

*Laboratory and Field Studies Related to
Radionuclide Migration at the
Nevada Test Site in Support of the
Underground Test Area Program and
Hydrologic Resources Management Project*

October 1, 1999–September 30, 2000

Los Alamos
NATIONAL LABORATORY

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Edited by Margaret Burgess, Group IM-1

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LA-13787-PR

Issued: January 2001

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CONTENTS

EXECUTIVE SUMMARY	vii
ABSTRACT	1
I. INTRODUCTION	2
II. RADIOCHEMICAL ANALYSES	2
A. The Cambric Site.....	2
B. The Cheshire Site (U20n)	8
C. The Almendro Site (U19v)	10
D. The Bilby Site (U3cn).....	11
III. GROUNDWATER CHARACTERIZATION.....	11
IV. PROGRAM SUPPORT ACTIVITIES	14
A. Document Reviews/Meetings.....	14
B. Presentations/Publications	15
ACKNOWLEDGMENTS.....	15
REFERENCES.....	16

EXECUTIVE SUMMARY

This report describes work done by Chemistry Division personnel at Los Alamos National Laboratory (LANL) during FY 2000 for the US Department of Energy/Nevada Operations Office (DOE/NV). Ours is part of a multiagency program supported by the Defense Programs and Environmental Restoration Divisions of DOE/NV. The missions of both of these divisions are strongly affected by the extent of radioactive contamination of the underground environment of the Nevada Test Site (NTS) because this influences the use of land and water resources there. We are attempting to develop a descriptive model that accounts for the present distribution of radionuclides and predicts future movement within or outside NTS boundaries. The LANL Chemistry Division contribution to this effort during the past year consisted of measurements of radionuclide concentrations in water samples collected from cavities or chimneys of nuclear test locations on the NTS. Because we have been sampling some of these locations for many years, we are able to identify trends in the data that give us insights into how radionuclides may become part of the hydrologic source term; that is, how they become mobile with groundwater. As a complement to this work, we did our first field test of a downhole probe that allows us to measure *in situ* water temperature, pH, specific conductance, dissolved oxygen, and oxidation-reduction potential. These parameters influence the speciation of radionuclides dissolved in groundwater and affect how they may interact with their geologic environment. Also, we continued to use our capability to measure colloid concentrations in our samples because there is a correlation between colloids and certain radionuclides at some locations.

We added more information to our database for the Cambric site where we have conducted studies since 1975. The concentrations of tritium and ^{85}Kr in the pumped hole (RNM-2S) and in the drill-back hole (RNM-1) show little change from previous samplings. We detect some tritium in the auxiliary hole UE5n, probably from diffusion of effluent water during the time RNM-2S was continually pumped. The Cambric studies were our first attempt to look in detail at the radionuclides in the immediate vicinity of a nuclear test, and these first observations led to the following generalizations that we still find valid. (1) Most of the radioactive material after a nuclear test is incorporated in the melt glass in the cavity, although volatile species are more broadly distributed. (2) Moving groundwater is needed to transport these radionuclides beyond the cavity/chimney region. (3) The distance that groundwater can transport radionuclides is highly dependent on the speciation of the residues; neutral, anionic, and colloidal materials move relatively freely while cationic materials are sorbed by the geologic media.

During FY 2000 we collected no new water samples from the Cheshire site on Pahute Mesa, but we did complete some analyses of earlier collections. Our summary of information gained since work began there in 1976 includes the following points (1) The generalizations concerning the near-field distribution of radionuclides and their movement based on Cambric observations also apply at Cheshire. (2) Colloids appear to play an important role in radionuclide transport at the Cheshire site. (3) Local thermal effects and hydraulic gradients influence

short-term and long-term distribution of radionuclides in the cavity / chimney region.

For the last three years we have collected water samples from the Alondro site because the water that filled the cavity has remained at a very high temperature at this location. We have a unique opportunity to see the effects of elevated temperature on the solubility and speciation of residues from a nuclear test. Thus far we have not yet been able to sample at the very bottom of the cavity, but we do seem to see variations with depth of both tritium and ⁸⁵Kr concentrations.

The Bilby site is important because the cavity produced by the test is close to the Paleozoic formations and the carbonate aquifer that underlies the NTS. As in previous years, our samples reveal no indication that the Bilby test produced radionuclide contamination of this aquifer.

We were finally able to make *in situ* water measurements with our Hydrolab Minisonde 4a multiprobe. We were able to measure temperature, specific conductivity, dissolved oxygen, pH, and oxidation-reduction potential in three uncontaminated wells at the NTS. These data are needed by the modeling group to better define the water chemistry and its effect on transport in groundwater at the NTS. This initial collection of data has enabled us to prepare procedures and learn lessons that will lead to more consistent and quantitative data collection in the future.

