*Laboratory and Field Studies Related to the
Hydrologic Resources Management Program*

October 1, 1993—September 30, 1994

Edited by Joseph L. Thompson

Contributors

W. L. Hawkins

M. Mathews

S. Maestas

J. L. Thompson

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

218

Los Alamos
NATIONAL LABORATORY

Los Alamos, New Mexico 87545

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

CONTENTS

ABSTRACT	1
EXECUTIVE SUMMARY	2
I. INTRODUCTION	4
II. PROGRAM COORDINATION AND TECHNICAL SUPPORT	4
III. OPERATIONAL SUPPORT	5
IV. GROUNDWATER PROTECTION	9
V. GROUNDWATER MONITORING	9
REFERENCES	20
APPENDIX	24

LABORATORY AND FIELD STUDIES RELATED TO THE HYDROLOGIC RESOURCES MANAGEMENT PROGRAM

October 1, 1993 — September 30, 1994

by

Joseph L. Thompson

Contributors

W. L. Hawkins, M. Mathews, S. Maestas, and J. L. Thompson

ABSTRACT

This report describes the work done at Los Alamos in FY 1994 for the Hydrologic Resources Management Program, a multi-organization project funded by the US Department of Energy/Nevada Operations Office. We participated in cooperative collaborations with University of California (UC), Berkeley, the Yucca Mountain Project, the Underground Test Area Operable Unit, and other participating organizations within the Hydrologic Resources Management Program (HRMP). We provided operational support to the Nevada Test Site (NTS) organizations by testing a water-evaporation system, championing the use of high-sensitivity logging equipment during drillbacks, and participating in the planning and execution of drilling operations at two nuclear test sites. Los Alamos personnel cooperated in preparing a proposal to drill beside and under a nuclear test located in unsaturated media. We gave assistance in laboratory work related to colloid migration and actinide sorption. In conjunction with personnel from the Lawrence Livermore Laboratory, we collected water samples from 10 wells at the NTS that are known to contain radionuclides. Our analyses of these samples suggest that radionuclides may not be moving away from cavity zones at appreciable rates. Recent field sampling shows clearly the need to purge wells of materials introduced during drilling and illustrates the inconsistency between water samples taken by bailing and those taken by pumping.

EXECUTIVE SUMMARY

Los Alamos has actively participated in the Hydrologic Resources Management Program (HRMP) since its inception some 20 years ago. Our long experience with field studies at the Nevada Test Site (NTS) as well as laboratory expertise in radionuclide analysis enables us to provide technical support for drilling and monitoring operations, to gather and interpret data on radionuclide movement in the underground environment, and to assist in the stewardship of water resources. There is a continuing need for the type of work done by the HRMP because of the continuing potential for contamination of NTS aquifers by residues from underground nuclear testing. This report describes in detail all the work done by Los Alamos personnel in FY 1994 as part of the HRMP.

We cooperate with other programs where there is mutual interest; this has led to extensive interaction with the Yucca Mountain Project (YMP) and the Underground Test Area Operable Unit (UGTA). We provide technical support to both these organizations through formal presentations and document reviews. We also are working with a professor at UC Berkeley on a project to model gaseous contaminant transport through NTS geologic media. Our cooperative field work with the other HRMP participant organizations, especially with the Lawrence Livermore National Laboratory (LLNL), has been mutually beneficial. In cooperation with LLNL personnel, we have recently sampled material from 10 sites on the NTS.

Los Alamos continues to provide support for NTS operations. In conjunction with the Desert Research Institute (DRI), we field-tested a solar-powered pump and spray system to speed up water evaporation from a storage tank at the Cambric site. We continued to explore the utility of high-sensitivity gamma logging to guide sidewall sampling in holes drilled in or near shot cavities. We provided technical input to the planning and execution of drillbacks at U-2gg and U-7ba. At U-7ba, we were involved in collecting a very extensive set of sidewall samples and are presently engaged in analyzing the radionuclide distribution within the cavity at that site. Although the radionuclides have been below the standing water level for 13 years, they apparently have not moved appreciably. Even very volatile species such as ^{137}Cs and tritium remain distributed in distinct patterns. This suggests that radionuclide movement away from cavity regions, at least in Yucca Flat, may be less of a problem than is generally believed. The implications of the observations at this site are far-reaching; we need to confirm them with detailed investigations at other shot sites.

Concern for protection of the groundwater is common to many programs at the NTS. With the YMP, we are seeking to understand how radionuclides may move through the vadose zone (from a shot cavity or from a repository) into an aquifer. We proposed a field study of a site on Rainier Mesa where radionuclide movement below an expended test might be observed. A decision on funding for

this study has been postponed for 2 years. We are collaborating with YMP personnel at Los Alamos in colloid transport studies and actinide sorption research employing microautoradiography.

The HRMP has monitored radioactivity in the water from several wells at the NTS for many years. During late 1993 and 1994, we sampled a number of these wells in cooperation with LLNL. Such sites as UE-7ns, UE-2ce, and U-20n had not been sampled for several years and were still being continuously pumped when the last samples were obtained. We found that grab samples taken at these sites do not correlate with samples taken during continuous pumping. At the Cambric site, where we have annual samples taken with both continuous pumping and limited-term pumping from the RNM-2S well, we observed that it was necessary to pump for several hours before the tritium concentration became constant. At U-20n, grab samples taken in 1994 were rather similar in tritium content to grab samples taken in 1988. This suggests that—even at this site with appreciable hydraulic gradients—tritium is not migrating away rapidly. Our sampling at U-4u, U-4t, and UE-3e#4 shows that the water in the small-diameter access tubes in these wells is severely contaminated with drilling fluids. We must find a way to purge these wells if we are to obtain representative samples by means of the piezometer tubes. The PM-2 study afforded an opportunity for all the HRMP organizations to combine their talents in response to an environmental contamination problem. The HRMP continues to provide the operational support and expertise needed for responsible management of water resources at the NTS.

I. INTRODUCTION

Almost 20 years ago, the US Department of Energy/Nevada Operations office and those national laboratories engaged in testing nuclear devices (Los Alamos National Laboratory and LLNL) established a research program to evaluate the environmental effect of underground nuclear testing at the NTS. This program continues, although it has expanded somewhat in scope and has undergone several name changes. It is now called the HRMP and includes the US Geological Survey (USGS) and the DRI as participants in addition to the laboratories. Our long involvement at the NTS enables program personnel to provide technical support to drilling and monitoring operations, to gather hydrologic and geologic data needed to interpret radionuclide movement in the underground environment, and to assist in the stewardship of water resources at the NTS. Underground nuclear testing at the NTS stopped in 1992, but the potential for contamination of groundwater by radioactive materials still exists because the residues from testing are close to or within the aquifers. Los Alamos contributes to the HRMP's expertise in nuclear containment and radionuclide measurement, as well as providing extensive experience in mounting field-scale tests. We describe our work for this program in our annual reports, ¹⁻¹⁷ in topical summary reports, ¹⁸⁻²² and in journal articles. ²³⁻²⁹

II. PROGRAM COORDINATION AND TECHNICAL SUPPORT

As noted in our 1993 annual report, it is increasingly difficult at Los Alamos to obtain Laboratory or Division support without charge. Even small programs like the HRMP are expected to pay for use of the counting room, computer support, general laboratory supplies, etc. This means we must devote much more effort to budget management. In a two-person program, a large fraction of our time is consumed with administrative, budget, health and safety, and waste-management issues. For these reasons, it is imperative that we cooperate and coordinate our work with other programs where possible.

