*Laboratory and Field Studies Related to the
Hydrologic Resources Management Program
October 1, 1995 — September 30, 1996*

*Edited by
Joseph L. Thompson*

*Contributors:
D. Wes Efurd
Donald J. Rokop
David L. Finnegan
Margaret A. Guell⁺
Annie B. Kersting*
Bennie A. Martinez
David K. Smith**

⁺University of California, Berkeley

**Lawrence Livermore National Laboratory*

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Los Alamos
NATIONAL LABORATORY

Los Alamos, New Mexico 87545

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EXECUTIVE SUMMARY

Los Alamos National Laboratory (LANL) is a member of a multi-agency group which has worked for many years to understand the geological and hydrological consequences of underground nuclear testing at the Nevada Test Site (NTS). Much of our recent research has been to evaluate the concentrations of radionuclides in groundwater near nuclear test cavities and determine whether they are mobile with flowing groundwater at these sites. An understanding of the physical and chemical parameters which control the mobilization and transport of radioactive contaminants is essential for responsible management of the land and water resources of the NTS, and for establishment of institutional controls to ensure public safety. Therefore, our research is important to environmental management and remediation programs at the NTS and to related programs like the Yucca Mountain Project which is evaluating a repository for nuclear wastes on the border of the NTS.

The major part of our research involves analysis of field samples, both water and rock, derived from the NTS. But, in addition to field work, we provide consultation services to appropriate groups needing information within our areas of expertise. This past year we co-authored summary reports on several LANL nuclear tests and helped with the completion of a study by a doctoral student on the movement of ^{85}Kr away from a nuclear test cavity. Whenever possible, we engage in cooperative work with personnel from the Lawrence Livermore National Laboratory (LLNL) and from the IT Corporation, a contractor at the NTS. These synergistic relationships have proved to be a very important way to increase our productivity. Funding for our program, which is currently known as the Hydrologic Resources Management Program (HRMP), comes from the Department of Energy / Nevada Operations Office (DOE/NV) budgets for defense programs and for environmental management. We publish our research in annual reports, Laboratory topical reports and journal articles. This annual report describes all our activities and presents all the data collected at LANL during FY 1996.

Recently the Underground Test Area Operable Unit (UGTA OU) program at the NTS began an evaluation of hydrologic properties (including radiologic contamination) of several sites on Pahute Mesa. IT Corporation personnel completed two wells in the vicinity of the TYBO test and three wells near the BULLION test. The two wells at TYBO were pumped briefly in January and February and more extensively in June and July. Large-volume water samples were sent to LANL, and we analyzed them for gamma-emitting radionuclides. In addition to those fission products normally found in groundwater adjacent to a nuclear cavity, we detected radionuclides usually present only in colloidal form. This prompted us to analyze our samples for plutonium, which is not detected in our gamma analyses and which might also be present as a colloid. We found plutonium in the water from both the wells at TYBO, though the amount in the well penetrating the deeper aquifer was very small. The concentration of plutonium in the ER-20-5#1 well is sufficiently large to be of interest and we have begun a study to determine the origin and mode of transport of this material. We were interested in the general question of colloid transport as well. Working with Annie Kersting from LLNL, we sought to determine the size, composition, and physical characteristics of

the particulates in the water from these wells. The observation of radionuclides associated with colloids near this nuclear test cavity may have important implications for our understanding of contaminant transport. We have observed a similar situation at only one other site on Pahute Mesa. If this proves to be a more general phenomenon than previously suspected, modeling predictions will have to be modified to account for this mode of radionuclide transport. Two of the wells at the BULLION site were pumped in 1996, and we analyzed water samples from both of them and sidewall cores from one. The water samples did not appear to contain colloidal material, but did have the expected suite of radionuclides commonly found in water near a nuclear test site of this age. Interpretation of the analyses of radioactivity in the cores is hampered because of questions about contamination during drilling of the well prior to coring.

LANL personnel were asked to help analyze cores taken from the collapsed chimney of the HYRAX event fired in 1962 in an area of the NTS now being used by the Low Level Waste Storage program. In conjunction with LLNL, we interpreted the presence of ^{137}Cs at relatively shallow depths to indicate migration of precursor radionuclides (especially, ^{137}Xe) at the time of the chimney collapse. This was our first opportunity to study a shallow collapse zone in unsaturated material and it would be quite interesting to see if other similar sites also showed ^{137}Cs contamination at shallow depths.

During 1996 we collaborated with LLNL in sampling several wells known to be contaminated with radionuclides. One of these, U-19v, is especially interesting because it has remained at a very high temperature since the nuclear detonation in 1973. Unfortunately, our ability to collect samples representative of formation water from these wells is seriously compromised because we are unable to clear the well bore prior to sampling. We continue to try to find a pump small enough to operate in the narrow casing or tubing in these wells, yet powerful enough to raise water several thousand feet. Solution to this problem remains a high priority of our program. In cooperation with the Desert Research Institute (DRI) and with IT Corporation personnel we did analyze water samples from several other wells which were being pumped. One of these wells contained no measurable radioactivity; the other, RNM-2S at the Cambric site, showed that it is necessary to pump a considerable volume of water before the tritium concentration reaches a constant value. The collection and analysis of water samples from wells into or adjacent to nuclear tests continues to be our most important route toward an increased understanding of radioactive contaminant transport at the NTS.

LABORATORY AND FIELD STUDIES RELATED TO THE HYDROLOGIC RESOURCES MANAGEMENT PROGRAM

October 1, 1995 -- September 30, 1996

Joseph L. Thompson

ABSTRACT

This report describes the work done at Los Alamos National Laboratory in FY 1996 for the Hydrologic Resources Management Program funded by the US Department of Energy / Nevada Operations office. Despite declining financial support we have been able to maintain a significant analytical effort because the Underground Test Area Operable Unit at the Nevada Test Site has drilled several wells adjacent to cavities produced by nuclear tests. We measured the radionuclide content in groundwater samples and rock cores taken from near cavities at two sites on Pahute Mesa. At one of these sites we detected plutonium in the groundwater in significant concentrations. Also we detected ^{137}Cs deposition in soils high in a collapsed chimney above the working point at a location in the Low Level Waste Management facility in Area 3 of the Nevada Test Site. We analyzed samples from four wells suspected or known to contain radionuclides. Sampling efforts in wells completed with small-bore tubing or casing continue to be hampered by our inability to adequately purge the well prior to sampling. We presented our work at a number of meetings and published several review articles.

