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Laboratory and Field Studies Related to the Radionuclide Migration Project

October 1, 1982—September 30, 1983

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LABORATORY AND FIELD STUDIES RELATED TO THE RADIONUCLIDE MIGRATION PROJECT

Annual Report

October 1, 1982--September 30, 1983

Compiled and Edited
by
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ABSTRACT

The FY 1983 laboratory and field studies related to the Radionuclide Migration project are described. Results are presented for radiochemical analyses of water samples collected from the RNM-1 well and the RNM-2S satellite well at the Cambric site. Data are included for tritium, ^{36}Cl, ^{85}Kr, ^{90}Sr, ^{129}I, and ^{137}Cs. Preliminary results from water collection at the Cheshire site are reported. Laboratory studies emphasize the sorptive behavior of tuff and its dependence on mineralogy.

I. INTRODUCTION

A field study of the radionuclide distribution around underground nuclear explosion cavities was initiated in 1974. The goal of this Radionuclide Migration (RNM) project was to determine the potential for movement, both on and off the Nevada Test Site (NTS), of radioactivity from underground nuclear explosions. Particular emphasis has been placed on studying the possible contamination of water supplies and the rates of migration of radionuclides from explosion-modified zones underground in various media at the NTS. It was also envisioned that the study might provide data relevant to the long-term safety of radioactive waste placed underground.

This ongoing project is sponsored by the Nevada Operations Office of the Department of Energy with the participation of Los Alamos National Laboratory, Lawrence Livermore National Laboratory, the US Geological Survey, the Desert Research Institute, and appropriate support organizations.

The 0.75-kt nuclear test Cambric was conducted May 14, 1965, beneath the water table in tuffaceous alluvium. This site was chosen for initial studies; it was anticipated that eventually tests in other geologic media would also be examined (see Sec. IV).

Cambric was chosen for a number of reasons. The Cambric explosion cavity is within the NTS Area 5 water-supply aquifer, and there was particular interest in possible contamination of water supplies. It was predicted that sufficient time had elapsed for groundwater to fill the cavity and chimney to the preshot static water level 73 m above the detonation point. If so, radionuclides might be present in the water and constitute a potential source for migration. The Cambric detonation point is only 294 m below ground surface, and thus, the re-entry drilling and sampling operations would be less difficult and expensive than for more deeply buried tests. The site in Frenchman Flat is far enough from the areas of active nuclear testing so that damage or interruption of the re-entry and sampling operations from those activities would be unlikely. Sufficient tritium (^3H or T) was present to provide an easily measurable tracer for water from the cavity region. The postshot debris also contained plutonium, uranium, and fission products whose concentrations in the rubble and groundwater from the cavity and chimney regions could be measured and compared. It was expected that the small yield would have little effect on the local hydrology. Further, it was judged that the alluvium constituted a good medium for hydrologic studies because it was more permeable than tuff and did not have large fissures or cracks through which the water might selectively flow.

The Cambric field studies can be divided into two phases. (1) The Cambric cavity was re-entered in 1974, and samples were taken to determine the radionuclide distribution between the solid material and water. (2) Beginning in October 1975, water was pumped from a satellite well located 91 m from the Cambric cavity; this induced a sufficient artificial gradient to draw water from the Cambric cavity and provided an opportunity to study radionuclide transport under field conditions. Where techniques were available or could be developed, concentrations of radionuclides detectable in water from RNM-2S have been determined. Many of these nuclides are not considered particularly hazardous in nuclear test debris, but the behavior of available mobile species is of value in understanding radionuclide transport, in general. Details of the early stages of the RNM Cambric experiment are given in Refs. 1 and 2, and more recent work is described in Refs. 3 through 5.

During FY 1983, water sampling was initiated at the Cheshire site located on Pahute Mesa at the NTS. Enough water was pumped from the cavity region to obtain what is probably a representative sample, and analyses were started for those radionuclides present at detectable levels. Preliminary results are reported in this document (see Sec. IV.B).

The laboratory program has primarily involved studies related to the sorptive behavior of NTS alluvium and tuff.

II. CAMBRIC STUDIES: RNM-2S

A. Continuation of Tritium, ^{85}Kr, and Gamma-Spectral Analyses

(W. R. Daniels, F. O. Lawrence, J. L. Thompson, S. Maestas, and A. J. Mitchell)

Pumping water from the RNM-2S satellite well at the Cambric site has continued at the rate of ~600 gal./minute, and weekly samples are analyzed for tritium. Detailed data for tritium concentrations through FY 1982 were summarized in Ref. 3 through 5 and are brought up-to-date in Table I and Figs. 1 and 2. Discontinuities in the plots correspond to periods when the pump was inoperative. Over 50% of the tritium from Cambric has now been removed from the satellite well.