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ABSTRACT

This report details the work of Chemistry Division personnel from Los Alamos National Laboratory in FY 2000 for the US Department of Energy/Nevada Operations Office under their Defense Programs and Environmental Restoration Divisions. Los Alamos is one of a number of agencies collaborating in an effort to describe the present and future movement of radionuclides in the underground environment of the Nevada Test Site. This fiscal year we collected and analyzed water samples from a number of expended test locations at the Nevada Test Site. We give the results of these analyses and summarize the information gained over the quarter century that we have been studying several of these sites. We find that by far most of the radioactive residues from a nuclear test are contained in the melt glass in the cavity. Those radionuclides that are mobile in water can be transported if the groundwater is moving due to hydraulic or thermal gradients. The extent to which they move is a function of their chemical speciation, with neutral or anionic materials traveling freely relative to cationic materials that tend to sorb on rock surfaces. However, radionuclides sorbed on colloids may be transported if the colloids are moving. Local conditions strongly influence the distribution and movement of radionuclides, and we continue to study sites such as Almendro, which is thermally quite hot, and Bilby where radionuclides do not appear to have moved a short distance from the cavity. We have begun field use of a tool that allows us to measure important groundwater properties *in situ*. We conclude our report by noting document reviews and publications produced in support of this program.

I. INTRODUCTION

In this report we describe the work done in the Chemistry Division at Los Alamos National Laboratory (LANL) for the Hydrologic Resources Management Program (HRMP) and the Underground Test Area (UGTA) projects. These are projects of the US Department of Energy, Nevada Operations Office (DOE/NV) conducted in the divisions of Defense Programs and Environmental Restoration. Our work supports the Defense Programs' concern for responsible stewardship of land and water resources at the Nevada Test Site (NTS), and assists the Environmental Restoration Division in assessing the radionuclide contamination resulting from nuclear weapons testing at the NTS. We collaborate with other technical organizations including the Lawrence Livermore National Laboratory (LLNL), the Desert Research Institute (DRI), the US Geological Survey (USGS), the US Environmental Protection Agency (EPA), and with contractors such as Bechtel Nevada (BN) and International Technology (IT).

Since 1973 LANL personnel have been participating in the study of the effects of nuclear testing on the environment at the NTS. We are particularly concerned with learning how radioactive residues from these tests may move underground in groundwater aquifers. An analysis of where radioactive nuclides are after being deposited some 10 to 40 years ago may enable us to evaluate the suitability of portions of the NTS for future use in testing, or for possible release for other uses. We need to know what fraction of the radioactive material associated with a nuclear test is still contained in the cavity region in melt glass (the radiologic source term), and what fraction has dissolved or formed colloids and can be transported with moving groundwater (the hydrologic source term). We also need to know the direction and velocity of groundwater flow at local test sites and through the region. Additionally, we need an understanding of the speciation and reactions (for example, sorption) of mobile radioactive materials. Using this type of information we are constructing models that describe the present and future extent of radioactive contamination of groundwater at the NTS. The work described in this report was done to learn more about the radiological and hydrological source terms at selected nuclear test sites. It provides the raw data from which models may be constructed, and allows a check of model predictions with present realities.

This report is for work done in FY 2000. It is the latest in a series of annual reports,¹⁻²³ topical reports,²⁴⁻³⁰ and journal articles.³¹⁻⁴²

II. RADIOCHEMICAL ANALYSES

A. The Cambric Site

The Cambric test was conducted in the alluvium of Frenchman Flat in 1965 at a depth of 294 m, some 70 m below the water table. Ten years later the RNM-1 hole was drilled into and through the cavity, and numerous rock and water samples were collected.²⁴ We found that nearly all of the radioactive material associated with the test was still in the cavity region. A satellite hole

(RNM-2S) was drilled 91 m from the cavity and pumping began in order to observe groundwater transport of radionuclides. We have periodically sampled water from both the RNM-1 and RNM-2S holes since 1975.²⁷ Continuous pumping at RNM-2S was terminated in 1991 after approximately 1.7E7 m³ of water had been discharged. We report here our latest analyses from Cambrian water samples and discuss them in the context of previous results.

RNM-1 On June 28, 2000, personnel from LANL, LLNL, DRI, and BN assembled at RNM-1 to collect water samples. This hole was last pumped in 1994.¹⁸ We ran the pump at approximately 40–50 g.p.m. from 09:15 until 14:43, discharging the water into a Baker tank. The LANL samples included small-volume grab samples for tritium and colloids, 2-L pressure tubes for krypton, and 206-L drum samples for fission products. We followed the sampling protocol used in previous years, pumping the hole for approximately five hours before collecting water in the pressure tubes and drums. The analyses of our samples are given in Table I, along with representative values from samples collected since 1991 (the year pumping of RNM-2S was terminated).

Table I. Radionuclides in RNM-1 Water Samples

Sample ID	Sample Date	Activity at Sample Time (Bq/L)			Activity at t_0 (Bq/L)*		
		³ H	⁸⁵ Kr	¹³⁷ Cs	³ H	⁸⁵ Kr	¹³⁷ Cs
434-3-91-001	05/21/91	<3.7E1	<3.7E-2				
434-7-91-002	05/21/91			1.9E-1			3.6E-1
434-3-92-001	09/15/92	3E1	<3.7E-2		1E2		
434-7-92-001	09/15/92			2.6E-1			4.9E-1
434-3-93-001	09/14/93	3E1	4.2E-2		1E2	3E-1	
434-7-93-002	09/14/93			1.6E-1			3.1E-1
434-3-94-003	09/13/94	<3.7E1	<3.7E-2		2E2		
434-7-94-002	09/13/94			2.1E-1			4.2E-1
4341-00-110	06/28/00	<2E1					
4341-00-150	06/28/00	2E1			1.5E2		
4341-00-210	06/28/00	6E1	3E-1		4E2	3E+0	
4341-00-220	06/28/00	3E1	<3.7E-2		2E2		
4341-00-230	06/28/00	3E1	<3.7E-2		2E2		
4341-00-130	06/28/00	3E1		3.0E-1	2E2		6.8E-1

*Zero time (t_0) for the Cambrian test was 05/14/65.