I. INTRODUCTION

Since 1973, Los Alamos National Laboratory (LANL) has been a participant in a multi-agency research effort to evaluate the environmental impact of underground nuclear weapons testing at the Nevada Test Site (NTS). Other organizations involved include the Lawrence Livermore National Laboratory (LLNL), the US Geological Survey (USGS), and the Desert Research Institute (DRI). This research program is now called the Hydrologic Resources Management Program (HRMP). It is managed by the US Department of Energy / Nevada Operations Office (DOE/NV). Since the end of nuclear testing at the NTS in 1992, LANL personnel in the HRMP program have worked primarily on measurement of radionuclides in the rock and groundwater adjacent to shot cavities. We seek to determine the distribution and chemical form of these fission products, fuel elements, and activation products, and endeavor to understand how they may move through their underground environment. This research is important for a number of programs at the NTS. These include the Yucca Mountain Project, which is evaluating a site adjacent to the NTS for a nuclear waste repository; the Defense Program which is responsible for groundwater stewardship and for future uses of the site; and the Environmental Monitoring and Remediation programs which evaluate present and future characteristics of the NTS water and soils. While in the past most of the financial support for the HRMP came from DOE Defense Programs, this year almost as much support was from the Underground Test Area Operable Unit (UGTA OU), which is part of the NTS environmental management program. LANL contributions to HRMP research in FY 1996 are presented in this report. Previous work has been described in annual reports,¹⁻¹⁹ topical summary reports,²⁰⁻²⁵ and journal articles.²⁶⁻³⁶

II. PROGRAM COORDINATION AND TECHNICAL SUPPORT

Program coordination involves management functions at LANL such as budgeting, personnel administration, regulatory compliance, and equipment and supply management. It also involves coordinating our work with other organizations within and outside of the Laboratory. Technical support includes LANL personnel providing information and technical advice to other participants in the HRMP and to other DOE programs. As we have noted in recent annual reports, budgets for the HRMP have severely declined in recent years, both for LANL and for the other participant organizations. This has noticeably impacted our ability to do field work; most of what we now do is analyze samples provided by other programs. Fortunately, the UGTA OU program has been actively investigating a number of sites adjacent to shot cavities and has generated water and soil samples of interest to us. We have been able to interact extensively with personnel from this program, notably those from their principal contractor, the IT Corporation. As part of the effort in environmental management, LANL provided reviews of our nuclear testing in several areas of the NTS (see Appendix). We also had the opportunity to work with the Low Level Waste Management program at the NTS on characterizing some samples from a location they are developing in Area 3. During the past year a student studying with Professor James Hunt at Berkeley finished work on modeling the movement of ⁸⁵Kr from the Cambric site at the NTS.

We continue to collaborate with Dave Sawyer (USGS, Denver) who is summarizing what is known about the Cheshire site at the NTS. The data generated at LANL in the HRMP program is presented in the appropriate sections of this report. In the Appendix we list technical meetings we attended which were related to this program and list publications which we generated.

III. GROUNDWATER PROTECTION

In this section we report on analyses of water and rock samples taken from sites adjacent to expended shot cavities. These analytical data are basic to our ability to understand the movement of radionuclides away from nuclear test cavities. We have to know what radionuclides are in the water and rock and their spatial distribution relative to the cavity before we can begin to surmise the mechanisms by which they were transported to those locations. Opportunities to sample in and adjacent to shot cavities are vital to the basic mission of the HRMP and we seek to exploit them whenever possible.

A. ER-20-5 #1 and #3

The TYBO test was fired on Pahute Mesa May 14, 1975 at a depth of 765 m (2510 ft), well below the static water table at 630 m (2067 ft). In November 1995 the UGTA OU program drilled well ER-20-5 #1, 278 m (912 ft) west of the TYBO test; the depth of ER-20-5 #1 was 860 m (2820 ft). In February 1996 they drilled well ER-20-5 #3 to a depth of 1309 m (4294 ft). Its location was about 30 m (100 ft) south of the #1 well. (An attempt to drill a #2 well had to be abandoned due to hole instability.) Both wells #1 and #3 were completed with 13 cm (5.5 inch) slotted casing hanging in the 294 cm (12.25 inch) bore and a Moyno pump above the casing. The intervals for water withdrawal in well #1 was 701 to 784 m (2300 to 2471 ft), and in well #3 was 1046 to 1183 m (3430 to 3882 ft). During 1996, two pumping exercises were conducted at each of these wells. Water samples were collected in 55-gal drums and returned to LANL for analysis. These samples were evaporated to dryness and the residues were counted on a Ge detector system to identify any gamma-emitting radionuclides present. The results of these analyses are given in Table I and Table II below.

Table I. Gamma Emitters in ER-20-5 #1 Water

Radionuclide	Activity at count time		Activity at $t_0 =$ 15 May 75		% Error
	Bq/L	pCi/L	Bq/L	pCi/L	
<i>after 3 Jan 96 pumping of 5000 gals</i>					
^3H	2.44E6	6.6E7	7.8E6	2.11E8	± 2
^{137}Cs	4.4E-1	1.19E1	7.1E-1	1.93E1	± 2
^{60}Co	6.9E-2	1.9E0	1.08E0	2.9E1	± 4
^{152}Eu	5.8E-2	1.6E0	1.68E-1	4.5E0	± 4
^{154}Eu	7.0E-2	1.88E0	3.8E-1	1.02E1	± 5
^{155}Eu	1.7E-2	4.7E-1	3.6E-1	9.8E0	± 10
<i>after 3 Jun 96 pumping of 401,000 gals</i>					
^3H	2.52E6	6.81E7	8.24E6	2.23E8	± 2
^{137}Cs	5.7E-1	1.55E1	9.34E-1	2.52E1	± 2
^{60}Co	6.8E-2	1.8E0	1.11E0	3.0E1	± 4
^{152}Eu	5.6E-2	1.5E0	1.67E-1	4.5E0	± 4
^{154}Eu	6.3E-2	1.70E0	3.6E-1	9.3E0	± 5
^{155}Eu	1.6E-2	4.4E-1	3.6E-1	9.3E0	± 10

The data in Table I show that there was not much change in the activity levels of detected radionuclides after the more extensive pumping in June. The presence of ^3H , ^{137}Cs and ^{60}Co in groundwater adjacent to a nuclear test cavity was expected; the presence of the europium isotopes was not. Europium isotopes have not often been detected in groundwater at the NTS and when they have been found, they were present as colloids. Therefore, a portion of the water collected from the June pumping was subjected to serial filtration to determine whether the radionuclides detected were associated with particulates. Annie Kersting from the Isotope Sciences Division at LLNL assisted in this work. The filters were used in this order: a prefilter (pore size nominally less than 800 nm), a 220 nm filter, a 50 nm filter, and a tangential flow filter with pore size 100,000 nominal molecular weight. After use, the filters were scanned with a Ge detector to measure their relative loading with gamma-emitters. The distribution of detected radionuclides (^{137}Cs , ^{60}Co , as well as the europium isotopes) was 70 - 87% on the prefilter, 10-20% on the tangential filter, and very small amounts on the intermediate-sized filters. Further characterization of the composition of the filtered material is being done at LLNL.