This year we had a number of joint endeavors with other organizations. We are working with Professor James Hunt (UC-Berkeley), who is developing a model of the elution of ⁸⁵Kr from the RNM-2S well at Cambric. We are helping Dave Sawyer (USGS-Denver) prepare a summary report on the Cheshire site. We have had numerous meetings with personnel in the YMP to discuss a drilling program on Rainier Mesa at the NTS. We support the UGTA program at the NTS by reviewing documents and making technical presentations at their working group meetings. This year Los Alamos prepared and published (with LLNL) an inventory of residual radionuclides from all nuclear tests conducted underground at the NTS. Although the inventory was not financed by the HRMP, we helped with its preparation. This inventory will be a very useful tool for our program as we evaluate radionuclide migration at the NTS. Other notable examples of cooperative work within the HRMP are the characterization of radioactive contamination at the PM-2 hole, which was a joint effort by all the organizations in the HRMP, and the "hot hole" sampling program carried out by LLNL and Los Alamos personnel. Los Alamos participation in the HRMP and related programs is reflected in the appended list of meetings attended and presentations/publications.

III. OPERATIONAL SUPPORT

Los Alamos contributes to the development of new equipment and techniques for NTS operations. During the summer of 1992, we worked with DRI to install a solar-powered pump and spray system that would speed up the evaporation of water impounded in a Baker tank at the Cambric site. This system was successfully tested and its performance is described in an October 1993 DRI memo.³⁰ Similar enhanced evaporation systems may prove quite useful at other NTS sites where fluids may not be discharged and transport or long-term storage is expensive.

For several years Los Alamos has promoted the use of high-sensitivity gamma logging in drillback operations to guide sampling in regions other than the shot puddle. This technique is described in some detail in Ref. 29. During the summer of 1994, drilling operations were conducted at U-2gg and U-7ba. In both cases, Los Alamos received TracerScan gamma-ray spectroscopy logs taken by Halliburton and analyzed these for the presence of fission products. The results are detailed in reports from Mark Mathews, a staff member at Los Alamos.^{31,32} At U-2gg all the activity attributable to fission products was at a depth interval of 518 to 527 m (1700 to 1730 ft). The gamma activity from ^{137}Cs was so dominant that other radionuclides could not be identified from the log. Because ^{137}Cs has short-lived gaseous precursors, its presence in this narrow depth interval some 30 m from the cavity wall probably indicates a fracture injection at the time of the test. Tritium was also identified from drilling returns collected at about the same depth. At U-7ba the Halliburton TracerScan gamma log was used to identify depths for sidewall sampling with the Hunt tool. This drillback at U-7ba is described in some detail below. Of importance here is the fact that high-sensitivity logging in the cavity/chimney complex provides valuable information about the distribution of radionuclides outside the puddle region. Thus far, the spectral evidence from this tool has not allowed us to identify specific radionuclides, but the gross activity levels do provide guidance for sampling that otherwise would have to be done blindly. Our experience with this methodology should prove useful for other NTS programs that require drilling into or adjacent to shot cavities.

Drillback at the LLNL test site U-2gg was conducted in April 1994. The hole U-2ggps2a was drilled into the cavity, and hole U-2ggps3a was drilled within 30 m of the cavity wall. Los Alamos HRMP involvement in these operations was limited to participation in planning and the gamma log analyses already discussed. In September 1994, we participated in sampling water at U-2ggps3a and have now analyzed this sample for tritium and ^{85}Kr . It is probable that the water is not representative of formation water at this site because the hole was never purged of materials introduced during drilling and during the emplacement of a piezometer tube.

Sample Identification	Sample Date	Activity at Sample Time (Bq/ml)		Activity at 03/09/89 (Bq/ml)	
		³ H	⁸⁵ Kr	³ H	⁸⁵ Kr
U-2gg	09/21/94	2.8E-1	3.6E-4	3.8E-1	5.2E-4

The drillback at Los Alamos test site U-7ba involved the Laboratory HRMP personnel as participants in all phases of the operation. The test Baseball was conducted at this site on January 15, 1981, at a depth of 564 m—well below the standing water level at ~512 m. It had not previously been drilled back and debris was needed for diagnostic purposes. The operation served to maintain skills in postshot drilling and provided an opportunity to evaluate radionuclide distribution in the cavity and chimney 13 years after the event. Drilling at this site took place between June 6 and June 15, 1994. A 25-cm-diam hole, U-7baps1a, was drilled at about 22° from vertical to a measured depth of 711 m. Halliburton TracerScan gamma logs were taken over the interval of 396 to 588 m measured depth. Sidewall samples were collected with the Hunt tool from 677 to 559 m measured depth. Then a sidetrack hole, U-7baps1as, was drilled from ~523 to 711 m measured depth. The sidetrack hole was at a slightly different angle than the original hole, and the holes were probably separated by 10- to 15-m when they exited the bottom of the cavity. The sidetrack hole was logged with a gamma counter (not as sensitive as the Halliburton tool), and activity was detected between 674 and 588 m measured depth. Sidewall samples were collected over this interval using the Hunt tool. The 71 sidewall samples obtained from the two holes were returned to Los Alamos. The sidetrack hole was completed by cementing in place a 7.3-cm-i.d. tube with slots from 604 to 585 m measured depth. This tube has a Moyno stator attached so that in the future water can be pumped out from the cavity region.

When the 71 samples from U-7baps1a and U-7baps1as arrived at Los Alamos, we high-graded 24 of them (washed out native material, leaving mainly shot glass and some dense rock) and provided splits to LLNL for diagnostic analyses. We are in the process of analyzing the remaining samples for both tritium content and gamma-emitting radionuclides. At the time of this report, we have examined the samples from U-7baps1as by the following process. A sample is placed in a glass vessel connected through an ice bath to a vacuum system. It is heated until completely dry, the water is collected, and the sample is then pulverized to a homogenous powder. The tritium content in the water is measured with a liquid scintillation counter, and an aliquot of the powdered sample is analyzed for gamma-emitting radionuclides by using a calibrated Ge counter.