The data in Table I show that the concentrations of the measured species in the immediate vicinity of the Cambrian test have changed very little in the nine years since pumping at RNM-2S stopped. At that time, the ³H and ⁸⁵Kr concentrations had been lowered to values close to our detection limits (~E1 Bq/L for ³H and ~E-2 Bq/L for ⁸⁵Kr). These radionuclides, mobile with groundwater, were drawn away from the cavity region and discharged in the effluent from the RNM-2S pump and are not diffusing (or flowing) back. This is consistent with all our other observations at this site; in the absence of an

artificial gradient imposed by pumping, the groundwater has very little movement. We are able to measure ^{137}Cs with a higher sensitivity than ^3H or ^{85}Kr . From 1975 to 1991 the ^{137}Cs concentration decreased from an initial value¹¹ of approximately 17 Bq/L to the values shown in Table I. This radionuclide was moving away with groundwater, but was never detected in the effluent at RNM-2S. Laboratory experiments have shown that cesium cations have a high probability of being sorbed on the mineral surfaces present in the alluvium at this site, and we believe this has prevented it from being transported in detectable quantities over the 91 m between the cavity region and the RNM-2S pump. Since 1991 there has been little water movement at RNM-1 and the ^{137}Cs concentration can approach a steady-state value dictated by the rate of melt glass dissolution and the rate of sorption on mineral surfaces. Our data suggest that the concentration of this radionuclide is changing very slowly, if at all. In future years it will be interesting to track the hint of an increasing concentration seen in this year's measurement.

Although the water samples in Table I were taken after approximately five hours of pumping at RNM-1, we did collect several grab samples at different times in order to assess the changes in colloid concentration with pumping. Our data are shown in Figure 1. The initial concentration of colloids (approximately 50–200 nm) in the undisturbed groundwater was approximately $7.6\text{E}7$ particles/mL; it fell almost 2 orders of magnitude after five and one-half hours of pumping. This is in agreement with previous results from RNM-2S.²³ It appears that moving water rapidly through an alluvial aquifer significantly depletes the colloid content and thus also depletes the concentration of any radionuclides associated with those colloids.

RNM-2S We routinely analyzed the effluent from the RNM-2S well during the 16 years it was pumped. Approximately 92% of the ^3H and 43% of the ^{85}Kr produced by the Cambric test were discharged from the RNM-2S well.¹⁸ In addition, we measured small amounts of ^{106}Ru , ^{129}I , ^{36}Cl , and ^{99}Tc in the effluent.²⁶ We have not detected cationic species such as $^{90}\text{Sr}^{2+}$ and $^{137}\text{Cs}^+$. Since the cessation of continuous pumping in 1991, we have analyzed water from RNM-2S when opportunities arose to do so. Representative data from 1991 through 1999 are presented in Table II, along with our FY 2000 values. As in the case of RNM-1, we see little change in the concentrations of the radionuclides in RNM-2S. The variability of values for ^{85}Kr is a reflection of the difficulty in measuring this radionuclide at very low concentrations.

Colloid Concentrations in RNM-1 Groundwater Samples (Collected 6-28-00)