Having observed that there were radionuclides in the groundwater at this site which were colloidal or associated with particulates, we decided to check our samples for the presence of plutonium. If plutonium were present in groundwater, it would probably be in the form of colloids; plutonium is not detectable with our normal gamma scanning technique. The samples were treated radiochemically to dissolve and isolate the plutonium which was then electroplated on platinum disks and alpha counted. The radionuclides identified by this procedure were ^{238}Pu and $^{239,240}\text{Pu}$. The electroplated material was dissolved from the disks and isotopically analyzed in a mass spectrometer. These analyses indicated that the plutonium in the residues from both the January and June pumping was the same. Also, the plutonium caught on the filters and that in the water was isotopically the same, and the distribution of plutonium on the filters was not unlike that of the gamma-emitting radionuclides, i.e., about 87% on the prefilter and 12% on the tangential filter. The concentration level of ^{239}Pu (the dominant isotope) in the January pumping was 0.36 pCi/L and in the June pumping 0.18 pCi/L. At the NTS, ^{239}Pu levels in groundwater in excess of 0.07 pCi/L trigger further detailed analyses for plutonium and other actinides. Therefore, the observation of these levels of plutonium in groundwater at ER-20-5 #1 was unexpected and was considered very significant.

Table II. Gamma Emitters in ER-20-5 #3 Water

Radionuclide	Activity at count time		Activity at $t_0 =$ 14 May 75		% Error
	Bq/L	pCi/L	Bq/L	pCi/L	
<i>after 15 Feb 96 pumping of 8000 gals</i>					
^3H	2.4E3	6.5E4	7.8E3	2.1E5	± 4
^{137}Cs	6.4E-3	1.7E-1	1.04E-2	2.8E-1	± 7
^{60}Co	2E-3	5E-2	3E-2	8E-1	± 20
<i>after 31 Jul 96 pumping of 531,359 gals</i>					
^3H	5.6E3	1.46E5	1.9E4	5.0E5	± 4
^{137}Cs	5.3E-3	1.4E-1	8.7E-3	2.3E-1	± 15
^{60}Co	3E-3	9E-2	6E-2	1.5E0	± 20

As the data in Table II show, there were some changes in the concentrations of detected radionuclides in well #3 after an extended pumping period. The ^3H and ^{60}Co concentrations doubled while the ^{137}Cs decreased. In general, the levels of radionuclides in well #3 were several orders of magnitude lower than in well #1.

After plutonium was detected in the groundwater at well #1, we analyzed the residue from the second pumping at well #3 for plutonium. Plutonium was found in this sample but at a concentration of $5.5\text{E-}3$ pCi/L. Thus the plutonium concentration was several orders of magnitude lower than in groundwater from well #1, as were the concentrations of the other radionuclides. The plutonium was isotopically identical to that in well #1.

In summary, our 1996 studies of radionuclides in groundwater in the vicinity of the TYBO event showed that there were relatively small changes in the radionuclide concentrations even after large amounts of water were withdrawn from the wells. The concentrations of detected radionuclides were several orders of magnitude lower in the water from well #3, which came from a deeper aquifer than well #1. All the detected radionuclides (except tritium) seemed to be associated with filterable particulates. Plutonium was present at significant levels in the groundwater from well #1.

B. ER-20-6 #1 and #2

The BULLION test was conducted on Pahute Mesa June 13, 1990 at a depth of 674 m (2211 ft), below the static water level at 619 m (2030 ft). During March and April of 1996, three wells, ER-20-6 #1, #2, and #3, were drilled by the UGTA OU program at 166 m (544 ft), 207 m (680 ft), and 296 m (971 ft) respectively from BULLION ground zero. These wells, each 975 m (3200 ft) deep, were along a line south-west of BULLION in the direction of the natural groundwater flow. The wells were completed with 13 cm (5.5 inch) slotted casing hanging in the 294 cm (12.25 inch) bore and a Moyno pump above the casing (well #3 has a submersible pump). The intervals for water withdrawal were: wells #1 and #2 765-829 m; 856-884 m (2510-2720 ft; 2810-2900 ft); and well #3 765-854 m (2510-2802 ft). Water was collected from well #1 on March 16, 1996 and from well #2 on April 2, 1996; 55-gal drum samples were analyzed at LANL for tritium and for gamma emitting radionuclides. Tritium was measured by liquid scintillation counting and the gamma emitters determined with a Ge spectrometer after the samples were evaporated to dryness. The results of these analyses are given in Table III below. The tritium concentration in well #2 is down almost a factor of 2 relative to well #1; the other radionuclide concentrations are down about a factor of 4. It is tempting to speculate that these data show migration with groundwater from the BULLION cavity in a downgradient direction. However, such a conclusion remains speculative until we have more data on the hydrology and the areal distribution of radionuclides at this site. More experiments are underway to investigate the hydrology near BULLION.

Table III. Radionuclides in ER-20-6 Water

Radionuclide	Activity at count time		Activity at t ₀ = 13 Jun 90		% Error
	pCi/L	Bq/L	pCi/L	Bq/L	
<i>from well #1 after pumping 6,900 gals</i>					
H-3	1.70E6	6.30E4	2.36E6	8.74E4	<u>+2</u>
Ru-106	4.06E2	1.50E1	2.16E4	8.01E2	<u>+2</u>
Sb-125	1.83E2	6.78E0	8.09E2	3.00E1	<u>+2</u>
Cs-137	3.98E1	1.47E0	4.54E1	1.68E0	<u>+2</u>
Rh-102m	6.7E-1	2.5E-2	1.9E0	7.1E-2	<u>+6</u>
Co-60	3.6E-1	1.35E-2	7.8E-1	2.9E-2	<u>+7</u>
<i>from well #2 after pumping 20,000 gals</i>					
H-3	9.44E5	3.50E4	1.31E6	4.86E4	<u>+2</u>
Ru-106	1.20E2	4.45E0	6.57E3	2.43E2	<u>+2</u>
Sb-125	5.35E1	1.98E0	2.39E2	8.83E0	<u>+2</u>
Cs-137	1.32E1	4.9E-1	1.51E-1	5.61E-1	<u>+2</u>
Rh-102m	1.5E-1	5.5E-3	4.3E-1	1.6E-2	<u>+20</u>
Co-60	10E-2	3.6E-3	2.1E-1	7.8E-3	<u>+25</u>