TABLE I
TRITIUM CONCENTRATION IN WATER PUMPED FROM SATELLITE WELL RNM-2S

Sample Number	Total Volume Pumped (10^6 gal.)	Date[a]	Tritium[b] (pCi/mℓ)
G1350	1872.8	10/07/82	2229.9
G1351	1877.1	10/12/82	2253.6
G1352	1883.1	10/19/82	2241.1
G1353	1889.2	10/26/82	2245.4
G1354	1895.2	11/02/82	2199.5
G1355	1901.2	11/09/82	2182.1
G1356	1906.7	11/16/82	2199.4
G1357	1913.6	11/24/82	2192.3
G1358	1920.6	12/02/82	2184.1
G1359	1926.6	12/09/82	2161.0
G1360	1931.0	12/14/82	2146.3
G1361	1937.0	12/21/82	2137.5
G1362	1943.0	12/28/82	2128.7
G1363	1949.8	01/05/83	2140.0
G1364	1954.9	01/11/83	2119.7
G1365	1962.8	01/20/83	2130.2
G1366	1967.9	01/26/83	2123.0
G1367	1972.1	01/31/83	2119.7
G1368	1979.6	02/09/83	2104.2
G1369	1984.9	02/15/83	2058.2
G1370	1991.6	02/23/83	2043.1
G1371	1996.8	03/01/83	2016.8
G1372	2005.1	03/11/83	2047.7
G1373	2010.4	03/17/83	2053.3
G1374	2014.8	03/22/83	2061.9
G1375	2022.3	03/31/83	2052.4
G1376	2026.6	04/05/83	2054.4
G1377	2032.6	04/12/83	2026.7
G1378	2040.3	04/21/83	2018.6
G1379	2044.6	04/26/83	1999.4

TABLE I (cont)

Sample Number	Total Volume Pumped (10^6 gal.)	Date[a]	Tritium[b] (pCi/mℓ)
G1380	2052.3	05/05/83	1997.8
G1381	2057.4	05/11/83	1970.9
G1382	2069.5	05/25/83	1962.0
G1383	2076.9	06/03/83	1934.4
G1384	2082.4	06/09/83	1935.2
G1385	2089.1	06/17/83	1920.6
G1386	2093.4	06/22/83	1922.6
G1387	2100.5	06/30/83	1909.2
G1388	2106.4	07/07/83	1898.8
G1389	2112.5	07/14/83	1874.3
G1390	2118.5	07/21/83	1884.1
G1391	2129.6	08/03/83	1852.7
G1392	2136.4	08/11/83	1843.7
G1393	2141.6	08/17/83	1890.1
G1394	2147.5	08/25/83	1913.9
G1395	2154.3	09/02/83	1896.2
G1396	2159.4	09/08/83	1906.2
G1397	2165.4	09/15/83	1830.7
G1398	2171.4	09/22/83	1824.8
G1399	2176.7	09/28/83	1811.2

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[a] The pump at RNM-2S was off May 4 and 5, 1982, and for about 7 hours a day on July 7, 9, and 12, 1982.

[b] Standard deviations of counting data <0.1%.

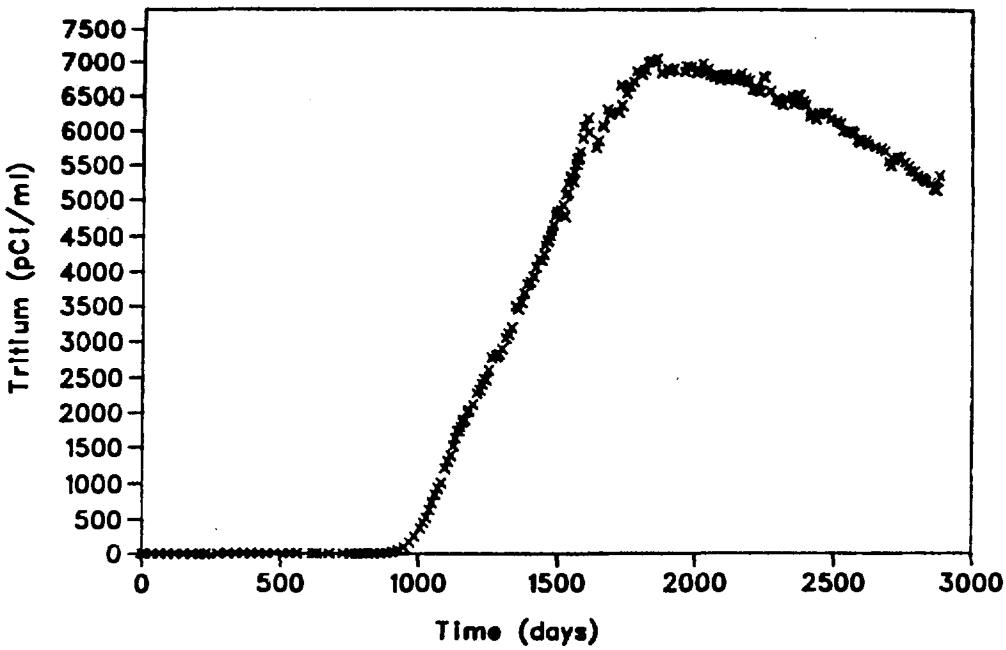

Fig. 1. Tritium concentration in water pumped from RNM-2S vs time. Values are corrected to Cambric zero time.

