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**Hydro-geochemical Studies of Uranium Mill-Tailing Piles
at Riverton, Wyoming and Maybell, Colorado**

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T. N. Narasimhan, R. M. Galbraith, A. White, A. Smith,

H. Schmidt, B. Moed, T. Tokunaga

**Earth Sciences Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720**

May 1982

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Annual Report for Fiscal 1981 prepared for the

DOE - UMTRAP Office, Albuquerque, N. M.

**This work was supported by the Assistant Secretary for Nuclear Energy, Division
of Remedial Action Programs through R. H. Campbell, Uranium Mill Tailings
Projects Office, Albuquerque; of the U.S. Department of Energy, under Contract
No. DE-AC03-76SF00098.**

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**Hydrogeochemical Studies of Uranium Mill Tailing Piles
at Riverton, Wyoming and Maybell, Colorado**

1.0 INTRODUCTION

1.1 The UMTRA Project

The Uranium Mill Tailings Remedial Action Project covers some 22 mill tailings sites spread over Arizona, Colorado, Idaho, New Mexico, Oregon, Pennsylvania, Texas, and Wyoming. Because of the environmental concerns over the potential health hazards from some of these sites that are located near population centers, a series of studies has been undertaken by the U.S. Department of Energy. The remedial action program is aimed at devising measures that will assure the environmental acceptability of these piles. Two remedial recourses are available: (i) Provide protective structures in situ where possible; or, (ii) move the tailings to a new, safe location. The basic need for either alternative is to understand the specific nature of the hazards, namely, ground water contamination and atmospheric pollution. Once the nature of the hazard is known, environmental impact statements can be prepared and protective measures can be devised for implementation by the architectural engineers.

1.2 Previous Work

Investigations by Markos and Bush (1980) indicate that mill tailings contain numerous radioactive and chemically toxic constituents and heavy metals. In addition, presence of chemical saline encrustations on the tailings surface, local occurrence of wet patches of tailings and other features led them to suspect that capillary potentials as well as chemical potentials could be driving the fluids within the partially saturated tailings. These findings, when presented at a peer review meeting in Albuquerque during November 1980, resulted in a consensus opinion that there is an urgent need to understand

the physico-chemical mechanisms that operate within these piles. It was felt that these mechanisms may control the long-term release of contaminants to the interstitial water and their subsequent transport to the ground water system. Therefore, any effort directed at containment must be designed to counter such transport phenomena. The time constraints on the development of this understanding were set by the programmatic need to have input to the architectural engineers by late 1982.

1.3 Purpose and Scope

This is an annual report of the activities carried out by the Lawrence Berkeley Laboratory (LBL) under the UMTRA program during fiscal year 1981. The LBL study was formally funded in late May, 1981 and field work commenced in June. Thus, this annual report essentially covers the period, June through September, 1981.

The purpose of the study by the Lawrence Berkeley Laboratory (LBL) is to develop an understanding the physio-chemical mechanisms occurring within and beneath the piles. Specifically, LBL would investigate; a) the release of contaminants to the interstitial fluid; and, b) the vertical transport of the contaminants either upward to the surface or downward to the water table. This investigation would determine the important contaminants, ascertain the influence of chemical/osmotic potentials (if any) on fluid movement, and investigate the possibility of temporal cycles in the upward/downward movement of fluids with seasonal changes in the moisture content of the piles.

Considering the large number of sites and the lack of certainty as to which of those will actually have to be moved, it was decided that LBL

should focus attention on a generic understanding of the problem by conducting studies at two carefully selected "typical sites". The sites would be selected with assistance from organizations already involved in the UMTRA project and personnel from Sandia National Laboratory.

The integrated field and laboratory investigation would encompass instrumentation to profile the hydrological, geochemical, and radiochemical parameters within the tailings piles. A drilling and sampling program would provide material for study in the laboratory and access for monitoring long term variables and for conducting short term transient tests in the field. These tests would be designed to measure the response of the tailings and interstitial fluids to stimuli such as precipitation and water table fluctuations. High resolution gamma ray spectrographic measurements of samples from the sites would be coupled with down-hole measurements provided by the Sandia Laboratories (SANDIA) to determine the distribution of radio elements within the tailings pile and indicate the mobility of these elements. Fluid samples from both within the tailings and the local ground water below the piles would identify the mobile constituents and provide a means of understanding the interface between the tailings and the ground water system. This chemical study would include the analysis of stable isotopes to determine fluid source and mixing as it is related to the emplacement of the pile, current precipitation patterns, and ground water movement. All of this information would be integrated into mathematical models to simulate fluid flow and chemical transport within a tailings pile. These then would form the data base that is provided to the architectural engineer for the design of the final disposal site. This data base will also provide input to others in the UMTRA program who are concerned with the preparation of environmental impact statements (EIS).

1.4 Methodology

The fundamental objective of the project is the understanding of the physical and chemical mechanisms that govern the release of the contaminants to the interstitial water and their subsequent, vertical transport within the partially saturated tailings.

Experience in the field of soil physics has clearly established that the hydraulic conductivity of partially saturated soil decreases rapidly with decreasing water saturation. Hence, the rates of water movement in partially saturated tailings must be very small, and detecting possible seasonal changes in the flow direction within the tailings is therefore a difficult task.

In simple, isothermal systems, a common method for detecting fluid flow is to measure the fluid potential and infer the velocity of flow from gradients of potential. The fluid potential is equal to the sum of elevation head and pressure head. In partially saturated materials, the latter is less than atmospheric pressure and is known as moisture suction. In practice, the accurate measurement of moisture suction is a difficult task. Considerable uncertainties arise due to heterogeneity within the tailings, thermal effects, and, possibly effects due to chemical potentials.

It is therefore necessary, at the outset, to take an integrated approach to the problem by a synthesized interpretation of the fluid flow field, using hydrological, geochemical and radiochemical data for the purpose. The key component in the present study is the "nest" of instruments. A nest consists of several tensiometers and samplers to measure fluid pressures and to collect water samples for geochemical and radiochemical analyses at different depths. In addition, repeat γ -ray logging in adjacent bore holes will also be

carried out. These data will be augmented by water samples and continuous water table measurements from boreholes adjacent to the instrument tests.

1.5 Personnel

The field operations, including drilling, sampling and instrumentation were implemented by Robert Galbraith with technical assistance from Robert Davis. The hydrological aspects of the program are conducted by T. N. Narasimhan, with technical assistance from Tetsu Tokunaga and expert advice on soil physics from Larry Waldron. Art White is in charge of the geochemistry component, assisted by Heidi Schmidt. The radiometric component of the project is under the charge of Al Smith with assistance from Barbara Moed. T. N. Narasimhan is in technical charge of the overall program.

1.6 Acknowledgements

We would like to thank Don Diego Gonzalez and Paul O'Brien of the Sandia National Laboratory for help in formulating and organizing this project. Our thanks are due to Mark Mathews of Uranium Mill Tailings Projects Office for all administrative help. The comments and criticisms of J. A. Cherry (University of Waterloo), Keros Cartwright (Illinois State Geological Survey), Michel Vauclin (University of Grenoble) and Thomas Shepherd (Colorado State University), who served on the peer review committee, were of great help in formulating further work. Larry Waldron of the University of California provided valuable advice on the measurement of unsaturated soil properties. Harold Wollenberg of LBL and Don Diego Gonzalez reviewed an earlier version of this manuscript and R. W. Davis of LBL provided invaluable technical assistance in setting up and conducting the field experiments. We would like to thank Alton Mitner for advice on radiation health safety in the field.

2.0 SITE SELECTION

2.1 Site Visits

On March 19, 1981 a meeting was held in Albuquerque, New Mexico, to determine which of the UMTRAP sites will best fit the needs of the LBL study. Representatives from the Sandia National Laboratory, Geochemistry and Environmental Research Inc. and the Colorado State University presented their understanding of the various piles. Based on the presentations, the sites at Riverton, Wyoming and Maybell, Colorado were chosen for further site-visits and confirmation.

On April 16 and 17 Art White and Bob Galbraith (LBL) with John Nelson and Tom Shepherd (Colorado State University) and Don Diego Gonzalez (Sandia National Laboratory) visited the Riverton and Maybell sites. They also visited two active mines in the Gas Hills Uranium District of Wyoming to gain a first-hand understanding of the methods of emplacing the tailings materials. After this visit a decision was made to carry out pilot drilling at both sites, especially to determine the acidity of individual piles since an "acidic" pile was considered to be typical for the present generic study.

2.2 Site Description

The geological and hydrological conditions at the Riverton and the Maybell sites are briefly summarized below, based on earlier reports by Ford, Bacon and Davis (1977, 1981).

2.2.1 The Riverton site

Geology: The Riverton pile (Fig. 2.1) rests on 5 to 8 m of soil and coarse-grained alluvium of the Wind River flood plain, underlain by approximately 610 m of the Wind River formation. The sedimentary formation consists of a sequence of lenticular, interbedded, nearly horizontal sandstones, silt-

stones and shales with minor bentonite, tuff and limestone. A simplified stratigraphic column is given in Figure 2.2.

Hydrology: The Little Wind River flows north-eastward about a km south-east of the pile (Fig. 2.3). The Wind River flows eastward about 1.5 km north of the site. Numerous irrigation ditches flow near the site and empty into marshy areas east and south-east of the site. Because of the extensive flood plain, slightly elevated location of the pile and protection from highway road grades, flood waters of the Wind River and Little Wind River cannot reach the tailings pile, although they could rise within the base of the tailings. Overland flow on the pile is limited to the precipitation that actually falls on the site. A ditch and berm protect the pile from off-site runoff onto the site and trap overland runoff from the pile on site.

Groundwater: The confined ground waters in the Wind River formation occur under very shallow as well as deeper artesian conditions. The shales act as confining layers to water in lenticular sandstone horizons, but the entire sequence behaves somewhat as a single aquifer. Intensive development of the area's ground water, including wells on the millsite, has affected water levels, flow gradients, and artesian pressures in the immediate vicinity of the city of Riverton. The ground water flow gradient is toward the Riverton well field, which is at a considerably greater depth than the potentially affected waters at the site. Recharge to the confined ground water system occurs by the flow of water across permeable bedrock. The tailings site is an area of potential recharge to the underlying aquifers of the Wind River formation. Ground water from various horizons within this formation is used for domestic water supplies without treatment over much of the rural area. The city's well field consists of 15 wells 150 to 240 m deep.

XBL 021-1733

Fig. 2.1 Map of Wyoming showing the location of Riverton

Ford, Bacon & Davis Inc.

Fig. 2.2 Idealized stratigraphic column of the Riverton site (after Ford, Bacon and Davis, 1981)

XBL 821-1734

Fig. 2.3 Location map of the Riverton tailings pile

This supply is barely adequate to supply peak daily pumping requirements during summer months. Two inactive wells located near the site have static water levels within a meter of ground level.

The unconfined ground waters consist of waters within terrace deposits, within river alluvium, and within the shallow bedrock of the Wind River Formation. These sources are hydraulically interconnected and act as a single system. Due to natural topography and return irrigation flows, much of the area is water-logged and evaporation results in salt deposits in the soils. The water table at the site is usually less than 2 m below the original land surface and unconfined ground water rise within the base of the tailings. Thus, there is a potential for contamination of the unconfined ground water, and of the surface water into which it discharges. Unconfined ground waters are not used for domestic water supplies in the Riverton area because of the insufficient quantity or poor chemical quality of the water, but the surface waters are used for irrigation and watering of stock.

The tailings are protected from winds and water erosion by soil and vegetative cover. High-intensity winds and storms are known in the area, and limited water erosion of some of the finer cover material is evident on the steeper western boundary of the pile. Coarser material has not been affected.

Meteorology: The climate in the Riverton area is semiarid, with an annual precipitation of about 25 cm/year. Winds in the area tend to be in an eastwest direction. Weather data are recorded at the Riverton airport.