On November 1, 1996 we received cores from ER20-6 #1. These sidewall samples, about 22 mm in diameter, were obtained by percussion or rotary coring on March 8 and 9, 1996. They were stored in small glass jars with metal screw caps; this storage may not have been completely air-tight. Our analysis procedure consisted of three parts: tritium extraction and measurement, geologic characterization, and measurement of gamma activity. The tritium was extracted by removing the jar lid and immediately placing the lid, jar, and contents into a heated vacuum chamber which exhausted through a cold trap that collected any water vapor evolved. The chamber was held at about 105 °C for eight hours. Water collected in the cold trap (at 0 °C) was analyzed for tritium by liquid scintillation counting. The core, now dry but otherwise not altered, was examined by a geologist nondestructively. Then it was broken into fragments ranging from pea-sized to powder, placed in a standard configuration in a Ge counting system, and any gamma-emitting radionuclides quantitatively evaluated. The core was then stored or used for further geological characterization. Our analytical data are presented in Tables IV and V below. There is considerable uncertainty in the measurement of tritium because some water may have been lost from some of the cores during storage for over seven months. Also, the amount extracted from several of the cores was extremely small and the fraction recovered may not have been 100%. Except for one

core, the gamma activity was generally quite low, and the values quoted are probably order-of-magnitude. The water table at ER20-6#1 was reported to be about 616 m (2020 ft), so the first four cores in our group presumably came from the vadose zone. This means that the gamma activity seen at 581 m (1907 ft) may have been emplaced by prompt injection at the time of the explosion; it could not be the result of groundwater transport. This interpretation cannot be certain, however, because we do not know how much the measured activities, both tritium and gamma, were the result of contamination by drilling fluids being returned through this section of the hole prior to sidewall coring.

Table IV. Tritium in Cores from ER-20-6 #1

IDENTIFICATION NUMBER	DEPTH meters (ft)	CORE TYPE	DRY WEIGHT (g)	WATER WEIGHT (g)	PERCENT WATER (%)	H-3 ACTIVITY Nov-96	H-3 (pCi/ml) 13-Jun-90	H-3 ACTIVITY Nov-96	H-3 ACTIVITY (Bq/L) 13-Jun-90
2061-96-311	576 (1890)	PERCUSSION	9.26	0.26	2.8	3.4E+2	4.9E+2	1.3E+4	1.8E+4
2061-96-321	578 (1896)	PERCUSSION	15.58	0.36	2.3	3.8E+3	5.4E+3	1.4E+5	2.0E+5
2061-96-331	581 (1907)	PERCUSSION	6.42	0.21	3.3	7.4E+2	1.1E+3	2.8E+4	3.9E+4
2061-96-341	584 (1915)	ROTARY	25.17	0.52	2.1	6.0E+2	8.7E+2	2.2E+4	3.2E+4
2061-96-351	668 (2190)	ROTARY	32.36	2.24	6.9	9.3E+3	1.3E+4	3.4E+5	5.0E+5
2061-96-361	672 (2205)	ROTARY	28.38	3.95	14	1.7E+4	2.5E+4	6.4E+5	9.3E+5
2061-96-371	756 (2480)	ROTARY	35.91	2.44	6.8	2.9E+3	4.2E+3	1.1E+5	1.6E+5

Table V. Gamma-emitters in Cores from ER-20-6 #1

IDENTIFICATION NUMBER	DEPTH meters (ft)	CORE TYPE	DRY WEIGHT (g)	Cs-137 ACTIVITY Nov-96	Cs-137 (pCi/g) 14.Jun 90	Cs-137 (Bq/KG) 14.Jun-90	Sb-125 ACTIVITY Nov-96	Sb-125 (pCi/g) 14.Jun 90	Sb-125 (Bq/KG) ACTIVITY Nov-96	Sb-125 (Bq/KG) ACTIVITY Nov-96	Sb-125 (Bq/KG) ACTIVITY Nov-96
2061-96-310	576 (1890)	PERCUSSION	9.26	1.1E+0	1.3E+0	4.8E+1					
2061-96-320	578 (1896)	PERCUSSION	15.58	4.6E-1	5.4E-1	2.0E+1					
2061-96-330	581 (1907)	PERCUSSION	6.42	3.8E+2	4.4E+2	1.4E+4	2.1E+1	1.1E+2	7.8E+2	3.9E+3	
2061-96-340	584 (1915)	ROTARY	25.17	5.6E-1	6.4E-1	2.4E+1					
2061-96-350	668 (2190)	ROTARY	32.36	5.8E-1	6.8E-1	2.5E+1					
2061-96-360	672 (2205)	ROTARY	28.38	1.6E+0	1.8E+0	6.8E+1					
2061-96-370	756 (2480)	ROTARY	35.91	4.6E-1	5.4E-1	2.0E+1					

C. U-3bh

In conjunction with David Smith from the Isotope Sciences Division of LLNL, we characterized the occurrence of radioactivity detected in cores returned from the U-3bh subsidence chimney. This was in response to a request by the Waste Management Division of the US DOE/NV. The cores had been collected as part of a drilling program to characterize the U-3bh site for the disposal of low-level radioactive wastes (LLW) at the NTS. The U-3bh site is located within the NTS Area 3 Radioactive Waste Management Site. The results of this investigation may have implications for other crater-chimney sites at the NTS where LLW disposal is currently being proposed. Additionally, these studies provide insight to the transport of volatile radionuclides in underground nuclear test cavity-chimney systems, specifically showing the ability of these species to migrate upwards from the working (firing) point to the near surface.

The request for radiologic characterization followed the discovery of gamma activity in two vertical boreholes (U-3bh #1 and U-3bh #2) drilled in the bottom of the subsidence crater created by the 1962 HYRAX (U-3bh) underground nuclear test. Although the two boreholes were separated by 15 m, ^{137}Cs was detected in both at a depth of 64 m (210 ft). A comprehensive data review for the HYRAX collapse zone is provided in Ref. 37 and will not be repeated here. A summary of HYRAX event, emplacement and phenomenological data is provided in Table VI.