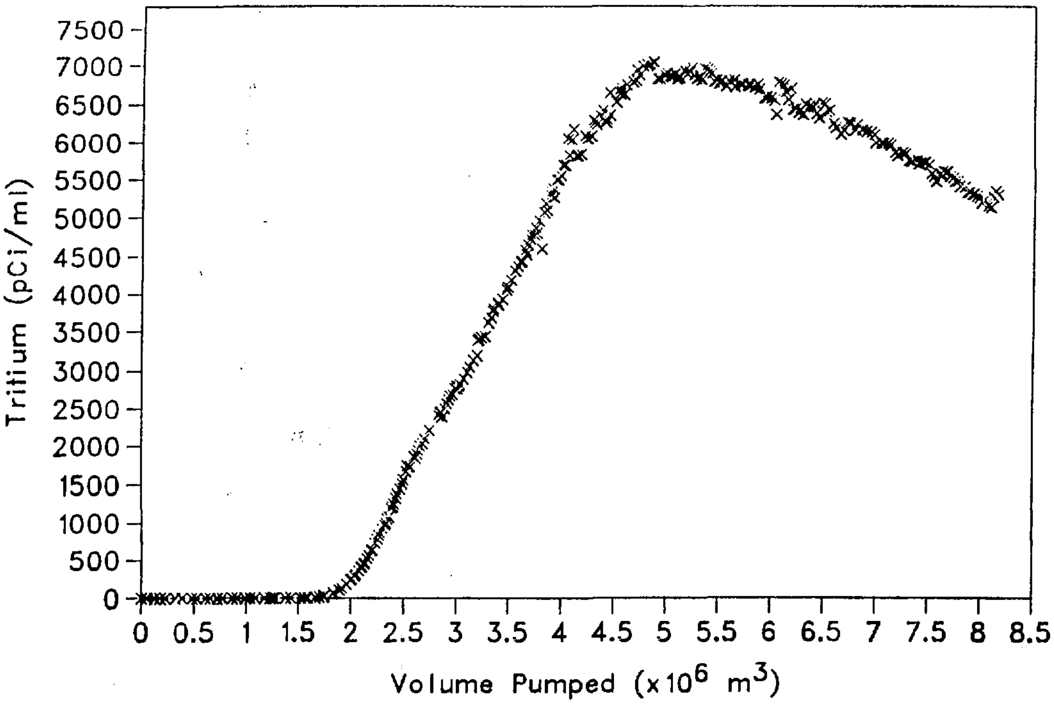

Fig. 2. Tritium concentration in water pumped from RNM-2S vs volume pumped. Values are corrected to Cambric zero time.

One or two of the so-called "pressurized" water samples are taken each month from the hose bib at RNM-2S and analyzed for ^{85}Kr, HT, and HTO. Detailed data for tritium and ^{85}Kr are presented in Table II and Figs. 3 and 4. The atom ratio for ^{85}Kr to tritium is roughly 0.5 of that calculated for Cambric, which suggests that krypton travels in the water with the HTO but either at a slower rate or with some loss before or during transit. It appears that the ^{85}Kr concentration has now reached a maximum.

Beginning in May 1978, each month a 55-gal. sample of RNM-2S water has been taken in a plastic-lined barrel. Several additional samples were taken by adding the water to barrels that already contain sufficient concentrated HCl to give a final HCl concentration of ~1 M; this water is intended for ^{99}Tc analysis. Thirty-four of the nonacidified samples have been concentrated to solids and wrapped in plastic for gamma-spectral analysis. To date, no gamma-emitting nuclides attributable to the Cambric event have been found in these concentrated samples, with the possible exception of ^{106}Ru (refer to Ref. 3 and 5). Other analytical procedures have detected ^{129}I and ^{36}Cl in the RNM-2S water (see Sec. II.C and II.D below). The absence of ^{90}Sr and ^{137}Cs in RNM-2S water has been confirmed by a radiochemical procedure detailed in Ref. 5, Sec. II.E. Thus, it appears that only negatively charged or neutral species have been transported from the cavity region to the satellite well. This conclusion is in agreement with expectations that were based on sorption behavior in laboratory experiments.

B. Transport of Tritium from the Cambric Cavity Region to RNM-2S: Modeling

(B. J. Travis and R. S. Rundberg)

Transport modeling in the Cambric experiment has been limited to preliminary attempts to describe the forced-flow movement of tritiated water from the Cambric cavity region to the satellite well. The general problems of modeling the RNM project were discussed extensively in an earlier report.[6]

1. Sauty Model. The transport of tritiated water to the satellite well was compared with Sauty's two-dimensional calculations[7] for instantaneous tracer injection in a radial, converging flow field that is similar to the RNM experiment. The shape of the elution curve depends on the Peclet number, which is inversely proportional to the dispersivity. An excellent fit to the earlier data was obtained with a Peclet number of 10, which corresponds to a

TABLE II

TRITIUM AND ^{85}Kr ANALYSES OF PRESSURIZED WATER SAMPLES FROM RNM-2S [a]