2.2.2 The Maybell site

Geology: The Maybell tailings pile is located (Fig. 2.4) on a gentle southwestern slope near the head of a small drainage system. The Browns Park Formation underlies the site and in turn is underlain by the Mancos Shale. The Browns Park Formation is primarily composed of sandstone units, and some shale layers within the formation act as barriers to the downward and upward migration of ground waters. A simplified stratigraphic column is shown in (Fig. 2.5).

Hydrology: The Yampa River, 8 km to the south, is the closest perennial stream flowing through the area downdrainage from the site. Drainage at the site consists of diversion ditches around the pile and drainage channels into Johnson Wash, a dry tributary of Lay Creek. Lay Creek enters the Yampa River approximately 4 km downstream from Johnson Wash. Other surface waters near the site consists of standing water in the inactive Rob Pit.

Groundwater: The unconfined ground waters of the area are within the Browns Park formation and in unconsolidated valley deposits. The water table at the site is about 45 m below the tailings-subsoil interface and the flow gradient is to the west-southwest. The confined ground waters occur within the lower sections of the Browns Park formation confined by shale layers. Deep aquifers confined by the thick sequence of Mancos Shale are also known.

Meteorology: Strong winds are common in the area and tend to blow from the west-southwest. The average annual rainfall at Craig is 35 cm. High-intensity rainfall such as thunderstorms are infrequent but can occur in the Maybell area during May through October.

Fig. 2.4 Map of Colorado showing the location of Maybell

Ford, Bacon & Davis Inc.

Fig. 2.5 Idealized stratigraphic column of the Maybell site
(after Ford, Bacon and Davis, 1977)

2.3 Pilot Drilling

The final phase of the site selection process was to determine, through pilot drilling, the acidity of the piles at the two sites. During mid-June, 1981 four exploratory holes at Riverton and three exploratory holes at Maybell were drilled using auger holes. The drill-cuttings were quickly analyzed for pH at the site and rough profiles of pH versus depth were obtained. These profiles are shown in Figure 2.6 for Riverton and Figure 2.7 for Maybell. The locations of these boreholes are shown in Figure 3.1 for Riverton and Figure 3.2 for Maybell. As can be seen from Figures. 2.6 and 2.7, the pH are generally less than about 4, indicating the existence of the desired acidic environments at both sites.

RIVERTON TAILINGS PILE

XBL 821-1736

Fig. 2.6 pH values as a function of depth for the test holes at Riverton

MAYBELL TAILINGS PILE

XBL 821-1740

Fig. 2.7 pH values as a function of depth for three boreholes at the Maybell site

3.0 SITE PREPARATION

The site preparation task was to transform the piles into a laboratory with a monitoring network to provide the necessary field data. The instrumentation would enable: collection of relatively undisturbed samples for physical and chemical measurements; cased holes for radiometric logging, water level measurements and water sample collection; and the collection of data on fluid potentials and chemical composition of waters within the unsaturated zone. Care had to be exercised to assure that physical disturbance of the in situ materials and their contamination with drilling fluids were kept at a minimum during the emplacement of the instruments. The procedures followed in order to achieve these ends are given in Appendix 1. The location of the bore holes at the two sites are given in Figures. 3.1 and 3.2. The details of the individual bore holes are given in Tables 3.1 and 3.2. At each site, 3 separate areas, designated A, B and C, were selected to account for potential gross spatial variability of the tailings material. Nests of bore holes were drilled at each chosen area.

The drilling program yielded 141 Shelby tube samples for laboratory analysis of physical, chemical and radiometric properties. Typically, a shelly tube sample is a 7.6 cm diameter stainless tube, about 50 cm long, containing the tailings material. Details of the sample collection are given in Appendix 1.

At Riverton, 6 cased bore holes have been completed (ranging in depth from 2 to 4 m), two at each area, to enable downhole radiometric logging and ground water monitoring. In addition 21 piezometers have also been installed in and around the pile. At Maybell, three cased bore holes have been completed down to 41 m.

MAYBELL TAILINGS PILE

X8L82I-1740

Fig. 2.7 pH values as a function of depth for three boreholes at the Maybell site

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Fig. 3.1 Map of the Riverton pile showing the location of sites A, B and C and the borehole locations

XBL 821-1737

Fig. 3.2 Map of the Maybell pile showing the location of sites A, B and C and the borehole locations

Table 3.1

Data from boreholes, Riverton Site

Borehole	Name Method	Depth Meters	Casing ID Centimeters	Depth to Alluvium Meters	Depth to Bedrock Meters
RA-1	Rotary	7.57	0.95	7.57	-----
RA-2	Rotary	6.58	10.0	6.81	-----
RA-3	Auger	8.38	10.0	6.27	9.45
RB-1	Rotary	5.99	0.95	5.99	-----
RB-2	Rotary	5.33	10.0	5.18	-----
RB-3	Auger	8.53	10.0	4.85	8.84
RC-1	Rotary	2.82	0.95	1.00	-----
RC-2	Rotary	3.96	10.0	1.93	-----
RC-3	Auger		15.0	1.92	4.42
RD-1		5.18	-----	-----	-----

Piezometers

P1		2.71	0.95	-----	-----
P2	Drive	4.78	0.95	-----	-----
P3	Point	1.15	0.95	-----	-----
P4		3.58	0.95	-----	-----
P5		1.45	0.95	-----	-----
P6		5.72	0.95	-----	-----
P7		6.80	0.95	-----	-----
P8	Dug	0.61	10.0	-----	-----
P9		0.75	10.0	-----	-----
P10		1.00	3.8	-----	-----
P11	Hollow	3.04	3.8	0.0	2.43
P12	Stem	3.04	3.8	0.0	2.50
P13	Augers	3.04	3.8	0.0	-----
P14		3.04	3.8	0.0	-----
P15		3.04	3.8	0.0	2.28
P16		3.96	3.8	0.0	3.96
P17					
P18					
P19					
P20					
P21					

Table 3.2

Data from boreholes, Maybell Site

Borehole Name	Depth Meters	Casing ID Centimeters	Depth to Bedrock Meters
MA-1	14.82	0.95	13.84
MA-2	41.15	10.0	13.51
MB-1	4.93	0.95	3.04
MB-2	41.15	10.0	3.30
MC-1	5.61	0.95	4.80
MC-2	41.15	10.0	4.62

4.0 HYDROLOGY

4.1 General

The goal of the hydrology component of the present work is to (a) decipher the fluid flow field in and around the tailings piles through the measurement of physical parameters, (b) decipher the influence, if any, of chemical and thermal potentials on the fluid flow field, and (c) decipher the redistribution of the various chemical species by the moving water. The activities during the period under review were restricted to the first of these tasks, namely, the measurement of physical parameters controlling fluid flow. The activities included data collection in the field as well as establishing a laboratory for measuring the properties of partially saturated materials.

4.2 Field Activities: Riverton

A key factor that governs the study of the hydrology of mill tailings is the fact that the mill tailings materials are partially saturated. Under conditions of partial saturation, the fluid pressure (frequently termed moisture suction or moisture tension) is less than atmospheric. Measurement of moisture suction and collection of water samples from partially saturated materials require special instruments known as tensiometers. One can also use these devices to collect water samples by applying a vacuum. In this report we shall call these sampling devices "suction water samplers" (SWS) for want of better terminology. These devices have sometimes been called lysimeters in the literature.

The effectiveness of a tensiometer drops rapidly as suctions approach an atmosphere in magnitude. For suctions larger than one atmosphere, instruments known as psychrometers are employed. However, they are more difficult to use than a tensiometer. Preliminary data from the Maybell

site indicated that the water table at that site lies at depths of about 50 meters below ground level, suggesting moisture suctions substantially in excess of one atmosphere within the tailings. Therefore, it was decided that the initial field activities would be better directed towards studying the pile at Riverton where the water table is shallow and moisture suctions of less than an atmosphere could be expected.

The basic instrument used in the present study is the tensiometer. In a tensiometer "nest", several tensiometers are clustered in a small area and reach down to different depths. If we neglect lateral variations in fluid potentials over small distances, we can use the fluid potential data from different depths to determine the vertical gradient of fluid potentials. In addition, we could also emplace within the nest, SWS's reaching down to different depths in order to discern the vertical variations in the chemical composition of the interstitial fluids.

The exploratory drilling work at Riverton indicated that the tailings materials are partially saturated and heterogeneous. On the small scale, changes in material properties could occur over a distance of a few centimeters, while on the largest scale, the materials were found to become progressively finer as one proceeds from the west to the east end of the tailings pile. Accordingly, it was decided to choose three separate locations within the tailings along an east-west line to cover the gross heterogeneity and to have a pair of tensiometer-SWS nests at each location to account for small scale heterogeneity. As shown schematically in Figure 4.1, each tensiometer nest consisted of five tensiometers, with the porous cups emplaced at depths of .31 m (12 inches), .47 m (18 inches), .61 m (24 inches), .76 m (30 inches) and .91 m (36 inches). These were arranged in a circular pattern with a

XBL 821-1742

Fig. 4.1 Schematic representation of a tensiometer nest with soil water samplers (SWS)

diameter of .61 m (2 feet). Each tensiometer was accompanied by an SWS located very close to it, to collect water samples from the same depth. These sites are designated RA, RB and RC (Fig. 4.2). At each site, the separation between the two nests was about 2 meters.

During the reporting period, both passive and active monitoring were carried out. The passive monitoring consisted of measuring the fluid potentials as a function of depth and time under prevailing natural conditions. The active monitoring, on the other hand, consisted of a series of three infiltration tests in which water was applied at the surface of the tailings at a controlled rate and the fluid potentials monitored as the water infiltrated into the tailings.

4.2.1 Passive Measurements The purpose of the passive measurements was to decipher the vertical movement of water within the tailings under natural conditions. At each of the three sites, one nest was dedicated to passive measurements, while the others were used for infiltration tests. At all three sites the infiltration tests showed no influence on the neighboring passive nest. This is to be expected since the flow is essentially vertical within the partially saturated tailings material. The observed undisturbed potentials are shown plotted in Figure 4.3, for the period August 25 to September 25.

At the outset one can see from Figure 4.3 that the potential profiles have remained more or less stable at the three sites over a one-month period. At all sites, the potentials decline towards the land surface. The depth of the water table at site A was about 4.8 m, at site B about 2.3 m and at site C between 1 and 2 meters below ground level. If we recognize that fluid pressure at the water table is atmospheric, then the fluid potential at

MILLSITE

WATER TOWER

NOTE:
MAP DEVELOPED FROM PBRADY
SURVEY DATA LOGGED
JULY 27, 1978

ALLEGH

EDGE OF TAILINGS

0 100 FT
CONTOUR INTERVAL 2 FT

XBL 821-1741

Fig. 4.2 Location of the tensiometer nests RA, RB and RC
at Riverton site

Fig. 4.3 Unlisturbed hydraulic head profiles at sites RA, RB and RC, Riverton, August-September, 1981

the water table equals elevation above datum, which in our case is the surface of the tailings. Thus, one can infer that below a depth of about one meter beneath the surface of the tailings, the fluid potential gradient must be downwards. Clearly, there is no hydrostatic equilibrium within the tailings.

If we completely neglect chemical potentials and thermal effects, the profiles of fluid potentials would indicate an upward movement of water within about a meter of the tailings surface and a downward movement of water within the central part of the tailings. The actual fluid fluxes or velocities are not known since we do not know the hydraulic conductivity of the materials. Hydraulic conductivity measurements of samples collected from the tailings will be determined in the laboratory during 1982. Since hydraulic conductivity decreases rapidly with water saturation, the fluxes should indeed be very small.