In this report, we show the relative activities of selected radionuclides over the depth range sampled. In time, we will have analyzed all of the gamma emitters and tritium in all the samples and will report these data on a quantitative basis. The dried samples are being retained and are available for analysis for other constituents or examination of such physical properties as crystallinity and surface alteration

caused by reactions with water in the postshot environment. Results to date are shown in Figs. 1-5. In each figure, the activity is plotted against the depth at which the sample was taken. The activity units are (for tritium) disintegrations per minute and (for the other radionuclides) gamma rays per minute (from a prominent transition). The tritium is widely distributed over the interval sampled, and is 3 orders of magnitude more concentrated in the upper part of the cavity than in the lower part. In contrast, ^{155}Eu is narrowly distributed, being largely confined to the puddle region. This radionuclide is a refractory fission product with no volatile precursors. The distribution of ^{60}Co , an activation product, is rather like that of europium, although somewhat broader. The volatile elements cesium and antimony are distributed throughout the cavity. The ^{137}Cs actually exists as the gas ^{137}Xe (half-life = 3.8 min) before becoming cesium and may be widely dispersed before its transformation.

The drillback at U-7ba was a significant event for the HRMP. It provided us with the opportunity to measure in detail the distribution of radionuclides at an expended test site. We collected samples over a far larger vertical and horizontal range than is normally possible. Even with the limited analyses done to date, we can see that there are very different distribution patterns for volatile and refractory elements. It appears that, once emplaced, these elements did not move very much in the postshot environment. One might imagine that species mobile in water (such as tritium or antimonate ion) would have homogenized their concentrations over a 13-year time span, but this seems to not be the case. Observed distribution patterns suggest that migration of these radionuclides, even within the confines of the cavity, has not taken place. It will be interesting to see if further analytical work supports this hypothesis. It may be possible to gain further insight into the mobility of species in the cavity water when we are able to pump water from the tube in U-7baps1as.

Fig. 1. Relative activity of tritium *vs* depth in U-7baps1as.

Fig. 2. Relative activity of ^{155}Eu vs depth in U-7baps1as.

Fig. 3. Relative activity of ^{60}Co vs depth in U-7baps1as.

Fig. 4. Relative activity of ^{137}Cs vs depth in U-7baps1as.

Fig. 5. Relative activity of ^{125}Sb vs depth in U-7baps1as.

IV. GROUNDWATER PROTECTION

As mentioned earlier, at Los Alamos we have several cooperative programs with the YMP. These are research collaborations directed at understanding how radionuclides, especially actinides, can move in the underground environment at the NTS and contaminate the aquifers there. Of special concern is radionuclide movement through the unsaturated zone from an expended test or repository to an aquifer. It has been hypothesized that colloids can be transported through the vadose zone by moving with groundwater in small fractures that are (at least temporarily) saturated. Working with YMP personnel, we sought to obtain funding for a field study that might show evidence for such migration if it did take place. We selected an expended test site on Rainier Mesa that was located in the vadose zone but was subject to episodic water pulses from rain or snow. We proposed to drill beside and under the cavity to look for radionuclide migration, especially migration that could be associated with colloid transport. This was to be a collaborative project between the HRMP, YMP and UGTA. After many meetings on the proposal, the YMP decided to postpone a funding decision for 2 years.

We are involved in several other Los Alamos programs directed toward understanding how the aquifer at the NTS could become contaminated by radionuclides through colloid transport. These programs, funded by the YMP, benefit from the technical expertise of HRMP personnel in certain laboratory procedures. Currently, HRMP personnel are assisting one graduate student who is validating a model of colloid transport by using columns of glass beads and another graduate student who is using microautoradiography to study actinide sorption on mineral phases of NTS rock .

V. GROUNDWATER MONITORING

Los Alamos and LLNL personnel cooperated in sampling water from a number of expended test sites where radioactivity had previously been detected. Some of this sampling was done toward the end of FY 1993 and only preliminary results were available for the annual report for that year. In the present report, we present all our analytical results for water sampling in FY 1993 and 1994.

RNM-1

The Cambric test was conducted in 1965 in alluvium at a depth of 294 m below the water table; 10 years later, the RNM-1 hole was drilled through and beneath the cavity. Most of the radioactive material associated with the test was still in the cavity region. Since 1984, we have periodically sampled water pumped from RNM-1. In 1975 we began pumping water from an adjacent satellite hole, RNM-2S to induce movement of dissolved radioactive materials with flowing groundwater. There was a gradual decline in the concentrations of tritium, ^{85}Kr , ^{90}Sr , and ^{137}Cs in RNM-1 waters from 1975 until pumping at RNM-2S was terminated in 1991 (Ref. 15). The results of our most recent water sampling at RNM-1 are shown in the table that

follows. For comparison, we have included average values obtained since pumping at the satellite well was stopped.

Sample Identification	Sample Date	Activity at Sample Time (Bq/ml)			Activity at 05/14/65 (Bq/ml)		
		³ H	⁸⁵ Kr	¹³⁷ Cs	³ H	⁸⁵ Kr	¹³⁷ Cs
434-3-91-001	05/21/91	<3.7E-2	<3.7E-5				
434-7-91-002	05/21/91			1.9E-4			3.6E-4
434-3-92-001	09/15/92	3E-2	<3.7E-5		1E-1		
434-7-92-001	09/15/92			2.6E-4			4.9E-4
434-3-93-001	09/14/93	3E-2	4.2E-5		1E-1	2.6E-4	
434-7-93-002	09/14/93			1.6E-4			3.1E-4
434-3-94-001	08/31/94	4E-2	<3.7E-5		2E-1		
434-3-94-003	09/13/94	<3.7E-2	<3.7E-5				
434-7-94-002	09/13/94			2.1E-4			4.2E-4

It is apparent that there have not been large changes in the radionuclide concentrations at RNM-1 since pumping of the satellite well stopped. Both the tritium and ⁸⁵Kr remain at concentrations that are detectable but not quantifiable with good accuracy. We see no trend in the ¹³⁷Cs data.

RNM-2S

After pumping of groundwater from this hole was started in 1975, the concentrations of both tritium and ⁸⁵Kr in the effluent rose to a maximum and then decreased gradually. Small amounts of anionic radionuclides have been detected in RNM-2S water, but no cations such as ⁹⁰Sr or ¹³⁷Cs (Ref. 21). Approximately 92% of the source term tritium and ~43% of the source term ⁸⁵Kr was pumped out before the pump was turned off in 1991. Representative data from recent samplings are shown below.