Table VI. HYRAX Event Data

Hole	U-3bh
Fire Date	9/14/62
Depth of Burial (DOB)	216 m
Geologic Medium at DOB	Alluvium (tuffaceous sand)
Hole Diameter	0.737 m
Drilled Depth	329 m
Casing Depth	265 m
Depth to Static Water Level (SWL)	488 m (estimated)
Announced Yield	Less than 20 kilotons
Time to Cavity Collapse	7.9 minutes
Crater Diameter	155.4 m
Crater Volume	169,000m ³

The cores analyzed by LLNL and LANL were collected from U-3bh #1 on February 7, 1996 and from U-3bh #2 on February 22, 1996. Cores were obtained by ODEX casing advance "dry" drilling. By eliminating the circulation of drilling fluids over the bit and core barrel as samples are collected, the distribution of soluble radionuclides is preserved in unsaturated media. Cores were intruded into 3" x 3" diameter high-density plastic cylinders. Each cylinder was terminated with plastic end caps wrapped with tape and further sealed in an aluminum foil envelope. A total of seven cores were shipped to the Laboratories; three to LLNL and four to LANL. Only cores with detectable activity above background were

shipped for characterization. The general strategy was to ship the cores with the highest activity to LANL for gamma and tritium counting; cores with lower level of activity were sent to LLNL for matrix characterization and gamma counting of size fractions. Table VII compiles the cores analyzed for this investigation. The cores were received at LLNL on March 22, 1996 and at LANL on March 25, 1996. In contrast to the Laboratory's experience with sidewall samples returned from post-shot drilling, these core materials were largely unconsolidated sediments. The sediments consist of moderately sorted, tightly packed, tuffaceous sandy soil supporting occasional subrounded to rounded pebbles.

Table VII. HYRAX Core Samples

LLNL	LANL
U-3bh #1 210.75 - 211.0 ft	U-3bh #1 211.0 - 211.25 ft
U-3bh #2 211.25 - 221.50 ft	U-3bh #1 211.25 - 211.50 ft
U-3bh #2 211.75 - 212.0 ft	U-3bh #2 211.50 - 211.75 ft
	U-3bh #2 212.0 - 212.25 ft

At LANL, each core was divided into roughly equal halves and dried in an apparatus which allowed collection of non-bound water. The samples were heated for six to ten hours under a vacuum of about 400 torr and a temperature about 120°C. The collected water was counted in a liquid scintillation counter to determine the tritium content. Duplicate aliquots from each water sample were counted. An aliquot from each dried sample was taken for gamma counting using an intrinsic Ge detector. The gamma spectra were analyzed to identify and quantitate the radionuclides contributing to the spectra. In selecting the aliquots of dried material for gamma counting, no particular effort was made to select soils of certain grain sizes; however, the larger pebbles were excluded from these aliquots. The water content, ^{137}Cs activity and tritium activity for the deepest and most radioactive bulk cores are shown in Table VIII. The water weight in the sample was determined by the difference in the wet and dry weights of the solids. The volume of water collected was also measured; the fraction of water recovered was 89 to 99 percent. The errors in the tritium activity are one sigma standard deviations of repetitive counts of the duplicate samples. There is good agreement for tritium concentrations between the cores in each hole, but very large differences between the two holes. In contrast, the activity of ^{137}Cs is approximately the same in the two holes. (No evaluation of errors was made for the ^{137}Cs activities in view of the lack of homogenization of the sample halves; however, the counting standard deviations were less than 1% in all cases.)

Table VIII. Water Content, ^{137}Cs and ^3H Activity For Bulk Cores from HYRAX

Core	Half	Weight (g)	Activity @ count time (4/96)		
U-3bh #1 211.0-211.25'	A	432.2 (wet) 411.9 (dry) 20.3 (water)	2.05E2 pCi/g 7.39 ± 0.36 pCi/ml	/ 7.61E3 Bq/kg (2.73 $\pm$ 0.13)E2 Bq/L	^{137}Cs ^3H
	B	304.9 (wet) 290.0 (dry) 14.9 (water)	3.37E2 pCi/g 7.66 ± 0.41 pCi/ml	/ 1.25E4 Bq/kg (2.83 $\pm$ 0.15)E2 Bq/L	^{137}Cs ^3H
U-3bh #1 211.25-211.50'	A	389.1 (wet) 371.8 (dry) 17.3 (water)	4.30E2 pCi/g 8.02 ± 0.27 pCi/ml	/ 1.59E4 Bq/kg (2.97 $\pm$ 0.10)E2 Bq/L	^{137}Cs ^3H
	B	323.4 (wet) 307.6 (dry) 15.8 (water)	4.40E2 pCi/g 7.97 ± 0.14 pCi/ml	/ 1.63E4 Bq/kg (2.96 $\pm$ 0.05)E2 Bq/L	^{137}Cs ^3H
U-3bh #2 211.50-211.75'	A	292.0 (wet) 271.1 (dry) 20.9 (water)	3.50E2 pCi/g (8.93 $\pm$ 0.04)E2 pCi/ml	/ 1.29E4 Bq/kg (3.30 $\pm$ 0.02)E4 Bq/L	^{137}Cs ^3H
	B	318.2 (wet) 296.3 (dry) 21.9 (water)	3.61E2 pCi/g (8.80 $\pm$ 0.08)E2 pCi/ml	/ 1.34E4 Bq/kg (3.26 $\pm$ 0.03)E4 Bq/L	^{137}Cs ^3H
U-3bh #2 212.0-212.25'	A	336.5 (wet) 312.6 (dry) 23.9 (water)	4.13E2 pCi/g (1.10 $\pm$ 0.01)E3 pCi/ml	/ 1.53E4 Bq/kg (4.06 $\pm$ 0.04)E4 Bq/L	^{137}Cs ^3H
	B	322.7 (wet) 304.5 (dry) 18.2 (water)	4.15E2 pCi/g (1.07 $\pm$ 0.01)E3 pCi/ml	/ 1.54E4 Bq/kg (3.96 $\pm$ 0.04)E4 Bq/L	^{137}Cs ^3H

Data returned from U-3bh #1 and U-3bh #2 indicate that significant transport of radionuclides can occur in the disturbed chimney region of a nuclear test conducted in the vadose zone. At HYRAX, radionuclides ascended 152 m into the collapse chimney -- that is, to the horizon at 64 m (211 ft) where ^{137}Cs was encountered. We believe that transport up to this level was due to movement of gases and vapors at the time the cavity and chimney formed. Radiochemical analyses of the U-3bh #1 and U-3bh #2 cores indicate the singular presence of ^{137}Cs as a gamma emitting fission product. ^{137}Cs is produced from the decay of gaseous fission product precursors. The ^{137}Cs decay scheme with cumulative fission yield of precursor species for actinide nuclear weapon fuels is provided in Table IX.³⁸

Table IX. ^{137}Cs Decay Scheme with Precursors, Half-Lives and Cumulative Fission Chain Yields