4.2.2 Infiltration Experiments: One infiltration test was conducted at each of the three sites at Riverton. The purpose was to gain quantitative insights into the hydraulic conductivity characteristics of the materials in situ. All the tests were of the constant-head type, with simultaneous measurement of the inflow rate at the tailings surface. At each site steel rings of 0.91 m (3 feet) diameter and 0.45 m high enclosed each of the tensiometer nests. The other nest continued to make passive measurements. For assuring direct contact of water with the tailings, cover materials were removed at sites RA and RB and a veneer of pea gravel was placed above the tailings surface. This highly permeable material also prevented the scouring of the tailings surface as water was quickly poured on the surface at the beginning of the experiment.

To assure the desired constant-head condition as well as to accurately measure the inflow rate as a function of time, the following apparatus was constructed (Fig. 4.4). The main part of the apparatus is a graduated plastic bottle which serves as a reservoir for water. The faucet at the bottom of this bottle is provided with a small pump which is operated by a float switch. The switch is activated when the water level within the cylinder falls below about 3 mm of the constant potential surface. The switch is automatically turned off when the water level rises back to the constant potential surface. By monitoring the water level within the reservoir, the rate of water influx into the tailings is continuously known. During the infiltration tests at sites RA and RB, a bromide tracer was mixed with the water. The water samples collected from the SWS's during these tests are yet to be analysed for the content of this tracer.

The infiltration tests at sites RA and RB were conducted on August 25, 1981. Tests at site RC were conducted on September 26, 1981. The data collected during these tests are graphically depicted in Figures. 4.5 and 4.6.

The infiltration fronts at all three sites were sensed by the tensiometers within an hour or two of the start of the experiments, suggesting fairly significant permeability for the tailings materials. As can be seen from Figure 4.5, the potentials build up rapidly in the tensiometers and the potentials approached values corresponding to unit hydraulic gradients at long times. When the prescribed head at the tailings surface exceeds 0, the soil below can become fully saturated and develop positive pore pressures at long times. The prescribed heads at sites RA and RB were 0.1 m while at site C, it was 0.03 m. However, since the pressure gages in the tensiometers could only read up to an atmosphere, we do not know if the pressures in some of the

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Fig. 4.4 Experimental set up for the infiltration test at Riverton

Infiltration Test Potential Profiles - Riverton, Wyoming

Pre-infiltration and Post-infiltration Potential Profiles

Infiltration Rates and Cumulative Infiltration

time minutes	i m/s	I m
1	0	0
2	71	8.9×10^{-5}
3	78	5.4×10^{-2}
4	154	8.7×10^{-6}
5	156	9.8×10^{-2}
6	240	8.7×10^{-6}
7	250	1.3×10^{-1}
8	255	3.0×10^{-6}
9	406	1.8×10^{-1}
10	440	source off
11	516	

RAT 6-11
8-26-81

time minutes	i m/s	I m
1	0	0
2	6	7.1×10^{-5}
3	13	2.7×10^{-2}
4	23	4.3×10^{-2}
5	40	7.3×10^{-2}
6	60	source off
7	130	

RBT 6-11
8-26-81

time minutes	i m/s	I m
1	0	0
2	29	8.9×10^{-5}
3	99	6.4×10^{-5}
4	104	6.3×10^{-2}
5	107	6.4×10^{-2}
6	159	6.1×10^{-6}
7	168	9.5×10^{-2}
8	251	9.35×10^{-2}
9	377	4.3×10^{-5}
10	377	9.3×10^{-2}
11	377	1.7×10^{-1}

RCT 1-5
9-25-81

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Fig. 4.5 Results of infiltration tests, Riverton, Wyoming

Fig. 4.6 Cumulative infiltration as a function of time for the three infiltration tests at Riverton

tensiometers actually exceeded atmospheric pressure. Under the circumstances, the long-term unit hydraulic gradient profile is taken to be an acceptable approximation. This assumption may lead to a slight over-estimation of hydraulic conductivity.

The cumulative infiltration as a function of time for all the tests is shown in Figure 4.6. At any instant, the slope of these curve should indicate the infiltration rate. If we assume that the long-term potential profile has a unit hydraulic gradient, then, the slope of the curves in Figure 4.6 at large times should give an estimate of the saturated hydraulic conductivity of the tailings materials at the three sites. As shown in Figure 4.6, the hydraulic conductivities for the three sites are:

Site RA	8×10^{-4}	cm/sec
Site RB	2.8×10^{-3}	cm/sec
Site RC	4.8×10^{-4}	cm/sec .

As already mentioned, these estimates are likely to be an upper bound, since the unit hydraulic gradient assumption is a likely underestimate of the actual gradient.

Both at sites RA and RB the tensiometers were monitored again about a month after the tests. As can be seen from the plots for these sites in Figure 4.5, the potential profiles have migrated to the left from the maximum values attained after the infiltration tests. Over the period of about a month, the excess moisture supplied by the test and stored temporarily in the upper one meter of the tailings has gradually been redistributed, presumably by vertically downwards drainage. It is particularly interesting that in both cases the profiles for September 25, 1981 lie distinctly to the right of those prior to the commencement of the test. This is clearly an indication that the hydraulic conductivity of the tailings under partial saturation must be extremely low.

4.3 Laboratory for Soil Physics Measurements

During the period under review, efforts were initiated to establish a laboratory for measuring the properties of partially saturated soils and to conduct fluid flow as well as chemical transport experiments. When completed, the lab will provide particle size distribution; determination of porous materials by sieve analysis and sedimentation; determination of porosity; determination of saturation characteristic as a function of moisture suction; and determination of hydraulic conductivity as a function of moisture suction.

5.0 GEOCHEMISTRY

5.1 General

The principal objective of the geochemistry component of the study is to generate field and laboratory data to help understand the chemical transport processes within the tailings as well as to understand the chemical interactions at the interface between the tailings and the water table. Additionally, an effort is under way to identify the specific characteristics that distinguish waters within the partially and fully saturated parts of the tailings, and within the shallow and deep aquifers. The proposed methodology includes analysis of carefully collected water samples from rainfall/snow; streams and ponds; the tailings; and from wells tapping the shallow and deep aquifer. The samples are to be analyzed for major and minor constituents, pH, eH and specific isotopes.

5.2 Field Activities at Riverton

Between July and September, 1981, three separate trips were made to the Riverton site for geochemical data collection. Additional shallow holes were drilled at locations away from the pile (up to 50 m laterally from site) in the shallow gravel aquifer in order to evaluate differences in the aquifer chemistry and the potential influence of downward and lateral transport from the overlying tailings. Several additional holes were also drilled and sampled within the tailings. Field measurements included pH, redox, dissolved oxygen, conductance, and total alkalinity. Results are summarized in Table 5.1. Six nests of water samplers (SWS) were also emplaced at the Riverton site at depths ranging from .31 to .91 m in the unsaturated zone. Several of the SWS'S contained standing water after sitting at atmospheric pressure for several weeks. All the samplers produced water (maximum quantity, approximately

250 ml) when subjected to applied vacuum for several hours. Controlled infiltration tests (section 4 of this report) were conducted at two of the nests using bromide-tagged water. Additional chemical samples were collected after each test.

A precipitation collector was constructed at Riverton to obtain tritium, deuterium, and oxygen-18 content of the recharge water. The precipitation was collected in double-ply plastic bags suspended in an 18-inch vertical standing pipe. A constriction in the lower third of the bag allows a minimum of atmospheric interaction once the water has flowed down through the narrow orifice. Two separate precipitation samples have been collected to date. By using a peristaltic pump and metering system, gas samples from the Riverton tailings were collected from piezometers inserted at various depths within the tailings.

During September, 1981, the first water samples were collected at Maybell. Two of the drilled holes were sampled using a submersible pump. The remaining hole plus two previously existing wells were bailed and samples were collected.

5.3 Analytical Results

Tables 5.1 and 5.2 respectively contain the current data for measured field parameters and major chemical components for the Riverton and Maybell sites. All of the analyses are being carried out at LBL with the exception of sulfate, which is being done by Coors Spectrochemical Inc. in Golden, Colorado. The last column marked C/A are the relative ratios of cations to anions indicating the relative accuracy of the results. In Table 5.1 the wells labeled P5, P8 through P21, and RA through RC are completed in the shallow gravel aquifer directly beneath or off site from the Riverton tailings.

Table 5.1

Chemical Analyses of Water Samples from and around the Riverton Site

(Units are $\mu\text{moles/l}$ except as noted)

Well #	Specific Conductance ($\mu\text{mho/cm}$)	pH	EH	D10	Alkalinity	Na	Mg	K	Ca	Si	Cl	Fe	Al	SO ₄	C/A
P1 6/11	12,900	5.89	---	---	---	37.3	26.9	2.25	12.1	---	4.03	57.6	---	107.18	---
P2 6/13	19,300	3.29	---	---	---	36.5	42.8	3.17	16.6	---	3.76	137	---	279.92	---
P3 6/11 Dry	---	3.29	---	---	---	---	---	---	---	---	---	---	---	---	---
P4 6/11 Dry	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
P5 6/11	1,280	7.13	---	---	5.40	3.33	1.40	.263	3.19	.325	1.02	.002	---	4.00	.88
P6	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
P7	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
P8 6/10	800	7.61	---	---	4.95	3.10	.815	.198	2.17	.377	0.367	.002	---	---	---
P9 6/10	5,500	6.35	---	---	10.6	27.5	5.62	.677	14.6	.568	1.96	.035	---	---	---
P10 6/10	2,900	7.40	---	---	---	---	---	---	---	---	---	---	---	---	---
P11 7/15	3,900	7.40	---	---	6.08	17.1	3.39	.228	7.56	.595	4.68	.003	---	14.36	.99
P12 7/15	1,600	7.6	---	---	5.91	9.31	1.13	.217	2.52	.457	1.41	.002	---	5.22	.93
P13 7/15	4,300	6.56	---	---	6.49	17.3	4.03	.619	13.9	.089	2.95	.090	---	22.58	.99
P14 7/15	3,600	7.53	---	---	6.91	10.9	4.53	.900	9.32	.767	3.07	.006	---	15.19	.98
P15 7/15	1,830	7.50	---	---	6.43	6.76	2.17	.215	4.54	.586	2.61	.002	---	6.50	.93
P16 7/15	940	7.0	---	---	4.3	3.93	.905	.105	1.76	.548	.817	.003	---	---	---
P17 8/28	4,800	6.97	---	---	11.1	24.8	6.71	.909	20.7	.463	2.92	.005	---	---	---
P18 8/28	4,600	6.70	---	---	18.5	18.5	6.83	1.20	17.9	.249	2.25	.075	---	---	---
P19 8/28	3,700	6.70	---	---	6.24	9.67	3.57	.957	17.6	.142	1.74	.048	---	---	---
P20 9/24	4,600	6.60	-70	5.80	12.5	30.8	5.66	.415	25.9	.570	1.71	.376	---	---	---
P21 9/24	3,100	6.79	-350	7.52	10.9	131	3.36	.213	10.1	.676	1.28	.016	---	---	---
RA2 8/28	2,200	6.99	---	---	2.48	6.26	.230	.235	9.32	---	.347	.140	---	---	---
RA3 8/26	---	---	-500	1.00	---	---	---	---	---	---	---	---	---	---	---
RB2 8/28	1,200	7.30	---	---	7.48	6.22	.177	.278	3.53	---	.453	.007	---	---	---
RB3 9/25	3,700	7.32	-37	---	8.30	18.2	3.36	.277	11.6	.392	1.13	.009	---	---	---
RC2	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
RC3 8/26	---	---	-30	4.30	---	---	---	---	---	---	---	---	---	---	---
Bromberg	920	8.80	---	---	2.57	7.84	.004	.010	.210	.131	.481	.002	---	2.76	.97
Brown	630	9.10	---	---	3.47	5.69	.000	.008	.090	.148	.149	.003	---	2.09	.75
Nipper	800	8.91	---	---	2.47	7.13	.04	.010	.185	.13	.359	.002	---	2.39	.99
Raymond	725	8.90	---	---	3.23	6.70	.000	.010	.132	.150	.235	.002	---	2.14	1.04
Schlottter	1,090	7.75	---	---	4.01	5.36	.724	.113	1.92	.566	3.91	.002	---	1.56	.98
AG2	1,120	7.52	---	---	5.10	4.43	1.63	.279	2.678	.452	.694	.003	---	4.13	.95
Little Wind River Wind River # Bridge	250	8.21	---	---	1.60	0.53	.218	.051	.715	.103	.065	.002	---	---	---
Little Wind River # St. Stephens	290	8.25	---	---	1.25	0.672	.342	.037	.660	.228	.081	.002	---	0.82	.70
Acid Plant Mill Pond #1	650	8.91	---	---	3.40	6.21	.002	.009	.165	.166	.332	.000	---	1.39	1.01
OH-1	3,600	7.19	---	---	3.00	18.6	4.01	.247	8.840	.142	4.71	.009	---	16.02	1.12
OH-2	---	---	---	---	---	6.21	.002	.006	.270	.192	.857	.002	---	2.21	---
OH-3	8,700	7.65	---	---	2.80	7.76	.004	.010	.785	.152	.638	.002	---	2.76	1.01
OH-4	650	9.55	---	---	.750	6.43	.006	.007	.255	.212	.910	.002	---	---	---

