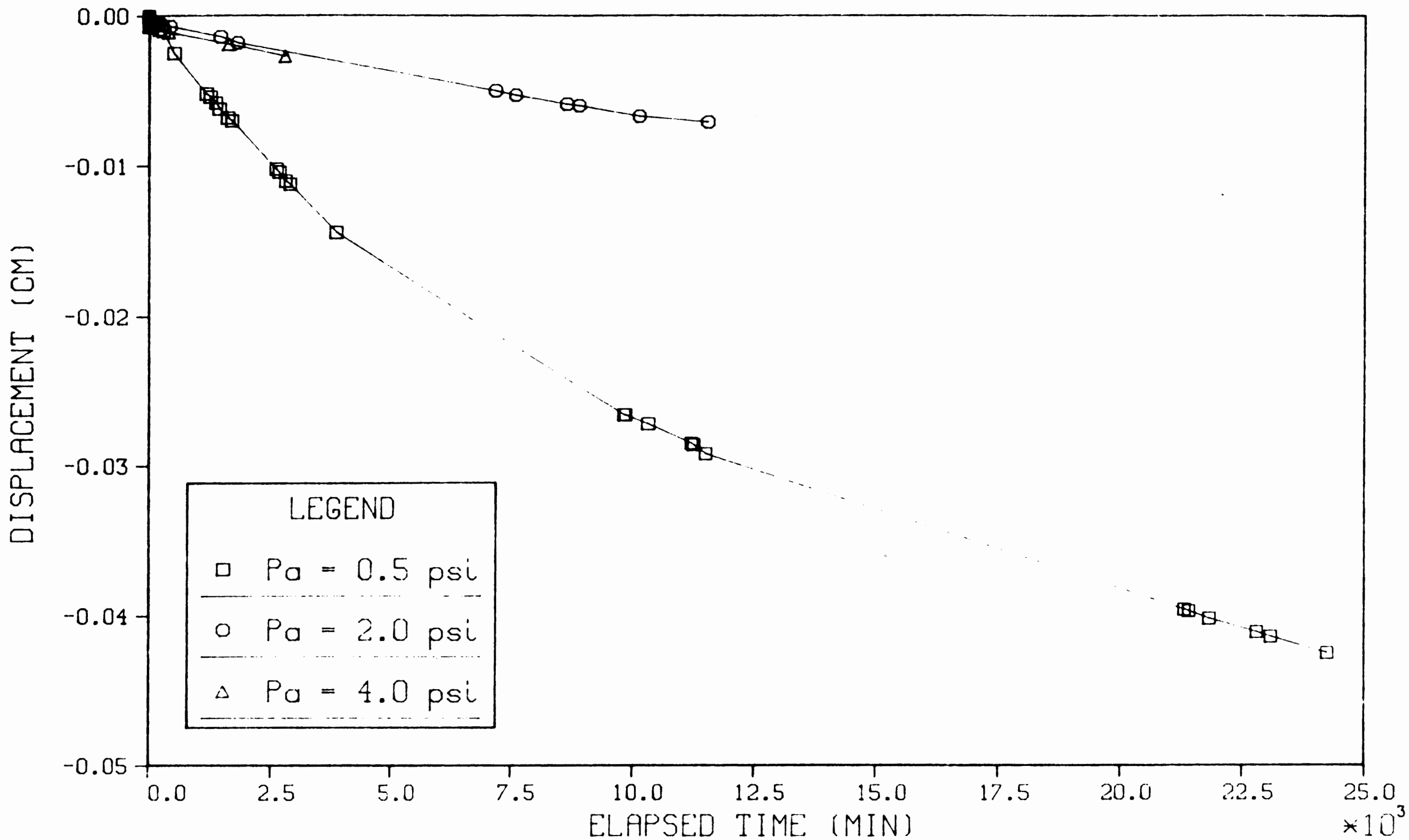

FIGURE 10. Unsaturated Consolidation Test for Sample SL-5; Change in Sample Height With Elapsed Time Following Incrementing of Pore Air Pressure (Pa)