^{137}Cs Precursors	$t_{1/2}$	Cumulative SNM* Fission Chain Yield
^{137}Sb	0.284 seconds	0.0025%
^{137}Te	2.5 seconds	0.4377%
^{137}I	24.5 seconds	2.56%
^{137}Xe	229.2 seconds	5.92%
^{137}Cs	30.1 years	6.09%

*SNM: Special nuclear materials as actinide nuclear weapon fuels

As Table IX shows, over 90% of the ^{137}Cs produced passes through the gaseous state as ^{137}Xe with a 229.2 second half-life. Iodine (and cesium itself) are relatively volatile and may also move as vapors some distance before condensing on the alluvial matrix. When the cavity collapse occurred at the HYRAX site at $t_0 + 7.9$ minutes, much of the 137 -chain-yield material was still in the form of ^{137}Xe ; probably most of the migration of this isotope occurred at this time as the chimney propagated upward. In addition to volatile gamma emitting radionuclides, tritium is produced in abundance in underground nuclear tests during the burning of thermonuclear fuels. At zero time, tritium is produced atomically but very shortly condenses to steam. Over 99% of the tritium is incorporated as molecular HTO. Because the steam is volatile, tritium will also be transported in the gas phase as are the ^{137}Cs precursors. Our experience at the NTS is that tritium rarely moves more than 1.4 cavity radii away from the working point at the time of the event. Other volatile fission products are generally confined within the cavity boundaries, suggesting that they condense to liquids or solids prior to chimney formation. The singular presence of ^{137}Cs in the U-3bh #1 and U-3bh #2 core implies this radionuclide was emplaced by gas transport (as ^{137}Xe) in the vadose zone shortly after zero-time. The distribution is notable. Despite the 15 m separation, ^{137}Cs was detected at identical depths in approximately the same concentrations in the two boreholes. Its precursor migrated 152 m (approximately 5 cavity radii) above the working point in a lined and stemmed emplacement hole. Macroscopic and microscopic textural examination indicates the absence of matrix fractures and emphasizes the importance of transport through the alluvial matrix. While ^{137}Cs abundances are nearly the same in the two boreholes, tritium abundances in U-3bh #1 and U-3bh #2 vary by two orders of magnitude. We suspect that there may be other causes for the observed tritium distribution.

The ^{137}Cs was transported approximately 5 cavity radii above the HYRAX working point. While discovery of gamma activity in a nuclear test chimney is not unexpected, the relatively shallow depth (64 m) and lateral extent of the contamination encountered in two separate boreholes is significant. Previous investigations of radionuclide migration adjacent to nuclear test cavities have appealed to two prompt mechanisms to transport radionuclides away from the working point. Nimz and Thompson²⁴ describe "prompt fracture injection" as a

mechanism to transport radionuclides as a high temperature and high pressure plasma along newly created and reactivated fractures produced by the detonation. They attribute radionuclide migration in the unsaturated zone at (U-3cn#5 (BILBY), UE-4g#2 U-9 ITS U-29, U-3kz (ALEMAN) and UE-2ce to prompt injection. More recently, Smith et al.³⁹ have investigated the occurrence of gaseous fission products in a discrete interval adjacent to the INGOT (U-2gg) working point and suggest that transport occurs for several minutes following the event as short-lived gaseous species (^{137}Xe and ^{90}Kr) migrate through prompt fractures opened by the explosion. The absence of fission products of low (^{144}Ce , ^{95}Zr , ^{155}Eu) or intermediate (^{54}Mn , ^{60}Co) volatility in the core samples strongly argues that ^{137}Cs was emplaced by the transport of precursor gases through the unconsolidated event chimney. While shorter lived fission products (^{125}Sb , ^{22}Na , ^{106}Ru , ^{134}Cs) with half-lives of ≈ 1 to 2 years arguably could have decayed away and not be detected in the thirty-four years since detonation, the presence of refractory species would be expected if the nuclides condensed from high temperature and pressure gases injected at or soon after zero time (assuming there was not significant geometric or chemical fractionation of the device during the detonation). The identical depth at which the gamma activity was encountered in the U-3bh #1 and #2 boreholes is strong evidence that transport was the result of a single front of radioactive gas that ascended through the collapsed alluvium. The ascent of gas approximately five cavity radii above the working point may be attributed to partial containment failure (early time). This is the result (in part) of physical and mineralogical properties of the Area 3 alluvium. Hawkins³⁷ reports that formation instability threatened completion of the emplacement hole and a 0.7 m diameter casing was cemented in U-3bh from the surface to a depth of 265 m. Following installation of the device, diagnostics, rack, and cabling, the hole was backfilled with several cubic meters of magnetite sand and then filled to the surface with dry sand. Stemming practice during this time (1962) was an evolving science; designs were adapted informally in the field based on containment experience.³⁷ The use of a cased hole and sand backfill likely channeled gas up the emplacement hole during initial cavity growth. The abundance of calcite in all size fractions (approaching 50% in the 150 μm and finer size fraction) of the U-3bh #2 core implies a significant amount of carbonate at the HYRAX working point. The vaporization and melting of this carbonate produced an abundance of noncondensable CO_2 gas that entrained the radioactive gases. Assuming an average composition for the NTS working point media (5.9 weight % calcite for Yucca Flat alluvium)⁴⁰ approximately 10^6 liters of CO_2 gas are produced per kiloton of nuclear explosive yield. Using the upper yield limit of 20 kilotons for HYRAX, $2.0\text{E}7$ liters of CO_2 were produced by the explosion. Because the alluvium probably consisted of approximately 50 weight % carbonate at the level of the working point, CO_2 production was likely much greater. As CO_2 and fission product gases were channeled upwards they breached the cased hole and migrated through the formation as a broad front. Failure of carbonate along grain boundaries enhanced the permeability. The ascent of the radioactive gas was facilitated by the porosity of the finer unconsolidated matrix and vitric clasts. The noncondensable and radioactive gases continued to migrate up the subsidence chimney after the cavity collapsed eight minutes after the explosion. Further

migration of the radioactive gases continued until ^{137}Xe precursor completely decayed to ^{137}Cs ; at this point the ^{137}Xe reached its maximum height in the chimney.