Sample Identification	Sample Date	Activity at Sample Time (Bq/ml)			Activity at 05/14/65 (Bq/ml)	
		³ H	⁸⁵ Kr	¹³⁷ Cs	³ H	⁸⁵ Kr
434-1-91-022	08/29/91	1.11E1	2.8E-4		4.93E1	1.5E-3
434-9-91-007	08/29/91			<3.7e-7		
434-1-92-002 ^a	09/15/92	2.1E0	2.2E-4		1.0E1	1.3E-3
434-9-92-002 ^b	09/15/92	6.0E0		<3.7E-7	2.8E1	
434-1-93-001 ^a	09/14/93	1.7E-1	3.9E-5		8.4E-1	2.4E-4
434-9-93-002 ^b	09/14/93	6.7E-1		<3.7E-7	3.3E0	

^aEarly sample.

^bLate sample.

We pumped relatively small volumes of water (~55 m³) during sampling campaigns in 1992 and 1993. A comparison of samples taken early and late during pumping seemed to indicate that the tritium concentrations were increasing during these limited pumping periods, so we could not be sure how accurately our measurements reflected the actual groundwater concentrations of this radionuclide. On August 29, 1994, we were able to pump water from RNM-2S for about 4 hours with the results shown here.

Sample Identification	Sample Time	Activity at Sample Time (Bq/ml)			Activity at 05/14/65 (Bq/ml)	
		³ H	⁸⁵ Kr	¹³⁷ Cs	³ H	⁸⁵ Kr
pump start	11:19					
#1 (500 ml)	11:35	5.2E-1			2.7E0	
#2 (500 ml)	11:48	4.4E0			2.3E1	
#3 (500 ml)	12:53	1.1E1			5.8E1	
#4 (500 ml)	14:08	1.1E1			5.5E1	
434-1-94-001	14:12	1.1E1	6.5E-4		5.5E1	4.3E-3
434-1-94-002	14:16	1.1E1	6.2E-4		5.5E1	4.1E-3
434-9-94-001	14:23			<3.7E-7		

These data suggest that after several hours of pumping the tritium concentration in the effluent water increased to approximately the concentration it had in 1991 when continuous pumping was terminated. This would mean that there is very little natural dispersal of tritium at this site; in the absence of the hydraulic gradient imposed by pumping, the tritium remains where it is. There is still no evidence of ¹³⁷Cs in the RNM-2S water.

UE-7ns

This satellite well was drilled in 1976 to a depth of 672 m and was completed with slotted casing in the bottom 62 m. It is 137 m from the Bourbon event, a test fired January 20, 1967, near the boundary of tuff and Paleozoic carbonate rocks and close to the carbonate aquifer. Intermittent pumping and water sampling was done at UE-7ns up until 1984, and a LLNL report³³ summarizes these data. Tritium concentrations were measured to be ~1E-2 to 1E-1 Bq/ml; the last LANL measurement in 1984 was 4.4E-2 Bq/ml. We know of no previous data on the ⁸⁵Kr concentration in UE-7ns water. The following information pertains to our 1993 sampling at this site.

Smple Identification	Sample Date	Sample Depth (Vertical)	Activity at 10/19/93 (Bq/ml)	
			³ H	⁸⁵ Kr
UE-7ns (LLNL)	08/24/93	617 m	<3.7E-2	
4444-93-001	08/24/93	617 m	<3.7E-2	1.4E-2

The concentration of tritium at UE-7ns continues to be quite low; it is not known whether continued pumping of this hole would bring tritium concentrations up to the previously measured values. The ratio of ⁸⁵Kr to tritium is much higher than that normally found in postshot samples.

UE-2ce

The Nash test was conducted in 1967 at U-2ce. The resulting cavity is in Paleozoic carbonate rock and is probably just above the watertable. Ten years after that test, the satellite well UE-2ce was drilled 183 m away. This well extends into the carbonate aquifer and is cased to draw only from that source. It was pumped and sampled intermittently from 1977 to 1984. Tritium analytical data from this period have been compiled in a LLNL document.³³ In 1978, when Los Alamos personnel measured the ⁸⁵Kr/³H ratio in water from UE-2ce (Ref. 3), the atom ratio (corrected to zero time for the Nash event) ranged from 1.5E-3 to 2.3E-3; this was approximately one-third the calculated ⁸⁵Kr/³H atom ratio for the Nash event. This ratio was again measured in 1984 and had increased to 5.5E-3. Los Alamos measurements of the tritium concentration in 1984 varied between 1.3E3 and 3.2E3 Bq/ml (activity at Nash zero time January 19, 1967).⁸ The table below shows our results from the 1993 sampling.

Sample Identification	Sample Date	Sample Depth (Vertical)	Activity at 10/23/93 (Bq/ml)		Activity at 01/19/67 (Bq/ml)	
			³ H	⁸⁵ Kr	³ H	⁸⁵ Kr
UE-2ce (LLNL)	08/25/93	445 m	5.0E0		2.2E1	
508-1-93-001	08/25/93	445 m	5.7E0	11.6E-1	2.5E1	8.8E-1

It is not possible to correlate these results with earlier data from UE-2ce because all previous samples were taken while the hole was being pumped. The krypton and tritium concentrations of water stagnant in a well bore may not be the same as in adjacent formation water. We do not know if pumping would bring the tritium concentration up to the 1984 level. As was the case in UE-7ns, the krypton-to-tritium ratio seems rather high compared to the expected value of $\sim 10^{-3}$.

U-4ups2a

The Dalhart test was conducted in 1988 at a vertical depth of 640 m, well below the preshot standing water level at 508 m. In 1990 we drilled U-4ups2a into the cavity region and emplaced a tubing with slots at a depth interval of 472 to 501 m (vertical). The postshot water level in this hole has been slowly rising and was about 477 m in December 1993 (Ref. 34). A water sample was collected in 1992 and analyzed for tritium and krypton. In 1993 LLNL shared grab samples and collected a pressurized sample for us. Our values from the 1992 and 1993 samplings are shown in the following table.

Sample Identification	Sample Date	Sample Depth (Vertical ^a)	Activity at 09/20/93 (Bq/ml)		Activity at 10/13/88 (Bq/ml)	
			³ H	⁸⁵ Kr	³ H	⁸⁵ Kr
1112-1-92-001	07/02/92	504 m	2.15E3	1.83E0	2.66E3	2.33E0
1112-1-93-001	08/31/93	484 m	1.95E3	6.89E1	2.57E3	9.60E1
U-4u(LLNL)	08/31/93	484 m	2.22E3		2.92E3	
U-4u(LLNL)	08/31/93	496 m	2.18E3		2.87E3	
U-4u(LLNL)	08/31/93	504 m	2.14E3		2.82E3	

^aThis assumes slant depth $\times 0.946$ = vertical depth.