Identification Number	Date Collected	Total Volume from RNM-2S (10^6 m^3)	Tritium Concentration		^{85}Kr Concentration		^{85}Kr/T (Atom Ratio x 10^5)	Ratio[b]
			(nCi/mℓ)	(10^{11} Atoms/mℓ)	(dpm/m)	(10^6 Atoms/mℓ)		
434-1-82-007	07/02/82	6.777	6.23	1.29	0.998	8.13	6.32	0.52
434-1-82-008	08/03/82	6.880	6.15	1.27	0.894	7.28	5.73	0.47
434-1-82-011	09/10/82	7.001	6.19	1.28	0.972	7.92	6.20	0.51
434-1-82-012	10/07/82	7.092	5.91	1.22	1.018	8.30	6.80	0.56
434-1-82-014	10/29/82	7.161	6.03	1.24	0.913	7.44	5.98	0.49
434-1-82-015	10/29/82	7.161	5.89	1.22	0.955	7.78	6.40	0.52
434-1-82-017	12/03/82	7.274	5.44	1.12	0.926	7.55	6.72	0.55
434-1-83-002	01/11/83	7.403	5.73	1.18	0.869	7.08	5.98	0.49
434-1-83-005	03/03/83	7.565	5.58	1.15	0.862	7.02	6.10	0.50
434-1-83-008	04/05/83	7.672	5.66	1.17	0.745	6.14	5.26	0.43
434-1-83-010	05/05/83	7.769	5.52	1.14	0.964	7.85	6.89	0.56
434-1-83-012	06/03/83	7.862	5.47	1.13	0.874	7.12	6.28	0.52
434-1-83-013	07/07/83	7.974	5.42	1.12	0.846	6.89	6.16	0.51

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[a] All activity levels corrected to Cambric zero time (May 14, 1965).

[b] Ratio of measured to calculated ^{85}Kr/T atom ratio of 1.22×10^{-4} at Cambric zero time.

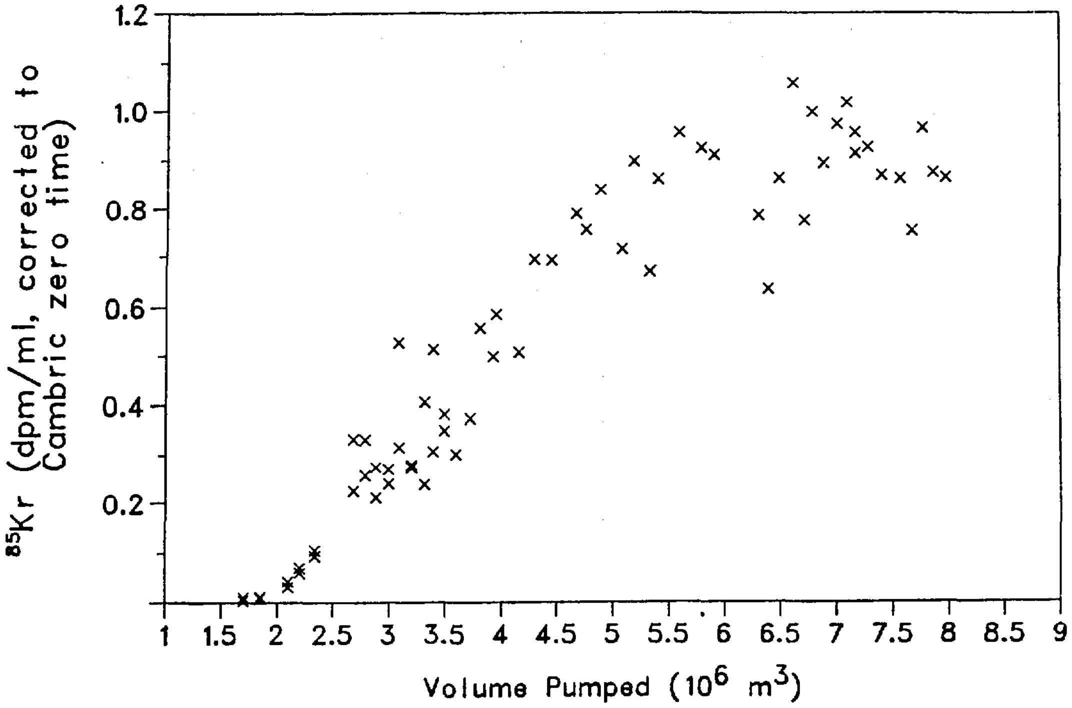

Fig. 3. The ^{85}Kr concentration in water pumped from RNM-2S. Values are corrected to Cambric zero time.