The data returned from the U-3bh #1 and U-3bh #2 cores is significant because it emphasizes the extent of radionuclide transport possible in the vadose zone. Few subsidence chimneys have been investigated to assess the vertical transport of radionuclides either by prompt injection, gas diffusion, or partial containment failure. Previous crater/chimney studies have concentrated on infiltration of water through regions of enhanced permeability in the crater and chimney region and mobilization of soluble radionuclides (^3H , ^{36}Cl) resident in the vadose zone.^{41,42} Experience at HYRAX demonstrates the ability of radionuclides to migrate significant distances (~ 5 cavity radii) in the vadose zone and to be deposited near the surface. The probability for this mode of radionuclide migration is greatest in older (pre-1970) events where modern containment practices were not implemented and in areas with lower formation strength that were prone to partial containment failure and movement of radionuclide through regions of enhanced matrix porosity. (This discussion of our results from U-3bh emphasizes work done at LANL. For a complete review of all results, including the fraction sizing and mineralogical analyses done at LLNL, see Ref. 43.

IV. GROUNDWATER MONITORING

Part of the LANL research in the HRMP program involves periodic sampling of wells at the NTS where radionuclides have been found in the water. Our sampling visits at some of these locations have occurred over many years, and provide a significant historical record of radionuclide association with groundwater. In recent years, our water collection has often been done in collaboration with LLNL personnel who have similar needs for samples. Water samples were analyzed in FY 1996 from the following sites:

A. ER-3-1

This well was drilled in the eastern part of Area 3 of the NTS to obtain geologic and hydrologic information in a region for which few data were available. There had been no nuclear testing close to this site, and it was believed to be hydrologically up-gradient from the heavily used Yucca Flat. LANL received a 55-gal drum of water from this site which had been collected by A. Burns of IT Corporation on November 9, 1995. We analyzed an aliquot for ^3H with a liquid scintillation counter, then evaporated the sample to dryness and counted the residue using a calibrated Ge detector. We detected no gamma activity due to radionuclides other than those naturally occurring, nor could we detect ^3H . The sensitivity of our systems is such that we could measure ^{137}Cs above about 4E-4 Bq/L (1E-2 pCi/L) and ^3H above about 4E1 Bq/L (1E3 pCi/L).

B. RNM-2S

The Cambric site in Area 5 is the location of a pumping experiment lasting from 1975 to 1991 in which groundwater-transported radionuclides were eluted from the shot cavity out a pumped well (RNM-2S) 91 m away. Since 1991 we have sampled water from this well about once a year. Our data¹⁸ seem to indicate that in the absence of continuous pumping there is little movement of tritium away from this well. On May 22, 1996 DRI personnel were pumping water from the RNM-2S well in connection with a tritium purification experiment, and we took the opportunity to obtain water samples. These were collected in small polyethylene bottles (grab), in evacuated stainless steel tubes (tube) and in 55-gal drums (drum). Analytical data from these samples are shown in Table X. The drum sample was evaporated to dryness and counted on a Ge detector. No gamma-emitting radionuclides other than those naturally occurring were detected. Comparison of the data in Table X with those from the last sampling in 1994¹⁸ indicates that the pumping time in 1996 was probably too short for the tritium concentration to rise to the maximum value (about 5.1E4 Bq/L at t_0) seen previously. It appears that this well must be pumped for about 3 hours before the tritium concentration reaches a steady state.

Table X. Radionuclides in Water from RNM-2S

Sample ID	Sample Type	Sample Time	Activity @ Sample Time (Bq/L)*		Activity @ t_0 = 14 May 65 (Bq/L)*	
			³ H	⁸⁵ Kr	³ H	⁸⁵ Kr
pump on		12:20				
#1	grab	12:25	2.4E2		1.4E3	
434-1-96-001	tube		not analyzed			
#2	grab	13:00	3.6E3		2.1E4	
#3	grab	13:30	6.3E3		3.6E4	
434-1-96-002	tube	13:40	7.9E3	5.9E-1	4.5E4	4.4E0
#4	grab	13:45	7.8E3		4.5E4	
434-9-96-001	drum	13:45				

*1 Bq/L = 27 pCi/L

For several years a doctoral student, Margaret Guell, has been working at UC Berkeley under the direction of Professor James Hunt to model the migration of ⁸⁵Kr at the Cambric site. The elution data from the pumped well (RNM-2S) indicated that less than half of the calculated Kr-85 source term was removed after 17 years of pumping, though over 92% of the tritium was removed. Also, the peak in the elution curve of the ⁸⁵Kr was delayed relative to the peak in the ³H elution curve, although both these materials are conservative tracers which do not react with the geologic media through which the groundwater moved. Guell postulated an explanation for these observations and tested it with a mathematical model which simulated the movement of tritium and krypton at this site. The model showed that the hypothesis was consistent with the observed behavior, but that the model was very sensitive to assumptions about initial radionuclide distributions and to

hydrologic parameters (some of which are not well measured). The hypothesis was that carbon dioxide gas evolved from the carbonate rock around the nuclear device contributed to the post-detonation migration of Kr-85 throughout the rubble chimney above the collapsed crater. This occurred because the working point of the Cambric device coincided with a stratum concentrated in secondary carbonate material; the result was an evolution of about three times the amount of non-condensable gas normally expected in a device of this yield. The tritium vapor condensed in the immediate cavity region and was not affected by the carbon dioxide. As the chimney collapsed, the gas moved upward, becoming distributed throughout the entire length of the chimney. If that chimney reached above the water table, "excess" CO₂ would have been released into the vadose zone. The behavior of this gas is particularly important to consider, since Kr-85 is a gaseous radionuclide; hence, where CO₂ moved, so did Kr-85. After chimney collapse, the gases were distributed throughout the chimney, with some "lost" above the water table. The different distribution of Kr-85 and ³H in and around the cavity resulted in the late elution of krypton relative to tritium as well as the loss of over half of the krypton. Guell then began to apply numerical models of increasing complexity to evaluate this scenario. A variety of numerical simulations were performed using the finite difference code TRACR3D. Analyses were conducted with a wide range of assumptions, since there is uncertainty about some of the Cambric field conditions. Using a calibration method based on the tritium elution curve, she obtained numerical simulations consistent with the suggested difference in the krypton and tritium distributions prior to pumping. However, beyond the argument of transport with carbon dioxide, she found additional factors which may have affected the initial radionuclide distribution at the Cambric site. One issue that does not appear to have been previously explored is that of thermally-induced convection currents. She spent some time exploring the possibility of buoyancy driven flow and how it may have affected the distribution of radionuclides prior to satellite well pumping. A second issue hinged on whether shallow natural hydraulic gradients may have caused migration of nuclides during the 10 years before pumping of the satellite well was initiated. Despite the extensive data from the field study, there are still uncertainties in some of the hydrologic parameters, making it impossible to conclusively resolve the results at Cambric. This study is not the final word on Cambric but does advance our ability to model a complex system and to identify significant parameters in contaminant transport.