Table 5.2

MAYBELL, COLORADO - Groundwater Analyses (mmole/l unless otherwise noted)

Well #	Specific Conductance ($\mu\text{mho/cm}$)	pH	E _H (mV)	D.O (ppm)	Alkalinity	Na	Mg	K	Ca	Si	Cl	Fe	A	SO ₄
MA 1 9/22	4,700	6.19	+210	---	8.46	15.7	4.20	.508	20.7	1.03	1.22	.005	---	---
MB 1 9/22	4,000	6.81	+255	---	4.50	3.55	4.63	.477	16.9	0.997	3.14	.003	---	---
MC 1 9/22	5,600	6.00	+240	---	7.70	10.9	5.24	.662	---	1.21	1.54	.010	---	---
K-1 9/23	5,600	6.40	+191	8.40	13.1	9.76	0.494	.692	18.4	0.570	2.44	.002	---	---
Observation 9/23	700	7.40	+150	8.35	4.30	0.530	5.24	.087	2.93	0.819	2.443	.007	---	---

The remaining wells are completed in the deeper, Wind River Formation. Chemical analyses are also shown for the two nearby rivers, the Wind River and the Little Wind River, and a nearby pond. In Table 5.2, samples labeled MA, MB, MC, and the observation well are from holes completed in the Browns Park Formation underlying the Maybell tailings. K 1 is from a shallow well in the gulch directly down gradient from the tailings.

Table 5.3 lists the results of the soil gas analyses from a number of samples taken within the Riverton tailings.

A number of samples were also collected from the Riverton and Maybell sites for isotopic analysis; specific isotopes of interest include deuterium, oxygen-18, carbon-13, and sulfur-34. Many of the analyses have yet to be performed by outside laboratories. Available data for D/¹⁸O are given in Table 5.4 and for tritium in Table 5.5.

5.4 Interpretation

One of the aims of the program is to understand the extent of and chemical mechanisms of vertical and lateral transport from beneath the tailings. Figure 5.1 shows variations of field parameters measured in ground water in the shallow gravel aquifer beneath the Riverton tailings. Upper values in the brackets are pH and the lower values, total conductances ($\mu\text{mho/cm}$) which reflect total contents of dissolved solids. As indicated, groundwater situated off site (P11, P12, P14, P15, P16) is slightly basic with pH ranging from 7.40 to 7.60. Ground water directly beneath the tailings (RA, RG, P5, P21, and P22), however, is less than neutral (range 6.99 - 6.60). The only sample which is basic is P5 which may reflect mixing from a nearby irrigation canal and the thin tailings in this area.

TABLE 5.3

Gas component analysis from the unsaturated zone
of the Riverton mill tailings (WT%)

Sample Site	O ₂ - N ₂	CO ₂	H ₂ O
RB #1	76.8	13.4	9.8
P-2	92.9	0.45	6.6
P-3	80.8	9.6	9.6
P-4	75.7	18.2	6.2
P-6	67.8	23.6	8.6
P-7	59.5	31.4	9.1

TABLE 5.4

Deuterium/oxygen-18 ratios for Riverton
groundwaters (reported as parts per mille
deviation from SMOW)

Site No.	¹⁸ O	D
P-1	- 16.22	- 131
P-2	- 16.70	- 133
P-5	- 16.91	- 133
P-8	- 18.07	- 130
P-9	- 15.15	- 124
P-10	- 16.44	- 128
Well C#2	- 17.48	- 131
OS-1	- 17.94	- 139
Acid Plant Well	- 17.46	- 133
Wind River	- 17.40	- 132
Little Wind River	- 17.13	- 123
Pond #1	- 10.77	- 104

TABLE 5.5

Tritium analyses for groundwaters from and around
the Riverton site (reported as Pic/1)

	Site No.	Concentration
	P-1	$2.09 (\pm 0.24) \times 10^2$
Shallow	P-9	$2.21 (\pm 0.25) \times 10^2$
Gravel	P-11	$2.31 (\pm 0.27) \times 10^2$
Aquifer	Site C	$3.09 (\pm 0.35) \times 10^2$
	Schotter well	$2.15 (\pm 0.24) \times 10^2$
Deep Wind		
River Formation	Brown well	$4.16 (\pm 1.8) \times 10^0$
Aquifer	Raymond well	$3.8 (\pm 1.6) \times 10^0$

Fig. 5.1 Location of sampling sites and distribution of pH and conductance values, Riverton site (conductance in units of $\mu\text{mho/cm}$)

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Ground waters collected from points beneath trenches immediately adjacent to the tailings on the south (P9, P13, P17 and P18) and on the east (P19) have an even lower pH (ranging from 6.70 to 6.35). This data suggests that acid seepage from the tailings and trenches has not been totally neutralized or buffered by carbonate minerals within the soil zone or the aquifer. The high concentrations of CO₂ in the tailings (up to 31.4 wt%) suggest that at least some neutralization occurs, probably by the reaction:

It is interesting to note that the one low CO₂ value in Table 5.3 occurred over an area of the tailings pile which is underlain by the plastic liner encountered during drilling. As expected, such a liner would act as a barrier to upward movement of CO₂ produced by acid-carbonate reactions in the soil zone.

The available data from off-site locations suggests that an acid component has not moved laterally from the tailings. However, no off-site ground water information is yet available from directly south of the tailings due to property boundaries. Based on surface drainage patterns and gradients, the probable direction of potential lateral transport would be southward.

As discussed under hydrology, a deeper aquifer (300-400 m) lies under the shallow gravel aquifer and tailings pile. The question arises whether elements will be transported downward from the tailings into the deeper aquifer which is the major domestic and agricultural water supply for the surrounding area.

Figure 5.2 shows a plot of the deuterium oxygen-18 content of the shallow and deep aquifer as well as those for the Wind River and Little Wind River. Values are expressed as δD and $\delta^{18}O$ which are the deviations in parts per mille from standard mean seawater (SMOW). The solid line is the "Craig line" for meteoric water for North American precipitation. As expected, the data, including precipitation from saturated air masses, generally plot close to the line. The two points which deviate from the line, P9 and pond #1, represent very shallow or standing surface water bodies which have been subjected to evaporative fractionation. The similarity in the composition of the shallow and deep groundwater and the rivers at the Riverton site suggest a common origin of the three. Most probably both the shallow gravel aquifer and the Wind River aquifer are both recharged from the nearby rivers.

The tritium values for samples taken from both the shallow and deep aquifers are given in Table 5.5. As indicated by the relatively high contents of 3H , the shallow gravel aquifer has received significant post bomb water (age < 30 years). The very low 3H concentrations in the deep aquifer indicate that this water is generally older than 30 years. The isotopic results suggest that although both aquifers within the flood plain have received surface recharge from the rivers, the relative cycling rate must be much higher in the shallow aquifer than in the deeper one. This result is also confirmed in the triangular composition plots for cations and anions shown in Figures 5.3 and 5.4. As indicated, a relative trend of increasing sodium over calcium exists in the order of: rivers < shallow aquifer < Wind River formation. This trend is probably due to progressive sodium-calcium exchange which is a function of increasing residence times and length of flow paths. As indicated in Figure 5.4, the anion ratios of HCO_3^- , Cl^- , and

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Fig. 5.2 Deuterium - Oxygen 18 ratios, Riverton site

Fig. 5.3 Relative mole fractions of major cations,
 Riverton site

Fig. 5.4 Relative mole fractions of major anions,
Riverton site

$\text{SO}_4^{=}$ are much more similar in composition than the cation ratios for the three water types, which is indicative of a sodium-calcium ion exchange process. The conclusion drawn from the above information is that no direct hydrologic connection appears to exist between the shallow gravel aquifer and the deeper Wind River aquifer over time-frame of tritium data (~ 30 years). Because no perceptible vertical water movement exists with depth, no chemical or radiochemical contamination of the deeper aquifer is expected over periods of several decades or several tens of decades, regardless of the type of chemical transport and reaction processes that may occur under the tailings. The greatest potential for off-site ground water contamination therefore is lateral transport in the shallow flood plain alluvium which appears connected hydrologically to surface flow in the Wind River and Little Wind River.

Geochemistry of water in the unsaturated zone within the tailings is just beginning to be interpreted at the close of the reporting period. The fact that in-situ water samples were successfully collected by suction water samplers for the first time in an UMTRAP tailing pile will be of great interest in determining upward and downward mobility of specific chemical and radionuclide species. Initial data indicate definite elemental profiles within the tailings, as demonstrated in Figures 5.5, 5.6, and 5.7. The relative abundance of sodium and calcium appears to decrease with depth along with a corresponding increase of magnesium. Such trends may be related to dissolution-precipitation relations involving sulfate species such as Na_2SO_4 , MgSO_4 , and CaSO_4 .

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Fig. 5.5 Mole fraction of sodium as a function of depth, Riverton site

Fig. 5.6 Mole fraction of calcium as a function of depth, Riverton site

Fig. 5.7 Mole fraction of magnesium as a function of depth, Riverton site

6.0 RADIOCHEMISTRY

6.1 General

The goals of the radiochemistry component of the present study are:

a) to identify the most important radioactive elements present within the tailings piles; b) to study the relative abundances and vertical distributions of these elements within and immediately below the tailings; c) to obtain direct evidence, if possible, of the movement of water within the piles by repeated downhole radiometric logging of selected holes during different seasons and d) to semi-quantitatively investigate manifestations of radioactive materials on the surface of the piles.

6.2 Instrumentation

The key elements in the present radiochemical studies are three different types of γ -ray detection instruments. The first of these is a portable instrument which employs a NaI(Tl) Crystal. It is best suited for observing materials of lowest activity and is ideal for running rapid radiometric traverses on the site to locate "hot" spots and for general reconnaissance work.

The other two instruments are state-of-the art devices and fall into the general category of high-resolution γ -ray spectrometers. Both of them are based on the use of a pure Germanium Crystal detector and have the ability to differentiate many specific radionuclides in mixtures of high radioactivity materials.

A prototype high resolution γ -ray spectrometer using a Germanium detector has been constructed by SANDIA for purposes of downhole radiometric logging. This instrument, developed for exploration of radioactive mineral deposits will be adapted for the present study. It is proposed to use this tool for repeated, seasonal logging of selected boreholes.

If successful, these logs should help identify specific radioactive signatures whose changes in position with time may throw light on the vertical transport mechanisms within the piles. In addition to the Germanium detector, the above instrument also has pulsed neutron sources which make the instrument potentially capable of much wider applications than visualized in the present project. Its use in the present study will be limited to down-hole logging purposes during scheduled periods. The initial use of the prototype instrument is to be coordinated with the proposed assay program of SANDIA to be conducted starting early in Fiscal 1982 at Riverton and Maybell.