The water in this hole contained a good deal of suspended material. The sample from 484 m was a light tan fluid; that from 496 m was a brown thin sludge; and that from 504 m was a thick brown sludge with black particles. We centrifuged the samples to separate the bulk of the suspended material and then filtered the supernate through 45-nm-pore-size Nuclepore filters before the liquid scintillation counting. Despite the different appearances of these samples, the tritium content is rather uniform and similar to that in 1992. We combined the grab samples (~150 ml total) with the sample in the pressure tube (~2100 ml) and then dried and counted the residue with a Ge counter. The dominant radionuclides, ¹⁰⁶Ru-Rh, ⁶⁰Co, ¹²⁵Sb, and ¹³⁷Cs, were present at concentration levels of ~1E-2 Bq/ml. Smaller amounts of ¹⁴⁴Ce and ^{102m}Rh were detected—and probably also ⁵⁴Mn and ¹³⁴Cs. These are the same radionuclides identified in the 1992 sampling.¹⁶

U-4tps3a

This hole was drilled so as to pass close to the chimney and cavity but not actually penetrate them. Tritium was detected during drilling, but no fission products were identified. The drilling of this hole was discussed in detail in our 1993 annual report.¹⁷ The piezometer tubing emplaced in this hole has slots in the depth range from about 516 to 618 m (vertical). It is quite likely that the bottom of the piezometer tube is in the high-pressure zone seen in other holes in Yucca Flat

(for example, UE-4t#1 and UE-3e#4). If so, water may be flowing in the bottom section of the tube and out the top sections. It is unfortunate that our water samples were taken very high in the tube—much above the expected level of the water table. (An attempted sampling at a lower depth failed because mud clogged the inlet port.) No previous water sampling had been attempted in U-4tps3a.

Sample Identification	Sample Date	Sample Depth (Vertical) ^a	Activity at 09/20/93 (Bq/ml)		Activity at 11/14/86 (Bq/ml)	
			³ H	⁸⁵ Kr	³ H	⁸⁵ Kr
U-4t(LLNL)	08/31/93	311m	1.06E0		1.58E0	
1080-1-93-001	08/31/93	311m	(4.2±0.6)E-2	1E-4	(6.2±0.9)E-2	1E-4

^aThis assumes slant depth x 0.966 = vertical depth.

These water samples were a dark gray sludge. We centrifuged and filtered them in the same manner as the U-4ups3a samples. After aliquots were taken for tritium counting, the grab sample (~50 ml) and pressure-tube sample (~2190 ml) were combined, dried, and counted with a germanium detector. No gamma-emitting fission products were detected. It is quite interesting that only rather small concentrations of tritium were detected in this hole that was drilled approximately two cavity radii from a test conducted 7 years earlier. The actual levels of tritium in the piezometer tube are difficult to judge because two samplings at the same nominal depth on the same day gave different results. Hole U-4tps3a was never pumped out and there were several additions of substantial amounts of water during emplacement of the piezometer tube. This circumstance, plus the relatively shallow depth at which the samples were collected, makes it unclear that the samples are representative of formation groundwater.

UE-3e#4

This hole was drilled in 1990 to a depth of 701 m, and three tubes with slots over the intervals indicated were cemented into the hole: tube 1, 655-662 m; tube 2, 575-582 m; and tube 3, 493-500 m. The history of this hole is described in detail in Ref. 19. In our annual report from FY 1992, we summarized the tritium analyses from the three tubes, noting that there were particulates in all three tubes and a nonuniform distribution of tritium in tube 1.¹⁶ Analyses of water collected in 1993 from UE-3e#4 are given below; a few data from earlier analyses are included for comparison.

Sample Identification	Sample Date	Sample Depth (Vertical)	Activity at 12/03/93 (Bq/ml)		Activity at 03/08/90 (Bq/ml)	
			³ H	⁸⁵ Kr	³ H	⁸⁵ Kr
888-1-91-101	03/06/91	658 m			3.35E2	6.4E-1
888-1-92-102	07/01/92	658 m			2.13E2	1.80E-1
888-1-93-101	08/25/93	655 m	3.63E2	1.86E-1	4.48E2	2.36E-1
888-1-91-201	03/06/91	578 m			3.56E0	6.8E-3
888-1-93-201	08/26/93	544 m	2.00E0	4.44E-4	2.47E0	5.63E-4
888-1-91-301	03/06/91	483 m			3.46E1	1.3E-2
888-1-92-302	07/01/92	500 m			2.58E1	9.8E-3
888-1-93-301	08/25/93	497 m	1.79E1	5.76E-3	2.21E1	7.31E-3

U-19v

The Almendro test was conducted June 6, 1973, at a vertical depth of 1064 m—well below the preshot water level of about 671 m. After postshot sampling, the re-entry hole was being redrilled when the Dyna drill burned out and the drilling assembly was abandoned. The hole was left with 168-mm- (6-5/8-in.)-o.d. drill pipe down to the Otis plug and the drilling assembly below it. The depth of the Otis plug is ~1100 m vertical, some tens of meters above the cavity bottom. Various attempts to log this hole since 1973 have been thwarted by high temperatures in the cavity/chimney region. In June 1982, 9 years after the test, a temperature of ~200°C was measured near the Otis plug. At the time of our sampling in September 1993, the water temperature was ~45°C at a vertical depth of 942 m. This site provides us with an opportunity to investigate the effects of high temperatures on radionuclide distribution in the cavity/chimney region. The results of our first water sampling from this hole are given below.

Sample Identification	Sample Date	Sample Depth (Vertical) ^a	Activity at 12/07/93 (Bq/ml)		Activity at 06/06/73 (Bq/ml)	
			³ H	⁸⁵ Kr	³ H	⁸⁵ Kr
791-1-93-001	09/28/93	703 m	6.42E3	1.47E-1	2.03E4	5.52E-1
791-1-93-002	09/28/93	942 m	8.82E3	5.00E0	2.79E4	1.88E1

^aThis assumes slant depth x 0.936 = vertical depth.

After analyzing the water samples for tritium and ^{85}Kr , we dried them and counted them for 3000 min on a germanium counter to look for the presence of gamma-emitting fission products. The combined residue from the pressure tubes was ~2 g; only ^{137}Cs was detected, and that was ~0.1 Bq. Apparently the hot water in this hole has not resulted in high concentrations of low-solubility fission products.