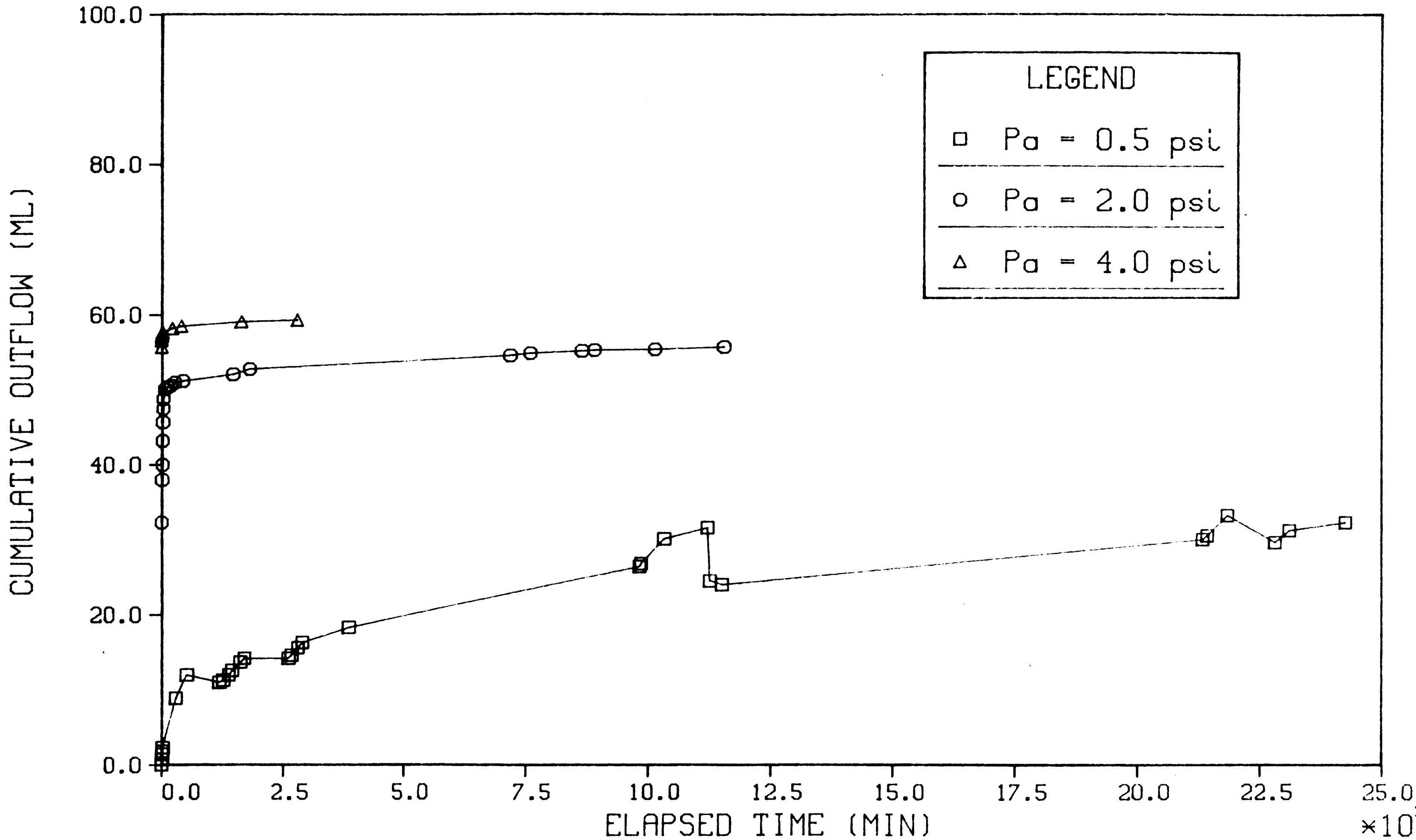

FIGURE 11. Unsaturated Consolidation Test for Sample SL-5; Cumulative Water Outflow With Time

small level. Other difficulties were encountered with entrapped air during the initial run, a problem that has subsequently been solved.

FUTURE WORK

The saturated consolidation tests are nearing completion. Future efforts in this direction include direct measurement of tailing sands permeability as a function of effective stress and investigation of the consolidation behavior of tailing sands-slimes mixtures. The unsaturated consolidation tests have just gotten under way during the previous month. Due to the length of time required to conduct these tests, it is expected that this testing will continue for several months, particularly for the tailings slimes. Due to the very small amount of consolidation observed for the tailings sands, it may be impossible to measure their unsaturated consolidation behavior at least over the entire surface. If initial results indicate this to be the case, desaturation curves will still be obtained. Additional tests on tailings slimes will be conducted to investigate path dependency and/or increase the measurement range if sufficient time remains following the conclusion of all other testing.