For purposes of detailed, day to day analysis of samples from the field, LBL assembled and tested a non-portable high resolution γ -ray spectrometer by late August 1981. This laboratory-based instrument is now in use and has been used to measure radioactivity profiles in the Shelby-tube samples already collected from Maybell.

6.3 Field Activities: Riverton Site

6.3.1 Surface γ -ray intensity survey: During June 1981, a γ -ray survey was conducted on the Riverton Site using the NaI(Tl) instrument. This survey is of considerable interest since the pile had been similarly surveyed in 1976 by the Oak Ridge National Laboratories (ORNL) (Hayward et al, 1980). The present study revealed a much wider range of γ -ray intensities than could be expected from the ORNL study. Numerous small areas, usually darker in color than the surrounding cover material, produced intensities up to about 500 μ R/hr, in contrast to an expected maximum of about 100 μ R/hr. An attempt was made to repeat one of the previous (1976) traverses across the width of the pile, but with much closer spacing of survey points. This traverse

confirmed the possibility that the previous survey missed the highest intensity areas due to the relatively wide spacing of measurement points. However, the LBL survey does suggest that the γ -levels are now elevated in comparison to the 1976 levels. If this observation is true, the present higher levels could be at least partly a consequence of wind erosion of cover since 1976. The elevated levels could also be due to widespread upward migration of radionuclides through the cover material.

Intercalibration of survey instruments might resolve whether this discrepancy actually reflects a change of in-situ conditions, but may not be possible due to the intervening years.

6.3.2 Shallow pit samples: In addition to the spectrometer survey, shallow pits were excavated at several locations on the Riverton pile to search for evidence of upward migration of contaminants in the zone between the present surface of cover material and the upper layer of tailings. Iron-stained horizons were frequently observed at some distance into the cover material. Samples of several visually distinct materials were obtained. Samples were also taken from several depths in the cover material, as a means to search for vertical gradients in radionuclide content. Details of the laboratory analysis of these samples are given in section 6.8.

6.4 Field Activities: Maybell

6.4.1 Surface γ -ray Intensity Survey: A γ -ray survey, similar to but more extensive than the one already described for Riverton was carried out at Maybell during June 1981. This was done using the NaI(Tl) instrument. For purposes of standardization and convenience, the grid map devised by

SANDIA for its assay program was used for locating the measurement sites. The results of the survey are shown plotted in Fig. 6.1. The observed γ -intensities ranged from 30 to 600 $\mu\text{R}/\text{hour}$. The higher intensities were confined to certain distinct areas of buff and gray color devoid of vegetative cover.

6.4.2 The Browns Park Formation: Two samples were collected from the Browns Park which underlies the Maybell tailings pile. The samples consist of cuttings obtained during extension of hole MB-2 from its previously-cased 5.8 m (19 ft) depth to below the water table (encountered at 27.4 m (90 ft) during drilling). These samples are believed to represent material that is free from direct contamination by any of the drilling operations. Sampling depths are only approximate since the material was collected from air drilling.

6.5 Logging of Cased Bore Holes

The downhole radiometric logging of cased boreholes is to be conducted in collaboration with the SANDIA group, using their proto-type tool. The SANDIA group can deploy two different instruments, capable of implementing three different techniques:

- 1) "passive" high-resolution γ -spectrometry, a multielement technique based on detection of γ -rays from radioactivity that is present prior to the logging activity;
- 2) "active" high-resolution γ -spectrometry, a multielement technique based on detection of γ -rays that accompany deexcitation of nuclei that have captured (mainly) thermalized neutrons that originated as 14 MeV neutrons from a pulsed neutron source located in an adjacent section of the logging tool;

- 3) pulsed fission neutron scanning, a uranium-specific technique based on detection of neutrons that accompany the fission of nuclei by (mainly) thermalized neutrons which originated as 14 MeV neutrons from a pulsed neutron source located in an adjacent section of the logging tool.

One tool, containing a neutron generator and a high-resolution γ -detector, performs the first two measurement techniques. The second tool, containing a neutron generator and a neutron detector, performs the third measurement technique.

The first logging session is expected to commence early in fiscal 1982. During this session, all the aforementioned techniques will be tried. Comparative evaluation of results from these techniques will provide guidelines for their application in subsequent logging sessions of the long-term monitoring program.

6.6 Laboratory Activities

6.6.1 New Instrument: All basic units of the high resolution Ge crystal γ -spectrometer were received, tested, assembled and calibrated for routine data acquisition. This system includes a main-frame multichannel pulse height analyser unit with the capacity to store 16,000 channels of spectral data, along with input routing which permits data collection from four detectors at (essentially) the same time. Three high-resolution detectors are commonly used: the newly acquired high-purity coaxial Ge-crystal to examine the energy range from about 100 to 2700 KeV, and two high-purity planar Ge-crystals to examine the energy range from about 30 to 400 KeV. The initial data collection effort was designed to provide background information that will be useful

during the first field season, during which the major activity will be down-hole logging with the SANDIA high-resolution γ -spectrometer system.

6.6.2 Radionuclide Decay Scheme Information

The decay chains of the three naturally-occurring radioactive series (the U-238, the U-235, and the Th-232 series) are long and complex. Greatly simplified versions of each are presented on Figures 6.2, 6.3, and 6.4, as an aid to improve clarity of the subsequent discussions. This information is organized to emphasize the viewpoint of γ -spectrometry, as described next.

The presence of a half-filled diamond attached to the lower right of a nuclide emblem on Figures 6.2, 6.3, and 6.4, signifies that the nuclide decay is accompanied by γ -ray emission that is regularly useful for quantitative determination by the γ -spectrometric methods employed here. The presence of an open diamond signifies that γ -emission is sometimes useful, usually when this nuclide appears in abundance far greater than in the equilibrium series case. The absence of a diamond signifies the nuclide cannot be detected by these methods. The dashed boxes enclosing certain groups of nuclides identify close associations among members that derive from the capabilities of γ -spectrometry, as modified by the effects of different half-lives for the various nuclides.

Nuclide half-lives enter into the analysis in a special way. Due to the chemical processing of the tailings material, disequilibrium conditions must be expected in all sampling situations. In particular, the detection of one specific nuclide cannot be used to infer the presence of an earlier member (as is the case when equilibrium exists), unless and until appropriate half-life dependent parameters of ingrowth and decay are correctly applied.

Fig. 6.2 Simplified Decay Scheme for U-238 Series

Fig. 6.3 Simplified Decay Scheme for U-235 Series

Th-232 CHAIN

Fig. 6.4 Simplified Decay Scheme for Th-232 Series

For example, disequilibria that may exist among the members

are readily resolved, because the longest half-life of consequence is 3.82 days. (Note that Ra-226 can be considered a stable nuclide on this time scale.) However, earlier members of the U-238 chain cannot be inferred from a determination of Ra-226 - - the intervening half-lives are simply too long for equilibrium to have been established since chemical processing; furthermore, the time scale of the study is too short to reveal any changes in radionuclide abundance that might permit such estimates to be made.

Determination of earlier members requires measurement of earlier members.

Note however, U-238 can be determined from measurement of either Th-234 or Pa-234m, under the same restrictions as were cited for the sequence Ra-226 Pb-214.

6.6.3 Analysis of samples from G. Markos and K. Bush: Formulation of the plan for the radiochemistry program was greatly facilitated by the availability, at the outset, of samples from the Riverton Pile and vicinity that had been collected during 1980 by G. Markos and K. Bush in a related DOE-funded mill tailings study. We received a suite of 28 samples that included examples of tailings material, underlying (presumed) natural material, material adjacent to the pile, and background material from as far as 9 km from the pile. They represented a vertical sampling range from surficial to about 2 meters depth. The high-resolution γ -spectrometric laboratory study of these samples disclosed that all radionuclides expected to be of value to this proposed program were observed in at least some members of this suite.

6.7 Study of Shelby Tube Samples

The Shelby tube samples collected during the drilling phase represent reasonably undisturbed specimens of the in situ material. These specimens are valuable from the radiometric perspective in that they can be systematically scanned to obtain radioactivity-depth profiles at the locations of the several bore holes that have been drilled at the two sites.

Essentially complete sections through the pile and into underlying natural strata were obtained by Shelby tube samplers at three sites on each tailings pile (Riverton and Maybell). Sites were designated A, B, and C, with an "R" or "M" prefix to identify the pile. Shelby tubes were obtained from two adjacent holes at each of the three sites on each pile. Both holes at each site on the Riverton pile were cased in preparation for downhole high-resolution γ -spectrometric logging. Only one hole at each site on the Maybell pile was cased in preparation for the same type of logging. Detailed laboratory γ -spectrometric measurements will establish one set of initial conditions at each of the nine holes.

The γ -spectrometric scanning of the Shelby tube samples is done by two different methods. These are: a) Gross γ -activity scanning and b) High resolution scanning.

6.7.1 Gross γ -activity: A 2" diameter by 2" thick NaI(Tl) crystal detector and multichannel pulse height analyzer were used for detailed scanning of gross γ -activity in each tube using the energy interval from 225 to 1340 KeV. An equilibrium uranium ore check source was used periodically to ensure constant system response. A 2" thickness of lead shielded the detector from the tube except for a 2" wide aperture. The tube was moved past the detector in one or two

inch increments. Errors associated with count integrals were 3% or smaller. Scanning of all 141 Shelby tubes has been completed with this system.

A computer program was written, tested, and utilized for reduction and plotting of these data. Results for each hole are shown in figures 6.5 to 6.16. The program assumes that the lower end of a Shelby tube corresponds to the bottom of the driven interval noted during drilling. If a Shelby tube was longer than the driven interval, the data points from the shallower end of that tube will overlap data points from the lower end of the adjacent and shallower tube. This effect is seen, for example, in the count rate profiles for holes RA-3 (Fig. 6.6), RB-3 (Fig. 6.8) and RC-2 (Fig. 6.9). Shelby tubes longer than the corresponding driven interval occur for either or both of the following reasons: the tube may scrape material from the sides of the hole as it is lowered to the bottom of the hole; material may fall from the sides of the hole to the bottom. This sample contamination can be accounted for during data synthesis because the length discrepancy is known, and the excess material always resides in the uphole portion of the Shelby tube. Gaps in the plotted data result from the material that can be lost from the bottom of the tube as it is brought to the surface; or, lower material can be pushed aside when a stiff clay plug forms within the tube. Loss of sample is more difficult to assess than is the excess material.

Hole RA-2 is a special case. It was the first hole from which Shelby tubes were taken. Routine use of a pipe cutter to remove the unfilled portion of the tubes was not begun until near the bottom of hole RA-2. All tubes above 220" depth had ~4 inches of cover (lower activity) material packed into the top in plastic bags for shipping purposes. These sections were not removed before scanning, and therefore explain the periodic dips seen in Figure 6.5.

Fig. 6.5 Net radioactive count rate, RA2, Riverton site

Fig. 6.6 Net radioactive count rate, RA3, Riverton site

Fig. 6.7 Net radioactive count rate, RB2, Riverton site

Fig. 6.8 Net radioactive count rate, RB3, Riverton site

Fig. 6.9 Net radioactive count rate, RC2, Riverton site

Fig. 6.10 Net radioactive count rate, RC3, Riverton site

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Fig. 6.11 Net radioactive count rate, MA1, Maybell site

Fig. 6.12 Net radioactive count rate, MA2, Maybell site

Fig. 6.13 Net radioactive count rate, MB1, Maybell site

Fig. 6.14 Net radioactive count rate, MB2, Maybell site

Fig. 6.15 Net radioactive count rate, MC1, Maybell site

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Fig. 6.16 Net radioactive count rate, MC2, Maybell site

These profiles of radioactivity will be used to assist in selection of critical sections for detailed laboratory analyses, and for planning the downhole logging effort.