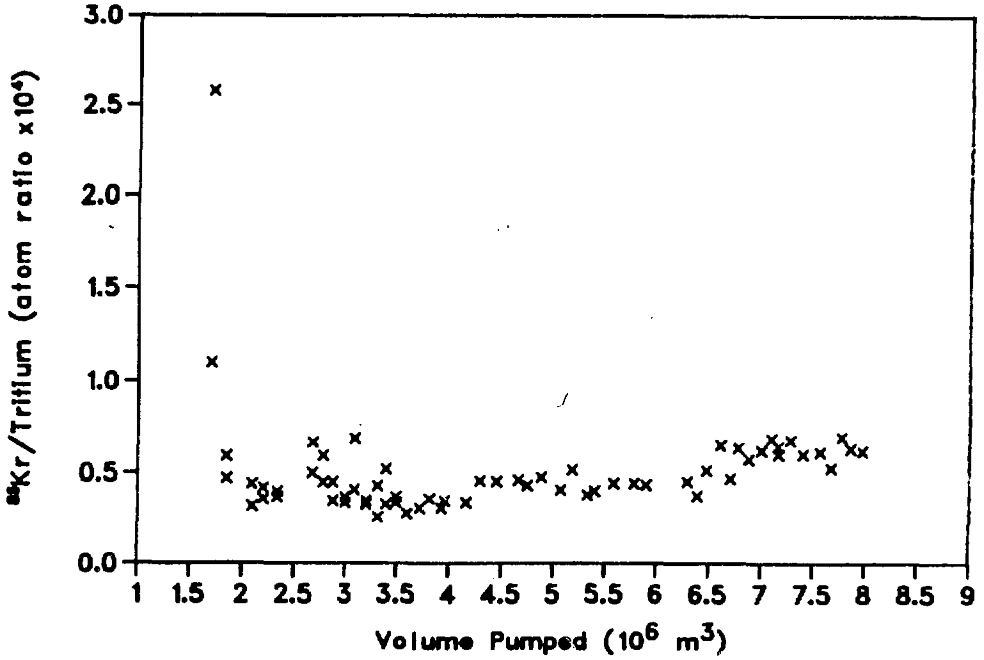

Fig. 4. Atom ratio of ^{85}Kr to tritium in water pumped from RNM-2S. Values are corrected to Cambric zero time.

dispersivity of 9.1 m (Fig. 5). The dimensionless time T_r is given on the upper abscissa. A dimensionless time of 1 corresponds to the time required to pump the volume of water contained in a cylinder whose radius is the distance from the satellite well to the source. This treatment invokes symmetry and treats the source as an annular ring. The dimensionless concentration C_r is calculated relative to the maximum concentration. The excellent fit using the Sauty treatment could be achieved only by allowing the tritium source term to float; the best fit was obtained with a source term that was 70% of the original calculated source term. The most recent data show an increasing divergence from the Sauty model predictions. A new effort will be made to determine whether a different combination of source term and Peclet number values will give a better fit to our expanding data set.

The indicated value for the dispersivity can be compared with the data presented by Borg et al.,[8] who reported longitudinal dispersivity values that were estimated by calibrating mathematical models for transport against observed transport in various field studies. Values ranged from 11.6 to 91 m for a wide variety of lithologies; the value was 21.3 m for a sand or gravel deposit, which is the lithology that probably most closely resembles the tuffaceous alluvium of the current experiment.

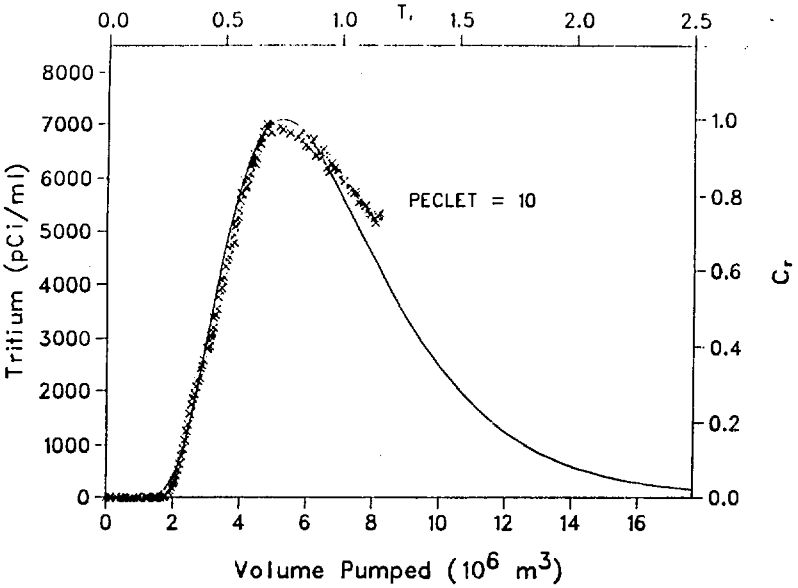

Fig. 5. Tritium concentration data (X) for RNM-2S water and calculated elution of tracer after instantaneous tracer injection in a radially converging flow field for Peclet number 10.

2. TRACR3D Model. A three-dimensional numerical simulation was also made of the overall transport problem for Cambric. The calculation includes site geometry, hydrology, source, pumping characteristics, and the transport of tritium from the source to RNM-2S. Results of this simulation are reported in detail in Ref. 5.

C. Transport of ^{36}Cl from Cambric to the Satellite Well (K. Wolfsberg, R. S. Rundberg, P. L. Wanek, H. W. Bentley, and D. Elmore)

The nuclide ^{36}Cl is produced in underground nuclear tests as a result of neutron capture by stable ^{35}Cl (76% relative abundance) that is in water, soil, and other materials in the vicinity of the tests. The $^{36}Cl/^{35}Cl$ ratios in two samples of water from the Cambric cavity were measured earlier[4] by negative thermal-ionization mass spectrometry and by tandem-accelerator mass spectrometry (TAMS); these measurements gave ^{36}Cl concentrations of ~4.5 x 10^{11} atoms/mℓ.