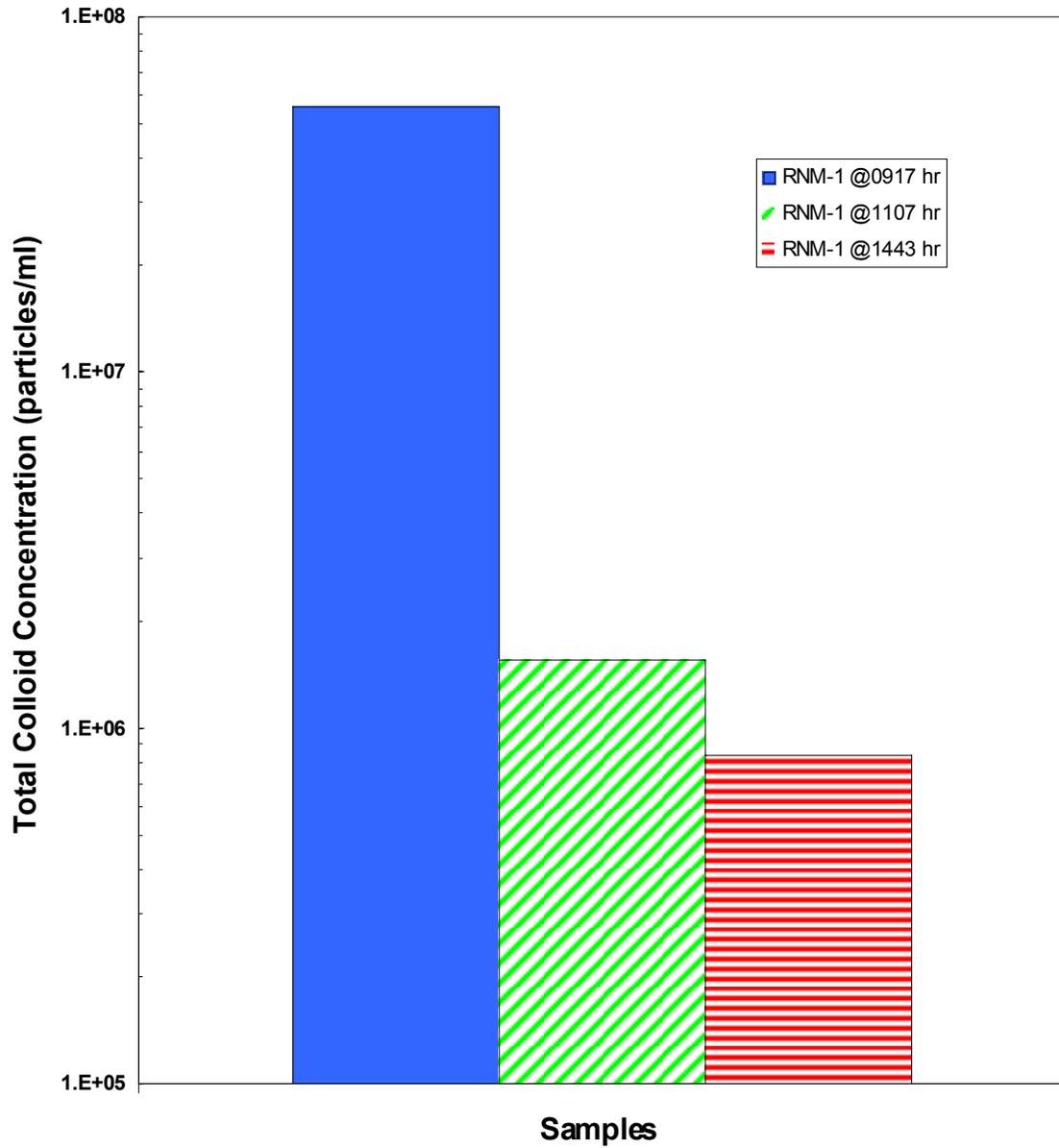


Figure 1. Changes in colloid concentration with pumping at RNM-1.

Table II. Radionuclides in RNM-2S Water Samples

Sample ID	Sample Date	Activity at Sample Time (Bq/L)		Activity at t_0 (Bq/L)	
		^3H	^{85}Kr	^3H	^{85}Kr
434-1-91-022	08/29/91	1.11E4	3E-1	4.9E4	2
434-1-94-002	08/29/94	1.10E4	6E-1	5.5E4	4
4342-99-190	06/10/99	7.0E3		4.9E4	
4342-99-210	06/10/99	8.0E3	3E-1	5.6E4	3
4342-00-110	06/14/00	7.8E3		5.7E	
4342-00-120	06/14/00	7.4E3		5.4E4	
4342-00-210	06/14/00	7.5E3	5E-1	5.5E4	5
4342-00-220	06/14/00	7.7E3	4E-1	5.6E4	4
4342-00-230	06/14/00	7.6E3		5.5E4	

UE5n This exploratory hole was drilled to a depth of 514 m in March 1976 and completed with a 27 cm casing to a depth of 464 m. It is east and south of the RNM-1 and RNM-2S holes. In September 1999 we participated with DRI and LLNL in sampling water withdrawn with a Bennett pump from approximately 3 m below the water level in the casing. The pumping rate was 1.9 L per minute; a modest purging of the hole took place prior to sample collection. The LANL samples consisted of small-volume grab samples for tritium and colloid analyses, pressure tubes for tritium, and ^{85}Kr analyses, and a 208-L drum for fission product analyses.

Table III. Radionuclides in Water From UE5n (activities at counting time November 1999)

Sample ID	Sample Type	^3H	^{85}Kr	^{137}Cs
		Bq/L	Bq/L	Bq/L
4343-99-110	grab	5.5E3		
4343-99-120	drum	5.0E3		5E-3
4343-99-210	pressure tube	4.9E3		
4343-99-220	pressure tube	5.3E3	<3.7E-2	
4343-99-230	pressure tube	5.3E3	<3.7E-2	

The presence of a trace amount of ^{137}Cs in water from this hole is surprising in view of our experience at RNM-2S where we were unable to move ^{137}Cs 91 m from the Cambic test in the course of 16 years of pumping groundwater.²⁷ We have recounted our samples and eliminated the possibility of contamination in the counter. However, because of unique sampling conditions and the very small quantity detected there was a chance for contamination of the sample at the time of collection as well as the possibility during the analytical process. Because only one drum sample was collected, we are anxious to obtain another water sample from this hole in order to resolve this uncertainty.

The broader issue as to the source of the tritium is also not entirely clear. The unlined ditch down which the effluent from RNM-2S ran from 1975 to 1991 passes within approximately 100 m from UE5n. The hole itself is almost equidistant between the Cambric test (U5e) and Diluted Waters test (U5b), both approximately 565 m away. At the Cambric site there is apparently very little water movement at the cavity depth (approximately 300 m) because the radionuclides residual to the test in 1965 were still present when the cavity was re-entered in 1974. If such low water movement were also true at the Diluted Waters site, then it would seem that the activity at UE5n would most likely come from lateral diffusion from the ditch. The tritium activity in ditch water peaked at approximately $2.6E5$ Bq/L (corrected to Cambric $t_0 = 14$ May 1965) in 1980, and declined to $4.9E4$ Bq/L when pumping was stopped in 1991. Present levels of tritium activity at RNM-2S are approximately the same as when pumping was stopped (that is, $5.5E4$ Bq/L corrected to t_0 or $7.6E3$ Bq/L at present time). The current tritium content at UE5n is somewhat below that at RNM-2S.