6.7.2 High-Resolution Studies: Systematic study of Shelby Tubes samples was begun, using the laboratory high-resolution coaxial Ge-detector γ -spectrometer system. These measurements, taken on intact (full) tubes, were designed to disclose relative concentrations of several radionuclides at various sampled depths. Such information will provide guidance to the field program of downhole high-resolution γ -spectrometric logging; it will also help to decide how to divide material from the full tubes into small samples for detailed laboratory analyses.

The tube samples were of 3-inch diameter, and varied in length from 15" to 26". At least one spectrum was taken on each tube, usually at the center of the length. The desired section of a tube was positioned against the detector housing for each measurement. The detector was operated in the LBL Low Background Facility, to eliminate the need for shielding against the natural terrestrial γ -field. Local shielding was not used to reduce detector response to radioactivity located in more distant sections of a tube.

Each spectrum consisted of 4096 channels of data, covering the energy interval from about 40 to 2700 KeV. Relative concentrations of specific radionuclides were usually determined from closely spaced pairs of γ -rays with energies greater than 500 KeV. Listed below are several useful pairs of peaks.

PEAK (KeV)	PRODUCING RADIONUCLIDE	RADIONUCLIDE OF INTEREST
583	Tl-208	Th-228 from Th-232 series
609	Bi-214	Ra-226 from U-238 series
1001	Pa-234m	U-238 from U-238 series
1120	Bi-214	Ra-226 from U-238 series
832	Pb-211	Ac-227 from U-235 series
839	Bi-214	Ra-226 from U-238 series

The relative concentration of the producer is directly relatable to the concentration of the radionuclide of interest so long as the halflives of the intervening decay chain members are short compared to that of the radionuclide of interest.

Particular emphasis was given to identifying contrasts in radionuclide content with depth, for example: U-238, as indicated by the 1001 KeV γ -ray from Pa-234m decay; and Ra-226, as indicated by the 1120 KeV γ -ray from Bi-214 decay. Significant changes in the abundance of these radionuclides, or changes in the ratio between the two, should serve as useful horizon markers during the extended downhole monitoring phase of this program. Figure 6.17 shows the profiles for these two radionuclides from Maybell hole MC-2. An abrupt change in the Ra/U ratio in the tailings occurs at about 100 inches depth. The change in the Ra/U ratio reflects a change in the U abundance in the tailings. Gross γ -activity scanning indicated that the tailings/soil interface occurs at about 200 inches depth in hole MC-2. A similar change in the Ra/U ratio was observed in hole MA-2 at 100" depth, although the tailings/soil interface occurs at about 540 inches depth in this hole. No similar change in Ra/U ratio was noted within the tailings column in hole MB-2. In all cases Ra-226 was the dominant radionuclide.

XBL82I-1761

Fig. 6.17 Variation of Ra-226 and U-238 with depth in bore hole MC2, Maybell site

Ra-226 content varied only slowly with depth until reaching the lower interface, where a decrease of two to three orders of magnitude occurred.

Similar study of the Riverton Shelby tubes is underway.

6.7.3 High-Resolution Analysis of the Browns Park Formation, Maybell:

Results are given here for analyses of the downhole samples obtained from the Browns Park formation during drilling of Maybell hole MB-2. Values obtained from the NaI(Tl) crystal γ -spectrometer are based on γ -rays with energies > 1000 KeV, measured in samples that weigh the order of 1000 grams, and reflect the equilibrium U and Th concentrations calculated from the observed abundances of late members in each decay chain. Values obtained from the high-resolution Ge-crystal γ -spectrometer are based on γ -rays with energies < 200 KeV, measured in samples that weigh on the order of 100 grams, and reflect the radionuclide concentrations actually present in the materials.

MB-2, ~48 ft depth

NaI(Tl) results:	Uranium (equilibrium)	4.43 ppm
	**Uranium (equilibrium)	1.48 pCi/gram
	Thorium (equilibrium)	5.13 ppm
	Potassium (elemental)	1.50 pct
	Rn-222 (emanation)	30. pct
Ge results:	**Uranium (elemental)	3.6 pCi/gram

MB-2, ~78 ft depth

NaI(Tl) results:	Uranium (equilibrium)	5.75 ppm
	**Uranium (equilibrium)	1.92 pCi/gram
	Thorium (equilibrium)	5.03 ppm
	Potassium (elemental)	1.46 pct
	Rn-222 (emanation)	37. pct
Ge results:	**Uranium (elemental)	4.4 pCi/gram

Values accompanied by double asterisks (**) can be compared directly for evidence of disequilibrium in the uranium series.

Despite the limited sampling, useful conclusions can be drawn from these results. Most important to our program are the following:

- 1) The equilibrium concentrations of both U and Th are not high compared to the expected range for sandstones;
- 2) The total concentration of elemental U is more than twice the concentration that is in equilibrium with Ra-226.

From (1) we note it should not be difficult to distinguish between tailings material and the underlying natural sandstone during downhole Y-logging.

From (2) we note there is disequilibrium between U and Ra, which must be due to one of the following:

1. downward movement of U from the tailings;
2. ground water transport from nearby natural high-U materials through this relatively unconsolidated formation;
3. leaching of Ra from the sandstone.

6.8 Study of Shallow Pit Samples

6.8.1 High-Resolution Study of Riverton Samples

Laboratory analyses (using the high-resolution device) of samples collected during the shallow pit excavations on the Riverton pile suggest the upward migration into the cover material of at least the following long-lived radionuclides:

U-238, U-235, Th-230, Ac-227, Ra-226, and Pb-210 (the two U decay chains)

Detailed results from one sequence of shallow pit samples are included here to illustrate the kind of information obtainable with the high-resolution Ge-detector as a laboratory γ -spectrometer. These samples were taken during excavation of one end of an oblong-shaped dark colored surface patch. The sampling traverse extended from inside the tailings across the interface into cover material along a line normal to the tailings/cover interface.

The absolute concentrations of all radionuclides discussed here are (except for Pb-212) greater than the natural concentrations expected in cover material, as estimated from measurement of a sample of the local source of this cover material. Hence, these elevated concentrations are taken to be associated in some way with the presence of the tailings. If the relative proportions of radionuclides found at above-natural levels are the same as those proportions observed in tailings material, then a simple mixing during the covering operation could explain the observation. However, if these proportions are different in cover material than in tailings, the most likely agency becomes fluid transport, with or without associated in-situ solid-solid and liquid-solid chemical reactions.

Figures 6.18 and 6.19 illustrate the kind of contrasts in radionuclide content that were observed. Each data point represents a sampling of a 1-inch thickness of material, related to the in-situ distribution as indicated schematically along the lower edge of each graph. The various profiles have been displaced along the relative vertical scale for clarity of presentation. The specific radionuclides and γ -energies belonging to these profiles are appropriately identified on each graph.

XBL 821-1758

Fig. 6.18 Profile of Th and Pb isotope concentrations along a tailings-cover traverse, Riverton site

XBL 621-1759

Fig. 6.19 Profile of U, Ra, Pb and Bi isotope concentrations along a tailings-cover traverse, Riverton site

First, consider the profiles on Figure 6.18. The profile for short-lived Th-234 should be diagnostic for uranium content in general, and literally for U-238 content. The profile for long-lived Th-230 should be diagnostic for the content of this nuclide. The profile or short-lived b-212 should be diagnostic for some combination of Ra-228 and Th-228 members of the Th-232 decay series. The striking contrast between the Th-234 profile and the Th-230 profile is likely to be a consequence of the different chemical behaviors of uranium and thorium: the observed Th-234 migrates as U-238, while Th-230 migrates as Th-230.

Next, consider the profiles on Figure 6.19. The four lowest profiles, from short-lived Bi-214 and Pb-214, can be diagnostic for Ra-226, provided there is negligible escape (emanation) of the intervening gaseous Rn-222, or when any significant emanation is properly taken into account. The next higher profile, from long-lived Pb-210, can also be diagnostic for Ra-226, again provided the Rn-222 emanation is either negligible or known. Departures in shape between the Pb-210 profile and the four others immediately below indicate either significant transport of Rn-222 or chemical fractionation. The 22-yr half-life of Pb-210 may permit insight into the behavior of Rn-222 emanation and migration over a time span the order of the life of the tailings pile, in contrast to the short-term information available from the pair Bi-214/Pb-214. The top profile is a composite from two long-lived radionuclides, U-235 and Ra-226. This profile should be intermediate in shape between the Bi-214/Pb-214 shapes and the Th-234 shape from Figures 6.18 and 6.19, unless the U-235/U-238 ratio is significantly different from its normal value.

This type of sampling and analysis can track the migration of these radionuclides, and through application of the relevant decay schemes,

can relate their distribution to the chemical environment. Among these nuclides, those with halflives that range from tens of minutes to tens of years may provide important evidence from which the time scale of past migrations can be estimated. These procedures will be expanded, refined, and applied to the problem of vertical migration throughout the monitoring phase of this project.

7.0 SUMMARY AND FURTHER WORK

7.1 Summary

The present study is the beginning phase of an effort to develop an understanding of the physico-chemical interactions that occur within two typical inactive uranium mill tailing piles under the jurisdiction of the UMTRA Program. These sites are located at Riverton, Wyoming and at Maybell, Colorado. The understanding is to be gained through integrated hydrological-geochemical-radiometric studies. The field work carried out during fiscal 1981 extended from June to September. During this period, exploratory drilling was completed at six locations on the Riverton and Maybell piles. Over 141 Shelby tube samples were collected, which represent relatively undisturbed core samples of the tailings material. In order to gain a maximum advantage of the short time available before the onset of the winter, it was decided to concentrate the rest of the data collection at the Riverton site, where the water table is shallow.

At the Riverton site 21 piezometers were installed in and around the site. At each of three selected sites along an east-west line a pair of tensiometer-soil water sampler (SWS) nests were installed, with individual tensiometers reaching down to a maximum depth of 0.9 meters. A precipitation collector was installed for collecting water samples for isotope analysis. A rain/snow gage was installed to measure rain and snow precipitation throughout the year. Water level recorders were installed on two cased boreholes to monitor water table fluctuations. Six cased bore holes were established for downhole radiometric logging by SANDIA using the high resolution gamma ray spectrometer.

The tensiometer data collected have shown that the tailings at Riverton are in a state of moderate saturation down to a depth of about a meter, with magnitudes of moisture suction less than one atmosphere. Passive monitoring of the tensiometers at the three sites has shown that over a period of a month from August 25 to September 25, the profiles of fluid potentials remained fairly stable with the gradients being upward within the first meter or so of the tailings surface. The data also suggested that the fluid potentials measured were higher than the water table elevation at all the sites, indicating a downward hydraulic gradient in the central portion of the pile. If chemical and thermal effects do not exist, then the observed gradients would suggest upward water flux within the first meter of the tailings surface and downward movement of water towards the water table in the central part of the pile. Actual flow velocities are unknown at this time since the unsaturated hydraulic conductivity of the tailings materials is unknown. Estimates of unsaturated hydraulic conductivities will be made from laboratory measurements during 1982.

Three infiltration tests were conducted, one at each of the three Riverton sites. The tests showed that tensiometers within a depth of a meter of the tailings surface sensed the migration of the infiltration front within a few hours. Saturated hydraulic conductivity of the materials within a meter of the surface was estimated to vary from 0.0028 cm/sec at site RB to 0.00048 cm/sec at site RC. These correspond to the range of values commonly associated with silty sands to clean sands. Monitoring of the tensiometers at sites RA and RB during late September, a month after the infiltration experiments at those sites, showed that the waters applied during the infiltration experiment were still in the process of being redistributed and that

the pre-infiltration tests conditions were not yet attained. This may suggest that the unsaturated hydraulic conductivity of the tailings may be very small. It was also noticed that although the passive monitoring nest at each site was only 2 meters away from the ones on which infiltration tests were being conducted, they did not sense the effect of the infiltration experiments. This suggests that the movement of water is dominantly vertical within the tailings.