Chlorine-36 produced by the Cambric event has now been detected in water samples from RNM-2S by using the accelerator-based mass spectrometry technique.[9-11] Results are given in Table III. Figure 6 shows a comparison of the tritium concentrations with the ^{36}Cl concentrations in RNM-2S water. The breakthrough of ^{36}Cl appears to occur earlier than that of tritium, and the maximum chloride concentration clearly occurs before that of tritium.

TABLE III

CHLORINE-36 CONCENTRATION IN RNM-2S WATER

Sample Number	Σ Volume Pumped (10^6 m^3)	^{36}Cl Concentration (10^8 atoms/mℓ)	Estimated Uncertainty (10^8 atoms/mℓ)
G 331	0.41	0.0062	0.0020
G 556	1.4	0.033	0.006
G 800	2.6	1.74	0.11
G 912	3.3	3.04	0.20
G 1119	4.2	3.94	0.37
G 1203	4.6	3.64	0.26
G 1269	5.3	3.56	0.25
G 1299	5.9	2.86	0.26

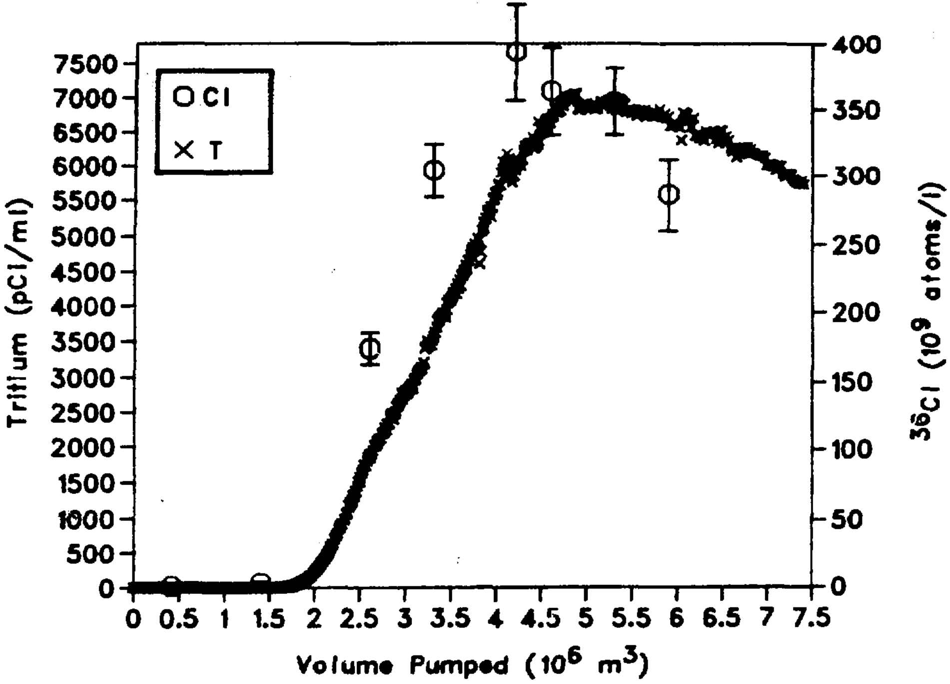

Fig. 6. Chlorine-36 and tritium concentrations in RNM-2S water. The error bars are the standard deviations for single measurements; they were obtained from the errors associated with measurements and estimated uncertainties for the various parameters entering into the calculation. These estimated uncertainties were propagated in quadrature.

This phenomenon, whereby anions are eluted earlier than cations or neutral species from packed columns, has been observed in soil chemistry studies[12,13] and column chromatography and is called anion exclusion. See Ref. 5 for a more complete discussion of the anion exclusion effect and for comparison of ^{36}Cl concentrations of RNM-2S with predictions based on the Sauty model. During the current fiscal year, 12 more samples from RNM-2S were prepared for ^{36}Cl analysis. When these analyses are complete, the data base will be sufficiently large to justify a more detailed modeling effort.

D. Concentration of ^{129}I in RNM-2S Water (K. Wolfsberg, K. S. Daniels, P. L. Wanek, H. W. Bentley, J. Fabryka-Martin, and D. Elmore)

Iodine-129 has been observed in the effluent water pumped from RNM-2S as well as in that from RNM-1. The concentrations are well below the concentrations guide (CG) for drinking water in a controlled area[14] (the concentration of ^{129}I in RNM-1 was 1.1 x 10^{-8} μCi/mℓ, whereas the CG is 6 x 10^{-8} μCi/mℓ), but mobile species are of interest for a general understanding of radionuclide transport. (Iodine-129 ranks among the most hazardous radionuclides in nuclear waste because of its biological activity and its lack of sorption on most minerals.)

Analyses of ^{129}I concentration in water samples from RNM-1 and RNM-2S were made by both TAMS and neutron activation analysis (NAA). The results to date for RNM-2S are presented in Table IV and in Fig. 7. Those for RNM-1 are presented in Sec. III. The samples for TAMS were prepared in 1981; those for NAA, in 1982 and 1983. Much smaller samples were used for TAMS.