It will be interesting to track concentration changes at this site in future years particularly to see if it rises above that at RNM-2S, thus suggesting diffusion of higher concentration tritium from the ditch. Such data would enable us to determine lateral diffusion rates through the alluvium of Frenchman Flat—rates essential for modeling this corrective action unit. Also, if we continue to obtain very low ^{85}Kr values in UE5n water, we may conclude that this dissolved gas was lost from the water while it was flowing along the ditch.

One sample was collected at UE5n for colloid analysis. The distribution of colloid sizes from 50 to 1000 nm was like samples from RNM-2S, and the colloid concentration was intermediate between samples taken initially and after several days of pumping at RNM-2S. The colloid results probably are related to the relatively low pump rate at UE5n and the relatively small volume of water purged from that hole. These data agree with our observation that the colloid content of water from the Frenchman Flat region is low relative to that in water from Pahute Mesa and is particularly low in holes that have been rapidly pumped.

A retrospect It has been 25 years since we began the field study at the Cambric site. During this time many of the radionuclides initially present have disappeared entirely or been considerably reduced by radioactive decay. Tritium and ^{85}Kr are down by approximately a factor of 4 and ^{137}Cs by a factor of 2. While 25 years is short on a geologic time scale, it is sufficiently long to note some properties of the site dynamics. For example, we have observed the interaction of groundwater with cavity melt glass long enough to rule out short-term unexpected behavior such as rapid dissolution because of radiation damage. This may be an appropriate time to review some of the major findings derived from our studies at Cambric.

The characteristic that most impressed those who initiated the study of the Cambric site was the fact that nearly all of the radionuclides detected were bound up in the melt glass in the cavity. That is, with the exception of tritium

and a few other radionuclides such as ^{85}Kr , the fraction dissolved in groundwater was 2 to 6 orders of magnitude less than that in the solid phase.²⁴ As noted above, this is still the situation after 25 years. And all other sites we have studied show the hydrologic source term to be orders of magnitude smaller than the radiologic source term. This is, of course, good news for nuclear waste management at the NTS because it means that the large inventory of radioactive material is largely immobilized in place at the test locations.

The second important observation we made at Cambric (and subsequently at other study sites) is that moving groundwater is required for radionuclides to migrate away from cavity regions. Where groundwater is essentially static even mobile tritium remains in place. Consequently, nuclear tests conducted in the vadose zone (approximately two-thirds of the NTS tests) are not likely to contribute to groundwater contamination unless episodic influxes of precipitation water can dissolve and transport radioactive material. With the limited precipitation in southern Nevada, this type of transport seems unlikely, but we have not done field studies to test this assumption.

A final observation from Cambric is that those radionuclides that are mobile in groundwater may be transported with very different efficiencies. While tritium moves unimpeded, ^{137}Cs goes only a short distance before being sorbed on mineral surfaces. In general neutral or anionic species are mobile, while cationic species are sorbed and are not mobile. A notable exception may occur if sorbed radionuclides attach to colloids that can then transport with groundwater.

The studies at Cambric were our first attempt to understand the long-range environmental consequences of underground nuclear testing at the NTS. They have provided the foundation of our knowledge on this subject and continue to provide significant information on site behavior on a long time scale. We hope to periodically revisit this study site for years to come.

B. The Cheshire Site (U20n)

We initiated studies at the Cheshire site in 1976 as a companion effort to our work at the Cambric site. The geology, hydrology, and test yield were different at these two locations, so we were able to examine the effects of these parameters. Water sampling at Cheshire in 1976 was rather limited, but in the period 1983–1986 we did extensive sampling of water from the cavity and chimney regions. In 1987 we drilled an auxiliary hole (UE-20n#1) downgradient from the cavity and collected water samples showing an association between colloids and radionuclides. We again pumped water from the drill-back hole (U-20n ps1 ddh) in 1998, sampling first the chimney and then the cavity some 350 m deeper. We collected small-volume grab samples for tritium and colloid analyses, 2-L pressure tubes for tritium and ^{85}Kr analyses, and 208-L barrel samples for evaporation and analysis for fission products. Several residues were analyzed after evaporation for plutonium and americium. Descriptions of our early work at Cheshire are given in annual reports from LANL⁷⁻¹¹ and LLNL⁴³⁻⁴⁴ and summarized in a topical report.³⁰ Our most recent analyses of water samples

from Cheshire are given in annual reports for FY 1998 and 1999.²²⁻²³ In Table IV we show representative analyses of Cheshire water from the cavity region collected during periods when the hole was being pumped, plus data from our most recent collection in October 1999.

Table IV. Radionuclides in Water From the Cavity Region at Cheshire (All activities are given relative to t_0 = February 14, 1976.)