C. U-20n ps#1 ddh

The Cheshire test at U-20n is the site of an extensive HRMP study⁸⁻¹² which was terminated around 1987 when a down-gradient well adjacent to U-20n ps#1 ddh became contaminated with iron hydroxide. We sampled the post shot well in 1994 and found levels of ³H and ⁸⁵Kr somewhat lower than in 1985, but not dramatically so.¹⁸ We believe that there is not good mixing vertically in the well bore at this site (a situation we have seen repeatedly at other locations); the data collected this past year tends to confirm this belief. The collections were made with 2-liter evacuated stainless steel tubes described in Ref. 19 in some detail. LLNL and LANL personnel worked together in this exercise. We used two tubes in tandem in each sample run, with the LLNL tube uppermost. The LLNL tube was opened in the field and a small

aliquot (split) given to LANL for tritium counting. The bottom tube was returned to LANL unopened for tritium and ^{85}Kr analysis. In some cases the entrance port clogged and only a small amount of liquid was collected. At LANL, we combined the contents of two tubes after the separation of ^{85}Kr and analyzed this material for gamma-emitting species. The results of our analyses are given in Table XI. There are variations of concentration with depth and also with which tube collected the sample. The values of ^3H concentration at 808 m are essentially the same as measured at that depth in 1994, though the ^{85}Kr concentration is somewhat higher.¹⁸ We believe our sampling results demonstrate once again the need to adequately clear the well before collecting down-hole samples. The concentrations in Table XI probably do not represent the actual aquifer concentrations.

Table XI. Radionuclides in Water from U-20n ps#1 ddh

Depth Sample ID	Radionuclide	Activity@ count time (July 1996)		Activity @ t_0 (14 Feb 1976)	
		Bq/L	pCi/L	Bq/L	pCi/L
777 m (2550 ft) LLNL split	^3H	1.9E6	5.0E7	5.9E6	1.6E8
808 m (2650 ft) LLNL split 852-1-96-002	^3H	1.9E6	5.1E7	6.0E6	1.6E8
	^3H	2.1E6	5.6E7	6.6E6	1.8E8
	^{85}Kr	3.4E1	9.9E2	1.3E2	3.5E3
838 m (2750 ft) LLNL split 852-1-96-003	^3H	1.1E6	2.9E7	3.4E6	9.0E7
	^3H	1.2E6	3.1E7	3.7E6	9.9E7
	^{85}Kr	1.4E3	3.7E4	5.2E3	1.4E5
910 m (2986 ft) LLNL split	^3H	1.1E6	2.9E7	3.4E6	9.1E7
composite of 852-1-96-002, 852-1-96-003	^{60}Co	trace			
	^{125}Sb	1.2E-1	3.2E0	1.8E0	4.9E1
	^{137}Cs	4.2E-1	1.1E-1	6.7E-1	1.8E1

D. U-19v

U-19v is the site of the Almendro test conducted June 6, 1973. This well is remarkable in that, although the water level has returned to near its pre-shot value, the well remains thermally quite hot. The re-entry hole contains 168-mm (6-5/8-in.) drill pipe terminating in an Otis plug and a burned-out Dyna drill. The Otis plug is a few tens of meters above the bottom of the cavity, at about 1100 m (3609 ft) vertical. Until 1993 we were unable to sample this well because of the high temperatures. In

cooperation with LLNL, we sampled U-19v again in 1996 and logged the temperature as deeply as we dared to go without damaging the probe. At 975 m (3200 ft) slant depth the temperature was about 43°C; at 1097 m (3600 ft) slant depth it was about 104°C. We anticipate using a different probe in the future which will allow us to log the temperature to the bottom of the drill string (about 1175 m slant depth). The water sampling with LLNL was done with evacuated tubes as described in section C above. Analytical results are presented in Table XII. The values reported in 1996 are not very different from those¹⁸ from 1993. This may be another indication of lack of vertical circulation within well bores.

Table XII. Radionuclides in Water from U-19v

Depth Sample ID	Radionuclide	Activity@ count time (July 1996)		Activity @ t ₀ (6 June 1973)	
		Bq/L	pCi/L	Bq/L	pCi/L
1006m (3300ft) LLNL split 791-1-96-001	³ H	7.4E6	2.0E8	2.7E7	7.2E8
	³ H	7.5E6	2.0E5	2.6E7	7.5E5
	⁸⁵ Kr	3.6E3	9.6E4	1.6E4	4.3E5
1093m (3585ft) LLNL split 791-1-96-002	³ H	7.4E6	2.0E8	2.7E7	7.2E8
	³ H	7.5E6	2.0E8	2.8E7	7.5E5
	⁸⁵ Kr	2.0E3	5.4E4	8.8E3	2.4E5
composite of 791-1-96-001, 791-1-96-002	⁶⁰ Co	trace			
	¹³⁷ Cs	1.0E-1	2.7E0	1.7E-1	4.6E0

V. OPERATIONAL SUPPORT

One of the tasks of the HRMP is to develop techniques for solving operational problems encountered at the NTS. During the past year we have put to use modified bailers which we designed and tested¹⁹ in 1995. These modified bailers (the stainless steel tubes referred to in several sections above) have proved better for collecting samples in wells with high particulate content than the unmodified tubes; however, they cannot help with the basic problem of stagnation within the well bore. We have sought for some time a way to remove appreciable volumes of water from small diameter tubing or casing at depths of 600 m (2000 ft). Our experiences at the NTS with swabbing, sand-bailing, jetting, and pumping with Moyno pumps have generally not been satisfactory. Improving our ability to sample water from small diameter tubes remains a high priority in this program.

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APPENDIX

Meetings Related to the HRMP and UGTA OU Programs

Tritium Measurement	DRI, Las Vegas	19-20 Oct 95
HRMP	DOE, Las Vegas	6-7 Dec 95
UGTA OU	DOE, Las Vegas	24-25 Apr 96
HRMP	LANL, Los Alamos	12-13 Jun 96
UGTA OU	DOE, Las Vegas	18 Jul 96

Presentations

"Radioactive Waste Storage in NM -- Lessons from NV" J. L. Thompson, New Mexico Conference on the Environment, March 12-14, 1996, (talk).

"Radionuclides in an Underground Environment" J. L. Thompson, 4th International Conference on Nuclear and Radiochemistry, September 8-13, St. Malo, France, (poster and extended abstract).

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H. N. Plannerer and J. L. Thompson, "Underground Tests Conducted in NTS Areas 5 and 11 Using Nuclear Devices Designed by LASL (U)," Los Alamos National Laboratory classified report LA-CP-96-273 (November 1996).