REFERENCES

Fredlund, D. G., and N. R. Morgenstern. 1976. "Constitutive Relations for Volume Change in Unsaturated Soil." Canadian Geotechnical Journal, 13:261-276.

Lo, K. Y. 1961. "Secondary Compression of Clays." Journal of the Soil Mechanics and Foundations Division, ASCE Proceedings. 87(SM4):61-87.

Lowe, J. F., P. F. Zaccheo, and H. S. Feldman. 1964. "Consolidation Testing With Back Pressure." Journal of Soil Mechanics and Foundations Division, ASCE Proceedings. 90(SM5):69-86.

Matyas, E. L., and H. S. Radhakrishna. 1968. "Volume Change Characteristics of Partially Saturated Soils." Geotechnique, 18:432-448.

McNabb, A. 1960. "A Mathematical Treatment of One-Dimensional Soil Consolidation." Quarterly of Applied Mathematics, 17(4):337-347.

Mesri, G. 1973. "Coefficient of Secondary Compression." Journal of the Soil Mechanics and Foundations Division, ASCE Proceedings, 99(SM1): 123-137.

Nelson, J. D., R. E. Wardwell, S. R. Abt, and W. P. Staub. 1983. Consolidation of Tailings. NUREG/CR-3204, Nuclear Regulatory Commission, Washington, D.C.

Rowe, P. W., and L. Barden. 1966. "A New Consolidation Cell." Geotechnique, 16:162-170.

Sherry, G. P. 1982. Constitutive Relationships for Unsaturated Uranium Mill Tailings. MS Thesis, Colorado State University.

Taylor, D. W. 1948. Fundamentals of Soil Mechanics. John Wiley, New York, New York.

Walker, L. K. 1968. "Secondary Settlements in Sensitive Clays." Canadian Geotechnical Journal, 6(2):219-222.

DISTRIBUTION

No. of Copies	
OFFSITE	
15	F. Swanberg E. F. Conti T. J. Nicholson Office of Nuclear Regulatory Research Nuclear Regulatory Commission Washington, DC 20555
2	G. Gnugnoli D. E. Martin Office of Nuclear Materials Safety and Safeguards Nuclear Regulatory Commission Washington, DC 20555
2	NRC Division of Technical Information and Document Control Nuclear Regulatory Commission Washington, DC 20555
2	Technical Information Center U.S. Department of Energy P.O. Box 62 Oak Ridge, TN 37830
	M. L. Matthews Department of Energy Albuquerque, NM 87115
	P. J. Magno ANR 460 U.S. Environmental Protection Agency 402 M Street S.W. Washington, DC 20460
	P. T. Owen Remedial Action Program Information Center Oak Ridge National Laboratory P.O. Box X, Building 2001 Oak Ridge, TN 38830
	V. C. Rogers Rogers & Associates Engineering Corporation P.O. Box 330 Salt Lake City, UT 84110
ONSITE	
86	Pacific Northwest Laboratory
	P. A. Beedlow
	W. J. Deutsch
	J. M. Doesburg
	D. W. Dragnich/C. E. Elderkin
	M. E. Dodson
	J. L. Downs-Berg
	R. M. Ecker
	M. R. Elmore
	R. L. Erikson
25	M. G. Foley
	J. S. Fruchter
10	G. W. Gee
	J. N. Hartley
	P. O. Jackson
	C. S. Kimball
	D. R. Kalkwarf
	C. T. Kincaid
	J. M. Latkovich
	E. A. Lepel
	M. J. Mason
	W. J. Martin
	D. W. Mayer
	T. J. McKeon
	I. C. Nelson
	R. W. Nelson
	K. B. Olsen
	B. E. Opitz
	R. W. Perkins
	S. R. Peterson
	D. E. Robertson
	A. E. Reisenauer
	T. W. Schrauf
	R. J. Serne
	D. R. Sherwood
	J. A. Stottlemyre
	R. L. Skaggs
	V. W. Thomas

No. of
Copies

ONSITE

S. W. Tyler
C. M. Unruh
P. C. Walkup
W. H. Walters
E. C. Watson
W. C. Weimer
L. L. Wendell
G. Whelan
J. A. Young
J. K. Young
Technical Information (4)
Publishing Coordination (2)