Sample ID	Sample Date	³ H Bq/L	⁸⁵ Kr Bq/L	¹²⁵ Sb Bq/L	¹³⁷ Cs Bq/L	^{239,240} Pu Bq/L
852-9-84-003	10/23/84	1.92E7	1.0E4	1.0E2	5.6E1	~7E-3
8521-98-210	09/21/98	4.0E6	3E3			
8521-98-170	09/21/98			1.2E2	9.6E1	
8521-98-180	09/21/98					2.1E-2
8521-99-210	10/12/99	7.5E6	4E3			
8521-99-220	10/12/99	7.5E6	3E3			
8521-99-230	10/12/99	7.2E6	4E3			
8521-99-140	10/12/99	7.0E6		6.0E1	1.00E2	

The data collected in 1999 corroborate data from 1998 and show that there have been no dramatic changes in the concentrations of those radionuclides we are able to monitor in Cheshire cavity waters. There is some indication that tritium concentrations continue to drop, while cesium may be increasing slightly, as discussed in our FY 1999 report.²³ And our earlier analyses show that the concentrations of all the radionuclides in the chimney samples are significantly lower than in the cavity.^{22,23} These observations are consistent with our understanding that the chimney is in a zone with more water movement than there is at the cavity depth.

A retrospect Our studies at the Cheshire site have both augmented and extended those at Cambric. Despite the differences in test yields and in the geology at the working point, at both sites the radioactive residues overwhelmingly reside in the cavity melt glass. Only tritium and volatile fission products such as ⁸⁵Kr (and the volatile precursors to ⁹⁰Sr and ¹³⁷Cs) are found in relatively high concentrations outside the cavity. What was observed in the low-yield test in alluvium at Cambric was also found to be true for the much higher yield test in rhyolite lava at Cheshire; the hydrologic source term is far smaller than the radiologic source term.

The hydrology at Cheshire is characterized by a more transmissive zone overlying the level containing the cavity and the hydrologic heads increase with depth.³⁰ For this reason the water movement is upward from the cavity through the chimney and then laterally toward the southwest. Such movement was enhanced by thermal convection while residual heat from the explosion was being dissipated. Similar situations may exist at other test locations and influence the dispersal of radionuclides in the posttest environment. It is important to

properly account for these initial conditions if we are to construct accurate models of radionuclide transport away from nuclear test sites.

Another aspect of radionuclide transport at the NTS was first observed at Cheshire. We found that some radioactive species were attached to colloids that could be removed from water samples by filtration.⁴⁴ We have since become much more aware that water transport of radioactive material is not simply a function of the solubility of the radionuclides, but also may depend on the colloid content of the groundwater. This factor is more important for Pahute Mesa than for Frenchman Flat because the latter has groundwater colloid concentrations approximately 3 orders of magnitude lower.²³ But in any event, an accurate predictive model for radionuclide migration must account for the possibility of transport with groundwater colloids.

C. The Almendro Site (U19v)

The Almendro site is unique among those we have studied at the NTS in that it has remained thermally hot for many years. The test was conducted in 1973; the bottom of the cavity is approximately 1.16E3 m vertical. In 1996 the temperature at 1.09E3 m was still 157°C. This elevated temperature has prevented sample collection until recent years and we still have not been able to sample from the bottom of the cavity. In Table V we show representative values of tritium and ⁸⁵Kr collected in pressure tubes during recent sampling campaigns. Because it takes several months to analyze the krypton activity, the data from those samples collected in September 2000 are only preliminary.

Table V. Tritium and ⁸⁵Kr in Water Samples From Almendro (All activities are corrected to the Almendro t₀ = June 6, 1973.)

Sample ID	Sample Date	Sample Depth Vertical (m)*	³ H Bq/L	⁸⁵ Kr Bq/L
7910-98-210	09/22/98	1.02E3	2.9E7	1.0E4
7910-99-220	08/17/99	9.14E2	2.1E7	4E3
7910-99-230	08/18/99	9.14E2	2.3E7	1E3
7910-00-210	09/27/00	9.42E2	2.7E7	
7910-00-220	09/27/00	9.42E2	2.6E7	

*This assumes slant depth x 0.936 = vertical depth

Almendro is a particularly interesting site because of its high temperature. We might expect that this would result in larger-than-normal concentrations of fission products in solution. However, our analyses of water samples collected in 1996 revealed measurable quantities of ¹³⁷Cs only, with perhaps a trace of ⁶⁰Co. Also, the ratio of ³H to ⁸⁵Kr is not especially high (say, relative to that in Cheshire) as would occur if the krypton gas was expelled because of low solubility at high temperature. Our current equipment will not allow us to sample to the bottom of the hole because of the high water temperature. In the coming years we hope to obtain equipment able to withstand high temperatures that will allow us to sample all the way to the bottom of this hole.