A number of water samples were collected from surface water bodies, wells, boreholes and precipitation collectors for chemical analysis. Analyses of these samples show that the water within the piles is distinctly acidic in nature and is high in dissolved solids. There is evidence that as water moves down from the tailings into the shallow water table, the acid is neutralized by the carbonate in the soil, with the precipitation of calcium sulphate and the liberation of carbon dioxide. Analysis of gas samples indicated that the partial pressure of carbon dioxide was particularly high (31 wt %) in some samples, suggesting that the buffering capacity of the soil may be limited in comparison with the acidity of the tailings water. In contrast to the tailings water, samples from shallow and deep ground water sources are neutral to alkaline in nature. Analysis of oxygen-18 isotope data indicate that both shallow ground water and ground water from a depth of about 122 meters have a common meteoric origin. However, tritium data show that the deeper water is distinctly older than 30 years. This leads to the inference that vertical migration of contaminants directly downward into the deep aquifer will be extremely slow, if at all. Attention therefore needs to be concentrated on lateral flow in the shallow ground water system immediately below the tailings. There is evidence that the prevalent direction of

movement of the shallow ground water is southward from the tailings towards privately owned lands. Data from sulphur isotope analysis indicate that sulphur-34 will be an ideal tracer for monitoring the contaminant plume.

Traverses made for gross radioactivity using a NaI instrument have indicated that at Riverton as well as at Maybell several hot patches exist with enhanced radioactivity. Comparison of the Riverton traverse results with earlier traverses by Oakridge National Laboratories as well as by EPA indicate that the surface radioactivity might in general have increased at these sites over the past few years. These patches might have arisen either due to erosion of the soil cover by natural processes or by the upward migration of the isotopes due to upwardly mobile interstitial water.

A high resolution gamma ray spectrometer, based on a Germanium crystal detector was assembled at LBL for laboratory scanning of field samples and cores. All the 141 Shelby tube samples were scanned by the NaI spectrometer for gross radioactivity. These scans are not only helpful in identifying the contact between the tailings and the soil, but are also very useful for selecting a limited number of samples for future laboratory analysis. High resolution analysis of samples from the Browns Park formation below the Maybell piles show that distinct differences exist in the radioactivity content of the tailings and the underlying Browns Park formation. Also, the disequilibrium found to exist between Uranium and Radium indicate that radioactive isotopes may be getting transported from the tailings to the bed rock.

7.2 Planning of Activities for 1982

Considering the time constraints of the over all UMTRA program goals, fiscal 1982 is an important year. Critical data must be generated to aid the architectural engineer in design activities. In order to help in optimal

planning of the 1982 efforts of LBL and to have an independent evaluation of the data gathered and the inferences drawn during 1981, a peer review committee was constituted during early September, 1981. This committee consisted of Dr. Keros Cartwright of the Illinois State Geological Survey, Dr. John A. Cherry of the University of Waterloo, Dr. Thomas Shepherd of Colorado State University and Dr. Michel Vauclin of the University of Grenoble in France. After a meeting of the committee at LBL on September 10, 1981, both oral and written comments were solicited from the members. These comments provided valuable insights into the nature of the field problem and have helped greatly in the plans discussed below under further work.

7.2.1 Definition of Objectives

For purposes of convenience, we can divide our discussion into three parts: field work at Riverton; field work at Maybell; and laboratory work.

7.2.1 A. Field Work at Riverton: Based on the data collected during the 1981 season, we can recognize the four following zones:

- a) the upper zone including the covering and the uppermost part of the tailings material
- b) the middle zone comprising the central part of the tailings
- c) the bottom zone including the lower part of the tailings and its interface with the water table

and

- d) the off-tailings zone, principally the region immediately to the south, which is the suspected direction of movement of the shallow ground water.

Each of the four zones mentioned above has its own hydrologic and geochemical character. The upper zone, being a boundary of the dynamic system is strongly subjected to the influence of fluctuations in atmospheric conditions as well as seasonal temperature variations. Fluid flow in this region will be influenced by changing thermal regimes. In addition, the physical nature of the cover material (its thickness, permeability, vegetation) will also be an important factor. Because of the complexity of the flow field, considerable effort will be needed to monitor the upper zone, both by way of detailed instrumentation and by way of sophisticated analysis of the data. Since the cover material at the Riverton site is fairly thin (less than a foot over much of the area), there arises a question as to how representative will be the study of the upper zone in respect of the much thicker covers (approximately one meter) that are proposed for future designs. Perhaps, detailed monitoring of thicker cover materials may be worthwhile elsewhere. While the study of the fluid flow dynamics in the upper zone will involve considerable effort, there is little doubt the study will be very valuable since the hydrodynamics of the soil-water system close to its interface with the atmosphere is not well understood at present.

The middle zone, being removed from the upper boundary as well as from the lower interface of the tailings with the fluctuating water table, is perhaps the most stable zone from which reliable data could be collected on the fluid flow and the geochemical interactions. Because of the relative stability, the data collected should be useful for extrapolation much further into the future than is possible otherwise. In the western part of the Riverton pile, where the tailings are thickest, this zone may extend from 1.5 to 4 meters below the surface.

The lower zone is also a boundary, along which conditions will change with time. The most obvious variation in this regard is the rise and fall of the water table. It is likely that the water table may indeed rise into the lower part of the tailings during the spring thaw season. This rise and fall of the water table will have very significant chemical implications in that the rising water table will bring the neutral or slightly alkaline ground water in contact with the acidic tailings water. Depending upon the buffering capacity of the ground water, several processes such as absorption, precipitation and coprecipitation will occur. An understanding of these processes will be valuable in understanding the long term contaminant potential of the Riverton pile. However, because of the presence of gravel and cobbles in the alluvial materials underlying the pile, coring and instrumentation of the lower zone will be time consuming and difficult. To the extent possible, attempts must be made to collect closely spaced samples along a vertical line traversing the upper two meters of the saturated zone of the seasonal high water table. In conjunction with the chemical samples from the fourth zone described below, the study of the lower zone will provide insights into the nature of contaminant flux from the tailings.

The off-tailings zone is the fourth zone that needs study to decipher the lateral flux of contaminants from the tailings into the shallow ground water reservoir. Inasmuch as the suspected movement of the shallow ground water is in a southerly direction, one or more piezometer nests will need to be installed in the area to the south of the pile, to monitor the fluid potentials as well as to collect water samples for chemical analysis. An important consideration in this regard is the fact that private lands exist very close to the tailings on the southern side. Permission has to be sought from the owner of the land before instruments are emplaced.

7.2.1 B. Field Work at Maybell: Little quantitative data was

collected during the 1981 season on the degree of saturation and the magnitude of moisture suction within the Maybell pile. There is reason to suspect that as a consequence of the deep water table (nearly 30 m below surface) saturations will be low and moisture suctions high in parts of the Maybell pile. Even when moisture suctions are relatively close to an atmosphere, available tensiometers can be used successfully only to a depth of 2 to 3 meters depth. At greater depths, one has to use other devices (resistivity devices; psychrometers) which are far less convenient to use than the tensiometers. The work at Maybell during the coming season will seek to understand the vertical flow field within the pile using much the same philosophy as at Riverton. However, instrumentation difficulties are likely to be encountered and will need to be resolved.

7.2.1 C. Data Uncertainty: Because of the considerable heterogeneity

existing within the piles, a critical question that will arise in the reduction of data, especially in regards to the hydraulic parameters, will be that of confidence or certainty. The certainty question will become especially crucial when one wants to decipher the existence of coupled phenomena that may be quite weak (e.g. osmotic potentials). The latest effort to incorporate uncertainty into rational analysis has directed many workers to collect the same kind of data from a large number of points (in space or in time) so that the data could be analyzed for mean tendencies and variances. In formulating the 1982 field work at Riverton and at Maybell, the need for such statistical work is immediately suggested. However, it must be recognized that for a meaningful statistical analysis 20 to 30 sample sets will normally be needed to have a reasonable representation of each variable phenomenon. In terms of

piezometer and tensiometer nests that are needed, statistical work will entail a significant amount of funds and time. Whether or not we could afford statistical data collection within the time and financial constraints of the project needs to be carefully evaluated.

7.2.1. D. Downhole Radiometric Logging: One of the most serious deficiencies of available techniques for studying chemical transport is that there is as yet no reliable method available to directly observe the flow of water. One of the principal objectives of the present study is to assess whether the movement of water within the tailings is controlled by chemical potentials in addition to mechanical potentials. This assessment will be greatly facilitated if, in addition to the simultaneous measurement of fluid potentials and chemical potentials, one can directly observe the movement of water. One possible way to do this will be to carry out downhole radiometric logging using high resolution gamma ray spectrometry and to look for specific radioactive signatures that change position with time (Nelson et al., 1980). The SANDIA downhole radiometric logger will be used for repeat logging of the same borehole at several different times with this purpose in mind. The success of this venture depends very much on the condition of the boreholes as well as the quality of the logging device. The entire attempt is experimental in nature and much experience has to be gained. The core samples already collected from the holes designated for logging will be scanned in the laboratory with the high resolution gamma ray spectrometer already commissioned at LBL. A comparison of the results of this scanning work with preliminary downhole data from the borehole logs should throw light on the feasibility of the downhole logging method as a tool for detecting the direction of movement of tailings water.

7.2.1. E. Laboratory Activities: A large number of relatively undisturbed samples have been collected for laboratory analysis from Riverton as well as from Maybell. These samples have been scanned already for the variation of the gross radioactivity with depth. Using these profiles as guides, a critical number of samples have to be selected for coordinated hydrological, geochemical and radiometric studies. In addition to measuring their properties such as size distribution, porosity, permeability, saturation and so on, the cores will also be used to conduct column experiments to study water and chemical transport under partially saturated, transient conditions. These column experiments are important since it is very time consuming and difficult to carry out chemical transport experiments under partially saturated conditions in the field.

7.2.1. F. Modeling: From the view point of priority, modeling will be at a low level during the 1982 fiscal year. A strong model-base is already available at LBL to simulate flow in the unsaturated zone (Narasimhan, 1977). This base will have to be extended if chemical potential indeed proves to be of importance with reference to mill tailings. Further work that may need to be done in the area of modeling should await field and laboratory data that will be forthcoming during fiscal 1982.

7.2.2 Work Plan for 1982

The technical objectives outlined above are to be prioritized in the context of the time constraints and the financial constraints of the overall UMTRA program. Towards that end, discussions will be held between LBL personnel and the technical advisers of the UMTRA program early in February to evaluate key issues, assign priorities and outline the final plan of action.

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Appendix 1

A1.0 SITE PREPARATION

A1.1 General

The tailings piles are complex systems of interfingering "deltas" artificially discharged from multiple discharge points. These deposits are composed of thin (less than 5 cm) layers of material that grade from sand at the discharge point to fine silt further away from these points. The depositional process causes the direction of flow from any discharge point to shift frequently. Near the discharge point, very coarse material will be deposited regardless of the direction of flow. However, within a few meters of the discharge point, coarse material may be bound above and below by slime. The monitoring instrumentation must accommodate both the vertical and lateral inhomogeneity within this complex environment. We decided, therefore, to have three study areas at each of the sites. These study areas would represent locations near, intermediate to, and relatively far from the tailings discharge points.

A.1.2 Drilling Method Considerations

The selection of drilling methods and instrumentation techniques would be largely dependent on the degree of saturation of the tailings and the physical properties of the crushed rock material that constitutes the tailings and the nature of the underlying alluvium. Given these conditions, the intended use of the borehole would set further limits on the drilling and completion procedures. The down-hole gamma-ray spectrometer would be looking at the borehole wall, and thus would require a minimum annulus between the casing and the borehole wall. This annulus would have to be filled with a material that has a minimum shielding effect, does not contribute gamma-rays

itself, and prevents radioactive tailings from dropping down the hole and producing an inaccurate distribution log. The hydrologic investigation would be concerned with the fluids at the bottom of the hole. The drilling process must not introduce contaminants from overlying materials or fluids, and the presence of the borehole must not short circuit natural flow systems within the pile. The method used to collect undisturbed samples for laboratory analysis is also limited by the physical properties of the tailings and their degree of saturation. Low saturation and poorly sorted grain size would enable the use of open tube type samplers. Saturated material or coarse, well sorted material would be difficult to collect as they would fluidize and fall out of an open ended sampler.