In general, the two analytical methods yielded similar results. Duplicate analyses were usually in good agreement. Nevertheless, there is enough scatter in the data to make it difficult to determine whether the ^{129}I breaks through at RNM-2S before the tritium or with it. However, it is clear that a large fraction of the ^{129}I is transported with the water without retardation. We will reanalyze the data to estimate the fraction of iodine transported.

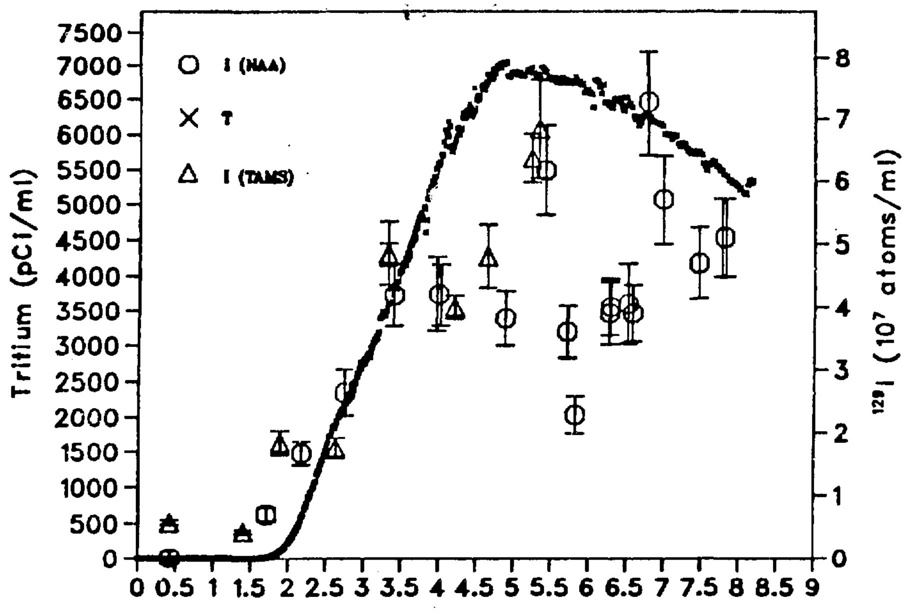

Fig. 7. Iodine-129 and tritium concentrations in RNM-2S water. The error bars are the standard deviations for single measurements; they were obtained from the errors associated with measurements and estimated uncertainties for various parameters entering into the calculation. These estimated uncertainties were propagated in quadrature.

TABLE IV

^{129}I CONCENTRATIONS IN RNM-2S WATERS

Sample Number	Total Volume Pumped (10^6 m^3)	^{129}I Concentration (10^7 atoms/mℓ)	Method[a]
G331	0.408	0.57 ± 0.04	TAMS
G328, G342	0.417	< 0.02	NAA
G556	1.40	0.42 ± 0.03	TAMS
G614, G618	1.71	0.70 ± 0.11	NAA
G653	1.89	1.83 ± 0.19	TAMS
G710, 711	2.17	1.7 ± 0.2	NAA
G818, G823, G827, G828	2.75	2.6 ± 0.4	NAA
G800	2.63	1.75 ± 0.16	TAMS
G942	3.32	4.84 ± 0.17	TAMS
G942	3.32	4.9 ± 0.5	TAMS
434-9-79-068	3.39	4.2 ± 0.5	NAA
G1066, G1020, G1071 G1015, G1016, G1080 G1081, G1085, G1086	3.95	4.2 ± 0.6	NAA
G1066, G1020, G1071 G1015, G1016, G1080 G1081, G1085, G1086	3.95	4.2 ± 0.5	NAA
G1119	4.20	4.0 ± 0.2	TAMS
G1203	4.64	4.8 ± 0.5	TAMS
434-9-80-010	4.88	3.8 ± 0.2	NAA
G1269	5.23	6.4 ± 0.4	TAMS
G1272	5.33	6.8 ± 0.8	TAMS
434-9-81-004	5.41	6.2 ± 0.7	NAA
G1293, G1294, G1295, G1296	5.82	2.3 ± 0.3	NAA
G1310, G1311, G1316, G1318	6.28	3.9 ± 0.5	NAA
323-9-82-002	6.28	4.0 ± 0.5	NAA
G1324, G1325, G1326	6.52	4.1 ± 0.6	NAA
434-9-82-002	6.58	3.9 ± 0.5	NAA
434-9-82-007	6.78	7.3 ± 0.8	NAA
434-9-82-009	6.99	5.7 ± 0.7	NAA
434-9-83-002	7.46[b]	4.7 ± 0.6	NAA
434-9-83-002	7.81	5.1 ± 0.6	NAA
434-9-83-002	7.81	5.1 ± 0.6	NAA

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[a] NAA at Los Alamos; TAMS at Rochester.

[b] The iodide carrier was added to the sample at the well. For all others, including the duplicates, the carrier was added at Los Alamos when the samples were purified.