D. The Bilby Site (U3cn)

The Bilby test was conducted in 1963 in tuffaceous rock close to the contact with underlying Paleozoic formations. Since the mid-1960s we have made many measurements at this site to see if any radioactivity is detectable in the carbonate aquifer. Water samples are obtained from the post-shot hole, a hole drilled into the cavity after a shot has been detonated, U3cn ps2 (access to the top of the chimney) and from the satellite hole U3cn#5 that is completed into the carbonate aquifer. The latter hole is cased so as to draw only from this aquifer; it is located some 60 m from the bottom of the test cavity. We last sampled water from both holes in 1997, detecting radioactivity only in the post-shot hole.²¹ These results were in conformance with previous analyses. This year we again sampled U3cn#5, collecting grab samples for tritium and colloid analyses, pressure tubes for tritium and ⁸⁵Kr, and 208-L drums for fission products. We could measure no radioactivity in these samples. Our levels of detection for tritium are approximately 4E1 Bq/L, for ⁸⁵Kr 4E-2 Bq/L, and for ¹³⁷Cs 4E-4 Bq/L. The colloid content of water from U3cn#5 was intermediate between that at Cambria (well purged) and that at Dalhart (very little purging). Before our sample collection, we pumped out from U3cn#5 approximately 5–6E1 m³ of water. We expect that with more pumping the colloid concentration might decrease. However, we have not previously measured colloids in the carbonate aquifer, so we do not have other reference data for comparison.

Bilby is one of the very few tests conducted near the Paleozoic formations at the NTS. It is reassuring that after almost 40 years there is no indication of radionuclide contamination of the carbonate aquifer because of this test.

III. GROUNDWATER CHARACTERIZATION

There has been a concern on the part of the modelers in the UGTA Program regarding the lack of *in situ* groundwater chemistry data from wells at the NTS. In September of 2000 LANL, in cooperation with the USGS, employed a Hydrolab Minisonde 4a multiprobe (M-4a) to measure parameters *in situ* in several uncontaminated wells at the NTS. The probe has the ability to measure the following water parameters: temperature, specific conductivity, dissolved oxygen, pH, and oxidation-reduction potential. This was the first time the M-4a was used in the field; therefore the objectives were to develop procedures to optimize the measurements within the well and to collect initial data.

Three wells were investigated during this work. The well information is presented in Table VI.

Table VI. Well and Sampling Information for Wells Measured with the M-4a Multiprobe

Well	Alt.	Depth (m)	Time (PDT)	Measurement Interval		Data Pts.
	(m)			(m)	(min)	
WW-5a	942	217	0930	3	1	11
W-3mi	1292	475	1100	3	2	11
W-2gk	1220	543	1235	3	3	21
WW-5a	942	217	1450	6	5	11

At each site the probe was programmed to collect data using a laptop computer. The time interval between measurements was varied to determine the optimum time interval. For each measurement, the circulator and instruments were given a one minute warm-up. Well WW-5a was measured at the beginning and end of the day to look for any changes due to differences in measurement intervals, and drift in the instrument over the course of the day.

The probe was connected to the USGS 823 m etape using bailing wire attached to the probe's plastic wire line adapter. The probe was lowered into the hole and measurements were taken at specified intervals (3 or 6 m). After all measurements were completed, the probe was removed from the hole and rinsed with clean water.

The probe was connected to a laptop computer and the data were checked to assure that the run had been successful. The data file was transferred from the probe to the computer for assessment. The data from each of the runs are in the following tables.

Table VII. Detailed Sampling Information and Parameter Data for First Measurement of Well WW-5a

Date	Time	Depth	Temp	SpCond	DO%	pH	ORP
MMDDYY	HHMMSS	m	°C	mS/cm	Sat	Units	mV
092500	103000	219	21.7	0.595	57.3	8.1	300
092500	103100	222	21.7	0.595	13.2	8.1	293
092500	103200	225	21.8	0.595	27.2	8.1	293
092500	103300	228	21.8	0.595	26.3	8.1	292
092500	103400	231	21.8	0.599	12.1	8.2	288
092500	103500	234	21.8	0.598	10.7	8.2	286
092500	103600	237	21.9	0.595	10.4	8.2	287
092500	103700	240	21.9	0.596	10.8	8.2	287
092500	103800	243	22.0	0.596	9.9	8.1	289
092500	103900	246	22.0	0.593	7.8	8.1	292
092500	104000	249	22.0	0.596	6.0	8.2	278

Table VIII. Detailed Sampling Information and Parameter Data for Well U3mi

Date	Time	Depth	Temp	SpCond	DO%	pH	ORP
MMDDYY	HHMMSS	m	°C	mS/cm	Sat	Units	mV
092500	120000	475	41.5	0.442	85.3	9.1	221
092500	120200	479	41.6	0.443	85.2	9.0	233
092500	120400	482	41.6	0.443	83.2	9.2	226
092500	120600	485	41.6	0.443	83.2	9.2	229
092500	120800	488	41.6	0.443	82.4	9.2	237
092500	121000	491	41.6	0.443	82.4	9.1	241
092500	121200	494	41.6	0.443	82.8	9.0	249
092500	121400	497	41.6	0.443	82.7	8.9	262
092500	121600	500	41.6	0.443	82.9	9.0	256
092500	121800	503	41.6	0.443	84.5	8.9	264
092500	122000	500	41.6	0.443	83.7	8.4	299