The first objective of site preparation was to determine the degree of saturation in both piles and gain a feeling for the strength, physical character, and stratigraphy within the piles. The drilling, conducted to determine the acidity of the Riverton pile, indicated that the tailings were unsaturated and that, because of the angularity of the crushed sand particles, the boreholes would stand open rather well. This drilling also indicated that driven-tube sampling would be feasible and that the tube length should be between 50 and 75 centimeters. Attempts to drive more than 75 cm resulted in the sampler plugging and the soft tailings being displaced by the plug rather than entering the tube. Tubes driven 50 cm almost always collected a good sample. It was therefore concluded that in order to increase productivity and reduce the time in the field, each tube should be driven at least 50 cm.

The saturated, coarse, river alluvium under the tailings at Riverton consisting of sands and cobbles was far more difficult to deal with. The

cobbles would be displaced by the rotary bit and then fall back into the borehole when the bit was pulled from the hole. One way to drill in this kind of material was with large, hollow stem augers that allow the casing to be inserted through the hollow stem. After the casing is in place, the augers are pulled out and the displaced material flows in around the casing. For the 10 cm internal diameter casing required for the gamma-ray logging, this technique would require augers with a 32 cm outer diameter. This leaves an annulus of over 10 cm, which, when backfilled, may make the logging impossible due to the shielding effect of the fill. In addition, the presence of such a large annulus increases the possibility that material might slough from the borehole wall before the annulus is backfilled. This has two bad effects. First, the annulus is increased in the area where the material comes off the wall and secondly it is decreased where the material comes to rest. The logging tool only looks at radiation intensity vs. energy; the apparent emission rate can decrease where the annulus is enlarged and increase where the annulus is reduced, simply due to the proximity of the material to the detector. This geometric effect would appear as an apparent change in the activity level of the tailings and the magnitude of the change would be a function of the volume of material that had slipped down the borehole rather than the actual distribution of the radio-nuclides in undisturbed tailings. We had to experiment with various drilling techniques until we identified the method best suited for this environment and the objective of this study.

A.1.3 Riverton: Drilling and Sampling

The alluvium at the Riverton site has a relatively flat surface and is easily distinguished from the overlying tailings on the basis of grain size (cobbles up to 20 cm) and color. The first drilling and sampling took place

at Riverton in early June. Continuous, 7.6 cm diameter, Shelby tube samples were taken through the pile to the top of the alluvium. These holes were then reamed with a 14 centimeter rotary bit and extended into the underlying alluvium. Two problems immediately developed; first the bit did not penetrate the cobbles, and secondly the circulating water eroded the part of the hole drilled in the tailings. Despite these difficulties, 10 cm inner diameter casing was installed in RA-2, and RB-2 through the tailings but not into the cobbles, while RC-2 was cased to a depth of 3.9 m below ground surface or 3.0 m below the bottom of the pile. The rotary drilling did result in a hole only slightly larger than the casing, so the tailings were allowed to close in around it without introducing any backfill material. The drilling water, however, had eroded the tailings and redistributed material along the borehole, and these holes did not extend far enough below the tailings to allow the logging of the bottom of the pile since the detector in the SANDIA logging tool is not located at the bottom of the tool.

The second drilling and sampling program at Riverton took place in July. After considering the alternatives we decided to use augers with an outer diameter of 18.5 cm. These would produce a hole slightly larger than the couplings on the 10 cm internal diameter casing. The augers would also penetrate the river alluvium and lift out the sand and smaller cobbles. It would probably take repeated drilling of the portion of the hole in the alluvium to achieve a stable hole into which to insert the casing, but the annulus would be kept to a minimum. The annulus would be filled with washed 0.5 cm gravel. Boreholes RA-3, RB-3 and RC-3 were completed through the river deposits with this method. Continuous Shelby tube samples were also taken through the tailings for each of these boreholes before the auger drilling began.

Piezometers P-11 through P-16 were also installed in the alluvium around the pile at this time using the 18.5 cm hollow stem augers and inserting a 3.8 cm PVC pipe down through the hollow stem. The lower 60 cm of pipe was slotted with a hand saw to allow water entry. Piezometers P-1 through P-7 had been installed in June using a drive point technique. Piezometers P-8 through P-10 were also installed in June by digging holes in the alluvium and installing slotted PVC stand-pipes. In September, piezometers P-17 through P-21 were installed using hollow stem augers. This completed the drilling at Riverton for the year.

A.1.4 Maybell: Drilling and Sampling

The pile at Maybell posed a different problem since it was deposited in a "V" shaped stream valley cut into the rock type from which the uranium ore was mined. Determining the pile/soil interface was difficult since the pile is composed of the same material as the underlying rock. In addition, the pile is very asymmetrical as is shown in the profiles in Figure A.1.1 making it difficult to predict the probable thickness of the tailings. This profile results from the discharge points having been located along the dam that formed the pond. The flow of tailings into the pond was in a direction towards the valley up-slope. The tailings would have a much lower pH than that of the bedrock or soil because of the acid leach process used in the mill. Simply measuring the pH of the Shelby tube samples should indicate the locus of the interface which could later be determined accurately with the radiometric measurements or petrographic analysis in the laboratory.

The first drilling at Maybell was strictly exploratory in nature and was intended to: 1) locate the bottom of the pile; 2) establish the degree of saturation of the tailings; and 3) determine the hardness of the underlying

MAYBELL TAILINGS PILE

XBL 821-1739

Fig. A.1.1 Profile of the Maybell tailings pile with projected lower boundaries

bedrock so that future drilling could be planned. Therefore, only Shelby tube sampling was conducted during this initial effort. The pH of the material in the lower end of each Shelby tube was measured to determine the acidity of the material at that depth. The presence of root material and some textural changes supported the determination of the interface.

As at Riverton, the Maybell pile was found to be unsaturated, although some samples contained more moisture than others, probably due to variabilities in the moisture-holding properties of different materials. The bore-hole walls were stable enough to drive the Shelby tubes without using any augers to hold the hole open. The underlying Browns Park formation was found to be relatively soft and could be penetrated by Shelby tubes to depths of one to two meters.

A 0.95 centimeter inner diameter polyethelene tube perforated over the lower 15 cm and wrapped with 200 mesh polyethelene screen was installed in each of the three holes (MA-1, MB-1, and MC-1) after which the hole was allowed to collapse. This tube would serve as gas sample points or piezometers if water accumulated in the sediments.

The program called for boreholes to penetrate the water table below the tailings pile. While the tailings proved to be cohesive enough to drill deep auger holes without casing, our experience at Riverton indicated that the tailings were fragile and would not stand up to the stress of a circulating drilling fluid. Water table measurements and water levels in old pits at Maybell indicated that we may have to drill as deep as 55 meters to intersect the water table under the tailings pile. This would require rotary drilling. It did not appear feasible to try to use augers to this depth in the dry bedrock.

Deep holes that penetrate the water table would have to be drilled in two stages. An auger drill would be used to drill through the tailings and about three meters into the bedrock. This hole would be cased and the annulus space in the bedrock would be filled with cement, the annulus space in the tailings would be filled with clean one centimeter gravel. Rotary drilling with water would then be used to deepen the hole to the water table.

In September we tried to implement this plan. The holes were first sampled with Shelby tubes, then reamed with augers and the 15 cm internal diameter casing was cemented into boreholes MA-2, MB-2, and MC-2. Rotary drilling began in hole MA-2, but within the first three meters of drilling roughly 400 liters of water had been lost. The Browns Park formation was too soft and permeable to allow us to keep drilling with water. Further rotary drilling was abandoned to avoid a major contamination of the formation by the drilling fluid.

In mid-September drilling was carried out to complete these holes using an air-rotary drill. The air would remove the cuttings with a minimum of stress on the bedrock and no water would be introduced into the groundwater system. The risk of drilling with air is that as one drills deeper, the cuttings, especially if they are damp, will tend to stick to the drill pipe and the possibility of getting the drill stuck in the hole will increase. The projected 55 meter depth would mean that drilling has to be very careful especially if there was a thick partially saturated zone above the water table. Holes MA-2, MB-2, and MC-2 were all drilled to 41 meters and cased with 10 cm inner diameter APS plastic casing. These holes were shallower than expected because water was encountered in each hole at depths of 24 to

30 meters below ground surface. The water level in MB-2 was measured at 29 meters below the top of the casing on September 22. Further geologic investigation is required to determine the reason for the water table being higher than expected in this area.

A1.5 Packaging of Samples and Shipment

The tailings being radioactive, care had to be taken so that the activities associated with our investigations did not spread this material beyond the boundaries of the tailings piles. Both the Riverton and the Maybell piles have a soil cover with good grass growth. Initial radiation measurements indicated that this soil cover provided a good barrier to the radioactive material below. However, there exist numerous patches up to several square meters in area on both piles where this cover is thin, nonexistent, or the radioelements have been transported through the cover and is exposed on the surface. In order to assure the safety of the project personnel and to assure safety regulations in general, a consultant was contracted to check on the radiation levels during the field operations and to assure that all equipment leaving the site was clean. His observations of our techniques and the general levels of both alpha and gamma radiation showed that the sites were relatively safe to work on and that good housekeeping should guarantee health safety.

The samples shipped to LEL were also checked to assure that they were well within the regulations for interstate shipment and would not contaminate any area of the laboratory where radiation exposure limits are stricter than most state or federal regulations. The Shelby tubes were capped with tight fitting plastic caps, sealed in a polyethylene tube, and packed in boxes for shipment. The radiation levels of this material were well within limits for general

truck freight transport. The movement of this material at LBL is monitored by the laboratory's Environmental Health and Safety division.

A.1.6 Field Instrumentation: Riverton, Wyoming

The installation of field instruments was commenced in July, 1981. Inasmuch as the much larger depth of the unsaturated zone would demand the use elaborate instrument set up, it was decided to concentrate attention on data gathering at Riverton for the rest of the year. The design of instrumentation at Maybell would draw upon the experience to be gained at Riverton.

Since the tailings are unsaturated, the pore pressures within the pile would all be less than atmospheric, so tensiometers would have to be used to measure the hydraulic potential within the piles. Similarly, ceramic cup lysimeters would have to be used to collect fluid samples from the unsaturated tailings. Six test sets of tensiometers and lysimeters were installed at Riverton in July so that some simple infiltration tests could be made to test the feasibility of using this instrumentation. The tests are discussed in detail in the Hydrology section of this report. Basically we found that these instruments could be used and that there are very local and sharp inhomogenieties in the tailings. We also learned that we should pack the annulus around these instruments with Kaolin to prevent short circuiting the flow of fluids through the tailings.

A disadvantage to these instruments is that they contain water and thus cannot be used in the winter when the ground is frozen. We have gained enough information to plan an extensive series of tests that can be run during the spring and summer of 1982.

To monitor precipitation on the pile, two instruments have been installed at Riverton. A precipitation collector was installed in July to simply collect a large sample of precipitation for isotope analysis. This was augmented in October with a tipping bucket rain/snow gauge which will measure the actual precipitation on the tailings pile. This gauge is equipped with a propane heater that will allow it to operate throughout the winter. These instruments are located in the southwest corner of the pile next to piezometers P1 and P2, Figure 3.1.

For water table monitoring, two spring-driven water level gauges were borrowed from the U.S. Geological Survey in Riverton and installed on boreholes RA-3 and RB-3. These will record the changes in the water table below the pile. Between our drilling programs in June and July it appeared that the water table had dropped one quarter to one half meter. Conceivably the water table could rise into the lower part of the tailings in the spring when the rivers are in flood, and in the summer from infiltration from nearby irrigated fields.

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