PM-2

This hole, located in the extreme north-west corner of Area 20 on the NTS, was completed to a vertical depth of 2677 m in October 1964. A 340-mm casing extends down 760 m, followed by a 236 mm casing to 1612 m. This smaller casing has been perforated over the intervals 762 to 899 m, 1052 to 1189 m, 1341 to 1350 m and 1561 to 1612 m. The bottom 1065 m of the hole is uncased. In December 1968, a Plowshare test, code named Schooner, was fired ~450 m from PM-2. The working point was only 111 m because this was a cratering demonstration. Apparently, no water samples were taken from PM-2 until August 1993, when elevated levels of tritium were detected. Samples collected in August and September of 1993 contained tritium in concentrations up to ~28 Bq/ml. The HRMP is participating in an effort to determine the mechanism by which tritium (assumed to come from Schooner) got into PM-2. On November 30, 1993, Los Alamos and LLNL personnel collected water samples in pressure tubes from several shallow depths in PM-2. The following day, we discovered that our pressure tubes (either in tandem or singly) would not go deeper than 984 m, where they encountered thick, black sludge. Analyses of the 1993 samples are shown here.

Sample Identification	Sample Date	Sample Depth (Vertical)	Activity at 01/05/94 (Bq/ml)		Activity at 12/68 (Bq/ml)	
			^3H	^{85}Kr	^3H	^{85}Kr
9991-93-001	11/30/93	305 m	5.41E-1	5.2E-4	2.2E0	2.6E-3
9991-93-002	11/30/93	610 m	2.70E1	<3.7E-5	1.1E2	
9991-93-003	11/30/93	823 m	2.57E1	<3.7E-5	1.1E2	

The water sample from 305 m was dark yellow-brown; the samples from the other depths were black. Filtering through 100-nm-pore filters did not remove the color. We prepared samples for liquid scintillation counting by using both untreated samples and water distilled from the samples. The untreated samples (even when diluted 6:1 with di-ionized water) resulted in a gray liquid when mixed with the Ultima Gold cocktail. These gave a lower count rate than their distilled analogs and we believe them to be color quenched. We reported the data from the distilled samples, although these also are slightly lower in tritium because of the distillation. There appears to be a measurable quantity of krypton in the sample from the highest sampling level, but not in the deeper samples. The krypton

concentrations are all very low and repeat sampling is indicated. After the water samples (~2200 ml each) were processed for tritium and ^{85}Kr , we dried them and counted them for 3000 min on a germanium counter. We detected no gamma activity in the 305-m sample and only a trace of ^{137}Cs in the 610-m sample. In the 823-m sample, the ^{137}Cs /tritium activity ratio at count time is $\sim 9.2\text{E-}5$. The calculated value of this ratio (supplied from LLNL) is $\sim 5.7\text{E-}5$ for the Schooner event. However, there are many factors that could make the activity ratio measured in the water sample different from the source term ratio.

We also used the germanium counter to count 5 ml of the sludge collected from 984 m as well as two small cinders (~5-g total weight) picked up from the surface between PM-2 and Schooner. The sludge contained no detectable gamma emitters; the cinders contained several bequerels of ^{60}Co , ^{154}Eu , ^{152}Eu , ^{137}Cs , and ^{133}Ba and lesser amounts of $^{108\text{m}}\text{Ag}$ and (possibly) ^{150}Eu and ^{155}Eu .

We again visited PM-2 in May 1994. We collected multiple water samples at several levels using our 2-l pressure tubes in tandem. Our procedure was to open one pressure tube (designated LLNL) in the field and take splits for the participating organizations. The other pressure tube was returned to Los Alamos for ^{85}Kr analysis as well as counting of tritium and gamma-emitting radionuclides. An effort to collect sludge at 984 m with a bailer was unsuccessful.

The samples were similar in appearance to those collected in 1993, and it was apparent that counting the untreated water for tritium using a liquid scintillation counter would result in quenching. We evaluated the severity of this problem in the following way. We added 5 ml of our standard tritium to 1 ml of the sample, then added 16 ml of the Ultima Gold cocktail. The count rate of this mixture was compared with an identical recipe in which 1 ml of di-ionized water was used instead of the sample. We found that the sample count was 0.610 lower than the di-ionized water count for the 823-m sample. For the 914-m sample, this ratio was 0.615, indicating even more quenching. The sample from 305 m showed no measurable quenching. We also distilled samples from each of the three depths and checked the distillate for quenching by the same technique. The distillates showed no quenching. The results of our analyses of both the LLNL and pressure tube samples are shown below.

Sample Identification	Sample Date	Sample Depth (Vertical)	Activity at 05/04/94 (Bq/ml)		Activity at 12/68 (Bq/ml)	
			³ H	⁸⁵ Kr	³ H	⁸⁵ Kr
Run1 (LLNL)	05/03/94	305 m	8.1E-1		3.4E0	
Run 1(LLNL)	05/03/94	823 m	2.61E1		1.1E2	
Run 1(LLNL)	05/04/94	823 m	2.61E1		1.1E2	
Run 2(LLNL)	05/04/94	823 m	2.66E1		1.1E2	
Run 3(LLNL)	05/04/94	823 m	2.62E1		1.1E2	
Run 1(LLNL)	05/04/94	914 m	2.64E1		1.1E2	
Run 2(LLNL)	05/04/94	914 m	2.60E1		1.1E2	
Run 3(LLNL)	05/04/94	914 m	2.63E1		1.1E2	
9991-94-001	05/04/94	305 m	7.7E-1	(9±4)E-5	3.2E0	~5E-4
9991-94-003	05/04/94	823 m	2.51E1	<3.7E-5	1.1E2	
9991-94-004	05/04/94	914 m	2.33E1	(9±3)E-5	9.7E1	~5E-4

After analyzing the samples for tritium and ⁸⁵Kr, we evaporated them to dryness and counted the residue with a germanium detector. The only radionuclide that was measurable in the gamma spectrum (other than background activities) was ¹³⁷Cs. None of this radionuclide was present in the evaporate from 305 m. The sample from 823 m had ~1E-5 Bq/ml (our detection limit) and the sample from 914 m had (9.6 ± 5.4)E-5 Bq/ml. In addition, personnel from Reynolds Electrical and Engineering Company (REECO) provided us with soil samples taken from the vicinity of the Schooner event in 1983. This material had been analyzed by REECO; when we gamma counted it to look for evidence of radionuclides not reported in the earlier analyses,³⁵ we detected ⁶⁰Co, ^{108m}Ag, ¹³⁷Cs, ²⁴¹Am, and ^{150,152,154,155}Eu. Most of these had been reported by REECO; we found no evidence for radionuclides with half-lives shorter than ⁶⁰Co. A more complete discussion of the PM-2 analytical work and data interpretation reflecting the combined efforts of all HRMP participants is contained in a report compiled by the USGS.³⁶

U-20n

The Cheshire test at U-20n was conducted in 1976 at a depth of 1174 m. Water samples were taken in the vicinity of the cavity in 1976, 1983, and 1984. In 1985 the lower portion of the hole was blocked with a packer and new perforations were made at a depth of about 820 m. The details of our study of this site are contained in a series of annual reports.⁸⁻¹¹ In 1994 we sampled water from U-20n for the first time since 1985. Water was collected in pressure tubes at three depths and analyzed for tritium and ⁸⁵Kr. The results are given below, along with data from previous sampling.