Table IX. Detailed Sampling Information and Parameter Data for Well U2gk

Date	Time	Depth	Temp	SpCond	DO%	pH	ORP
MMDDYY	HHMMSS	m	°C	mS/cm	Sat	Units	mV
092500	133500	543	27.7	0.393	54.3	8.5	261
092500	133800	546	27.7	0.394	41.2	8.3	276
092500	134100	549	27.8	0.394	40.0	8.5	268
092500	134400	552	27.7	0.394	38.9	8.3	283
092500	134700	555	27.8	0.394	38.8	8.3	281
092500	135000	558	27.8	0.394	38.8	8.5	271
092500	135300	561	27.8	0.394	38.3	8.5	276
092500	135600	564	27.8	0.394	38.2	8.6	273
092500	135900	567	27.8	0.394	38.4	8.5	277
092500	140200	570	27.8	0.394	38.2	8.5	280
092500	140500	567	27.8	0.394	38.1	8.6	275
092500	140800	564	27.8	0.394	38.2	8.6	276
092500	141100	561	27.8	0.394	38.0	8.6	278
092500	141400	558	27.8	0.394	38.1	8.6	279
092500	141700	555	27.8	0.394	38.2	8.6	280
092500	142000	552	27.8	0.394	38.1	8.6	281
092500	142300	549	27.8	0.393	38.0	8.6	283
092500	142600	546	27.8	0.393	38.1	7.8	332
092500	142900	546	27.8	0.393	38.1	7.8	334
092500	143200	543	27.7	0.393	37.9	8.4	299
092500	143500	543	27.7	0.393	37.9	8.5	292

Table X. Detailed Sampling Information and Parameter Data for Second Measurement of Well WW-5a

Date	Time	Depth	Temp	SpCond	DO%	pH	ORP
MMDDYY	HHMMSS	m	°C	mS/cm	Sat	Units	mV
092500	155000	217	21.8	0.595	12.9	9.6	264
092500	155500	223	21.8	0.595	10.9	9.3	275
092500	163500	223	21.8	0.594	9.6	9.6	255
092500	160000	230	21.8	0.595	10.2	9.7	253
092500	163000	230	21.8	0.595	9.5	9.4	265
092500	160500	236	21.9	0.595	10.1	9.6	257
092500	162500	236	21.9	0.595	9.5	9.6	253
092500	161000	242	22.0	0.596	7.9	9.6	253
092500	162000	242	22.0	0.595	7.7	9.6	251
092500	161500	248	22.1	0.597	4.8	9.5	257

These data are the first collected with this probe *in situ*. The probe had been calibrated in the laboratory and used there on samples collected previously.

A number of lessons were learned in the collection of these data.

(1) The longer time intervals between measurements (five minutes versus one minute) yielded more consistent data for %DO, pH, and oxidation reduction potential (ORP).

(2) The time interval did not affect temperature or specific conductivity measurements.

(3) Differences in pH between the early and late measurements in WW-5a indicate the need to calibrate before and after entering the well.

This initial collection of *in situ* data from these wells demonstrates the capability of the probe to make measurements useful to modelers in the UGTA Program. With updated procedures and experience gained from the initial fieldwork, more consistent data will be collected in the future.

IV. PROGRAM SUPPORT ACTIVITIES

A. Document Reviews/Meetings

One way in which we support the DOE/NV mission in Defense Programs and Environmental Restoration is to serve as expert reviewers generated for the UGTA and HRMP Programs. During the past year, we reviewed and edited a number of documents, including responses to comments from the State of Nevada on the corrective action investigation plans for Frenchman Flat and for Pahute Mesa and responses to the review of the regional model. We also presented a poster showing the results of our FY 1999 work and our proposed work for FY 2000.

We participate in the technical working group for the UGTA Program. In this capacity we assisted in presentations concerning the inclusion of cavity sampling as part of the NTS monitoring program and in the content of the technical working group charter, edited geophysical recommendations for Frenchman Flat, and made recommendations for data collection activities in Frenchman Flat and Pahute Mesa.

A significant amount of time this year was consumed by the writing, editing, and updating of field sampling and analytical laboratory procedures. All of our new or updated procedures went through internal review to ensure that they were current with all safety and security regulations and accurately reflected the activities in the field and laboratory.

B. Presentations/Publications

D. K. Smith made a presentation at the 24th International Symposium on the Scientific Basis for Nuclear Waste Management held August 27–August 31, 2000, in Sydney, Australia.

"Insights to Repository Performance Through Study of a Nuclear Test Site," D. K. Smith, A. B. Kersting, J. L. Thompson, and D. L. Finnegan Lawrence Livermore National Laboratory report UCRL-JC-137194 Rev. 1 Preprint.

Ward Hawkins presented and published the following report. "Hydrogeologic Investigations and Radionuclide Migration in Groundwater at the Nevada Test Site," W. L. Hawkins, J. L. Thompson, and D. L. Finnegan, in *Nuclear Physical Methods in Radioecological Investigations of Nuclear Test Sites*, S. S. Hecker, et al. (Eds.), pp. 61–74, Kluwer Academic Publishers, 2000.

At LANL we published the following technical report: "Laboratory and Field Studies Related to Radionuclide Migration at the Nevada Test Site," October 1, 1999–September 30, 2000, J. L. Thompson, Ed., Los Alamos National Laboratory report LA-13701-PR (February 2000).

ACKNOWLEDGMENTS

We are grateful to the many individuals from LLNL, DRI, USGS, and BN who provided assistance in collecting water samples, and to our coworkers at LANL who contributed to sample analyses. We thank Margaret Burgess for editorial assistance in the preparation of this report. Our work was funded by the Defense Programs and by the Environmental Restoration Divisions at DOE/NV.

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