Sample Identification	Sample Date	Sample Depth (measured)	Activity at 11/17/94 (Bq/ml)		Activity at 02/14/76 (Bq/ml)	
			³ H	⁸⁵ Kr	³ H	⁸⁵ Kr
852-1-85-008	11/04/85	pumped			1.44E4	8.9E0
852-1-88-001	07/19/88	724 m			7.78E3	7.8E-1
852-1-94-001	09/14/94	686 m	2.29E3	2.1E-2	6.59E3	7.2E-2
852-1-94-002	09/14/94	746 m	2.24E3	(lost)	6.44E3	
852-1-94-003	09/14/94	807 m	2.29E3	1.3E-2	6.59E3	4.4E-2

It is apparent that the levels of tritium and ⁸⁵Kr are lower now than previously. This may be the result of migration away from this site or it may be simply an artifact of the collection method. Note that there was a dramatic drop in the concentrations of both these radionuclides between the 1985 and 1988 sampling. If that drop had been due to migration, we would expect even larger concentration decreases between 1988 and 1994, but that is not the case. There is a strong indication that the changing concentrations in our samples from U-20n has more to do with how the water was obtained than with losses resulting from migration.

Conclusions About 1993 and 1994 Water Sampling

For many years, the HRMP and its predecessor organizations have supported monitoring of groundwater from selected sites at the NTS. These sites were generally locations where water was being pumped more or less continually (as at Cambric, Nash, and Cheshire) or were holes where we took grab samples during drilling operations (as at UE-3e#4, U-4tps3a, and U-4ups2a). Now there are an increasing number of holes fitted with piezometer tubes that are not pumped, but from which grab samples may be collected. The data presented above illustrate many of the problems associated with monitoring water from locations that are not being pumped or from which introduced materials have not been removed. The latest data from the Cambric RNM-2S well show quite clearly that at this site a pumping time of several hours (at >2 m³/hour) is necessary to reach a condition in which the effluent water composition is no longer changing. In 1993 we sampled U-7ns and UE-2ce for the first time since 1984. Samples had been collected during this earlier period when these holes were being pumped continuously. The tritium concentrations we measured in 1993 from bailed samples may not be representative of formation water because of poor mixing within the well bore; certainly they cannot easily be related to concentrations measured while the holes were being pumped. The data from U-4ups2a, UE-7ns, and UE-2ce seem to suggest an unexpected high ⁸⁵Kr/tritium ratio. Could krypton gas collect in undisturbed holes over periods of a year or more? More sampling of these holes and comparison after pumping or purging is in order. The obvious message is that we must be very cautious about interpreting water analyses from a well if the sampling methodologies are varying with time (that is, sometimes bailed and sometimes pumped).

Residual contaminants from drilling operations present another set of problems. For example, it is quite clear that U-4ups2a and U-4tps3a are contaminated with substantial amounts of material associated with drilling the holes and setting the piezometer tubes. Our measurements of tritium in these holes is uncertain because of dilution effects; quantitative measurement of fission products in the groundwater would be almost meaningless because of probable interactions between the fission products and introduced materials. And measurements of formation water parameters such as pH, conductivity, and dissolved constituents is quite impossible. An additional problem in effectively sampling water in relatively small diameter tubes is that there may not be mixing between various depths in the tubing. Our experimental evidence for poor mixing was discussed in our annual report from FY 1992 as part of the interpretation of UE-3e#4 data.¹⁶ In short, piezometer tube sampling stations are providing little useful data other than water levels. We must devise ways to pump these small-diameter tubes long enough to get formation water if they are to be used to their full potential.

ACKNOWLEDGMENTS

We appreciate the assistance of J. Headstream in gamma counting and J.H. Heiken for editorial review.

REFERENCES

1. D. C. Hoffman, "Summary of RNM Activities During FY-76 and FY-77 (July 1, 1976 to September 30, 1977)," Los Alamos Scientific Laboratory memorandum CNC-11 to R. W. Newman (November 10, 1977).
2. W. R. Daniels, "Summary of RNM Activities During FY-78 (October 1, 1977 to September 30, 1978)," Los Alamos Scientific Laboratory memorandum CNC-11 to R. W. Newman (November 16, 1978).
3. W. R. Daniels, "Summary of RNM Activities During FY-79 (October 1, 1978 to September 30, 1979)," Los Alamos Scientific Laboratory memorandum RNM-CNC-11/11/79-2 to R. W. Newman (November 9, 1979).
4. W. R. Daniels, ed., "Laboratory and Field Studies Related to the Radionuclide Migration Project, October 1, 1979 — September 30, 1980," Los Alamos National Laboratory report LA-8670-PR (February 1981).
5. W. R. Daniels, ed., "Laboratory and Field Studies Related to the Radionuclide Migration Project, October 1, 1980 — September 30, 1981," Los Alamos National Laboratory report LA-9192-PR (February 1982).

6. W. R. Daniels, ed., "Laboratory and Field Studies Related to the Radionuclide Migration Project, October 1, 1981 — September 30, 1982," Los Alamos National Laboratory report LA-9691-PR (May 1983).
7. W. R. Daniels and J. L. Thompson, comps. and eds., "Laboratory and Field Studies Related to the Radionuclide Migration Project, October 1, 1982 — September 30, 1983," Los Alamos National Laboratory report LA-10121-PR (April 1984).
8. J. L. Thompson, comp. and ed., "Laboratory and Field Studies Related to the Radionuclide Migration Project, October 1, 1983 — September 30, 1984," Los Alamos National Laboratory report LA-10372-PR (February 1985).
9. J. L. Thompson, comp. and ed., "Laboratory and Field Studies Related to the Radionuclide Migration Project, October 1, 1984 — September 30, 1985," Los Alamos National Laboratory report LA-10644-PR (January 1986).
10. J. L. Thompson, comp. and ed., "Laboratory and Field Studies Related to the Radionuclide Migration Project, October 1, 1985 — September 30, 1986," Los Alamos National Laboratory report LA-11081-PR (August 1987).
11. J. L. Thompson, comp. and ed., "Laboratory and Field Studies Related to the Radionuclide Migration Project, October 1, 1986 — September 30, 1987," Los Alamos National Laboratory report LA-11223-PR (February 1988).
12. J. L. Thompson, comp. and ed., "Laboratory and Field Studies Related to the Hydrology/ Radionuclide Migration Project, October 1, 1987 — September 30, 1988," Los Alamos National Laboratory report LA-11595-PR (July 1989).
13. J. L. Thompson, comp. and ed., "Laboratory and Field Studies Related to the Hydrology/ Radionuclide Migration Project, October 1, 1988 — September 30, 1989," Los Alamos National Laboratory report LA-11947-PR (November 1990).
14. J. L. Thompson, comp. and ed., "Laboratory and Field Studies Related to the Hydrology/ Radionuclide Migration Project, October 1, 1989 — September 30, 1990," Los Alamos National Laboratory report LA-12100-PR (May 1991).
15. J. L. Thompson, comp. and ed., "Laboratory and Field Studies Related to the Hydrology/ Radionuclide Migration Project, October 1, 1990 — September 30, 1991," Los Alamos National Laboratory report LA-12338-PR (June 1992).
16. J. L. Thompson, comp. and ed., "Laboratory and Field Studies Related to the Hydrology/ Radionuclide Migration Project, October 1, 1991 — September 30, 1992," Los Alamos National Laboratory report LA-12498-PR (January 1993).

17. J. L. Thompson, comp. and ed., "Hydrologic Resources Management Program, October 1, 1992 — September 30, 1993," Los Alamos National Laboratory report LA-12721-PR (January 1994).
18. D. C. Hoffman, J. R. Stone, and W. W. Dudley, Jr., "Radioactivity in the Underground Environment of the Cambric Nuclear Explosion at the Nevada Test Site," Los Alamos Scientific Laboratory report LA-6877-MS (July 1977).
19. J. L. Thompson, comp. and ed., "Interim Report of the Drilling History and Analysis for Nevada Test Site Hole UE3e#4," Los Alamos National Laboratory document LA-UR-12042-MS (December 1990).
20. E. A. Bryant, "Colloid Research at the Nevada Test Site," Los Alamos National Laboratory report LA-12301-MS (May 1992).
21. E. A. Bryant, "The Cambric Migration Experiment — A Summary Report," Los Alamos National Laboratory report LA-12335-MS (September 1992).
22. G. J. Nimz and J. L. Thompson, "Underground Radionuclide Migration at the Nevada Test Site," US Department of Energy/Nevada Field Office report DOE/NV-346 (November 1992).
23. D. C. Hoffman, "A Field Study in Radionuclide Migration," in *Radioactive Waste in Geologic Storage*, S. Fried, ed., ACS Symposium Series 100 (American Chemical Society, Washington, DC, 1979), p. 149.
24. D. C. Hoffman, W. R. Daniels, K. Wolfsberg, J. L. Thompson, R. S. Rundberg, S. L. Fraser, and K. S. Daniels, "A Review of a Field Study of Radionuclide Migration from an Underground Nuclear Explosion," International Atomic Energy Agency report IAEA-CN-43/469 (1983).
25. D. C. Hoffman and W. R. Daniels, "Assessment of the Potential for Radionuclide Migration from a Nuclear Explosion Cavity," in *Groundwater Contamination, Studies in Geochemistry* (National Academy Press, Washington, DC, 1984), p. 139.
26. J. L. Thompson and J. S. Gilmore, "Migration of Fission Products at the Nevada Test Site: Detection with an Isotopic Tracer," *Radiochim. Acta* **52/53** 229 (1991).
27. J. L. Thompson, "Radionuclide Migration Studies at the Nevada Test Site," *Radiochim. Acta* **54**, 149 (1991).

28. W. L. Hawkins, D. A. Trudeau, and S. L. Drellack, Jr., "Hydrogeologic Investigations at the Nevada Test Site," in *Proceedings of Industrial and Agricultural Impacts on the Hydrogeologic Environment*, Second USA/CIS Joint Conference on Environmental Hydrology and Hydrogeology, American Institute of Hydrology, May 17-20, 1993 (Washington, DC, 1993), pp. 87-104.
29. M. Mathews, K. Hahn, J. Thompson, L. Gadeken, and W. Madigan, "Dalhart Post Shot Investigation," in *Proceedings of the Fourth International Symposium of the Minerals and Geotechnical Logging Society*, Toronto, Canada, August, 1991 (Society of Professional Well Log Analysts, 6001 Gulf Freeway, Houston, TX 77023, 1993).
30. B. Lyles, "Cambic Enhanced Evaporation," Desert Research Institute memorandum to Paul Seaber, DRI (October 7, 1993).
31. M. Mathews, Los Alamos National Laboratory letter report EES3-94-238 to David Smith, Lawrence Livermore National Laboratory (July 13, 1994).
32. M. Mathews, Los Alamos National Laboratory memorandum EES3-94-260 to J. Thompson, Los Alamos National Laboratory (July 26, 1994).
33. R. W. Buddemeier and D. Isherwood, comps.; "Radionuclide Migration Project, 1984 Progress Report," Lawrence Livermore National Laboratory document UCRL-53628 (April 1985).
34. D. A. Trudeau, US Geological Survey, WRD, Las Vegas, Nevada, written communication, 1994.
35. R. D. McArthur and S. W. Mead, "NTS Radionuclide Inventory and Distribution Program Report #4, Areas 18 and 20," US Department of Energy document DOE/NV/10384-22 (April 1988).
36. G. M. Russell, "Summary of Information Concerning Radiological Contamination at Well PM-2, Nevada Test Site, Nye County, Nevada," US Geological Survey Water Resources Investigative Report 94-xxx (November 1994) *in review*.

APPENDIX

Program Activity

Meetings Attended (HRMP and Related Programs)

HRMP/DOE	October 20-21, 1993
YMP	January 18, 1994
UGTA/RIFS	January 18, 1994
HRMP/DRI	January 19-20, 1994
INVENTORY/UGTA	February 14, 1994
UGTA/RIFS	February 16, 1994
INVENTORY/LLNL	March 10, 1994
HRMP/LLNL	April 20-21, 1994
AGATE/IFS	April 27, 1994
INVENTORY/AGATE	May 5, 1994
AGATE/RIFS	May 17, 1994
HEMP/DRI	May 18, 1994
HRMP/DRI	June 15, 1994
UGTA/IT	July 20, 1994
HRMP/DOE	July 20-21, 1994
UGTA/RIFS	August 12, 1994
INVENTORY/LLNL	August 22-23, 1994
UGTA/RIFS	September 15, 1994

Presentations

"The Nevada Test Site: An Analog for a Nuclear Repository," at *Migration '93* in Charleston, South Carolina, December 14-18, 1993 (to be published in the proceedings from that conference).

Publications

M. Mathews, K. Hahn, J. Thompson, L. Gadeken, and W. Madigan, "Subsurface Radionuclide Investigation of a Nuclear Test," *J. Appl. Geophysics* **32**, 279-292 (1994).

J. L. Thompson, comp. and ed., "Hydrologic Resources Management Program, October 1, 1992 — September 30, 1993," Los Alamos National Laboratory report LA-12721-PR (January 1994).