E. RNM Water Analyses (P. L. Wanek)

Cation concentrations in RNM water samples, as determined by a Spectrometrics, 20-channel, direct-current, plasma-source emission spectrometer, were reported in Ref. 5, Sec. II.F. Anion concentrations were determined recently using a Dionex Model 1 ion chromatograph; the results are given in Table V.

III. CAMBRIC STUDIES: RNM-1 (V. M. Armijo, M. R. Cisneros, W. R. Daniels, J. Drake, G. W. Knobeloch, A. J. Mitchell, S. Maestas, and J. L. Thompson)

Continued sampling at RNM-1 measures the decrease of radionuclide concentrations that results from pumping at RNM-2S. The pump and packers are arranged so that water is drawn from Zones IV (chimney) and V (adjacent to the chimney). Based on measured water production rates, it appears that most of the water is from Zone IV. Samples for tritium, ^{85}Kr, ^{90}Sr, ^{137}Cs, and gamma-spectral analyses were collected in plastic containers, plastic-lined barrels (some acidified), and gas-tight pressurized bottles. At this time, ^{137}Cs is the only radionuclide identified by gamma analysis of the residues from evaporated 55-gal. samples; ^{137}Cs was also observed radiochemically. Data from the tritium analyses are given in Table VI. The concentration of this radionuclide continues to decrease as water is pumped away from the cavity region (see Ref. 5, Sec. III).

Tables VII and VIII show comparisons of tritium, ^{90}Sr, and ^{137}Cs concentrations in RNM-1 water samples collected after pumping began at RNM-2S. Values for the original samples collected from Zones IV and V are also included for comparison. The concentrations of all these nuclides in RNM-1 water appear to be decreasing as water is pumped from RNM-2S; however, there is also an increase in the strontium-to-tritium and cesium-to-tritium ratios. When strontium and cesium are leached or desorbed from the alluvium, their increased concentration in the water probably offsets losses that occur as cavity water is removed. The absence of strontium and cesium in RNM-2S water confirms laboratory predictions that, because of their high retention on the alluvium solid, these elements will not be transported far.

The ^{85}Kr/T ratios seem to indicate that krypton is being removed relative to tritium. Even with this trend, however, the most recent ^{85}Kr/T ratio is

TABLE V

ANION CONCENTRATIONS IN RNM-2S WATER SAMPLES

Sample Number	Anion Concentration[a] (mg/ℓ)						
	F^-	Cl^-	NO_2^-	PO_4^{3-}	Br^-	NO_3^-	SO_4^{2-}
G-377 (9-3-76)	0.4 ±0.02	22.5	<0.05	<0.16	<0.15	11.7 ±0.4	42. ±0.5
G-496 (6-13-77)	0.4 ±0.004	20.2	"	"	"	12.0 ±0.4	40. ±0.3
G-687 (7-3-78)	0.4 ±0.03	18.9	"	"	"	12.4 ±0.6	40. ±0.5
G-937 (7-6-79)	0.4 --	19.0	"	"	"	12.3 ±0.5	39. ±0.2
G-1172 (7-11-80)	0.4 ±0.03	17.4	"	"	"	12.5 ±0.6	39. ±0.1
G-1286 (7-17-81)	0.4 ±0.02	16.8	"	"	"	12.6 ±0.5	38. ±0.08
G-1316 (2-9-82)	0.4 ±0.03	16.5	"	"	"	12.8 ±0.8	38. ±0.4
G-1322 (3-23-82)	0.4 ±0.03	16.7	"	"	"	13.2 ±0.5	37. ±1.7

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[a] Water filtered through 0.05-µm Nuclepore polycarbonate membrane.

several times larger than that calculated for the Cambric source term value (Sec. II.A).

Data presented in Table IX concern ^{129}I concentrations in water samples taken at RNM-1. The B and C series samples were taken from zones below the cavity, D series samples from cavity level, and E and F series samples from above the cavity. (Reference 1 discusses the sampling at the RNM-1 site in detail.) The H and J series samples were taken after RNM-2S had been pumped for several years. The data indicate that the ^{129}I concentration decreased more rapidly than the tritium concentration in the upper cavity and chimney regions and, thus, gave a smaller "average radius" from the cavity center for

TABLE VI

RESULTS OF ANALYSIS OF RNM-1

SAMPLES COLLECTED APRIL 5-6, 1983

Sample Number	Volume Pumped (m^3)	T (nCi/mℓ) 4/23/83	T (nCi/mℓ) Corrected to 5/14/65[a]
N1	11.4	0.0121	0.0332
N2	22.7	0.0119	0.0327
N3	46.6	0.0117	0.0321
N4	56.4	0.0118	0.0324
434-3-83-001[b]	59.4	0.0121	0.0338
434-3-83-002[b]	61.3	0.0122	0.0342
N5	66.6	0.0121	0.0332
N6	76.8	0.0141	0.0387
Average			0.0338

---

[a] Values corrected for ratioactive decay since Cambric zero time.

[b] Collected in gas-tight pressurized bottles.

iodine than for tritium. After pumping started at the satellite well, the ^{129}I-to-tritium concentration ratio in the upper cavity and chimney regions was slightly higher.

The 1983 sampling of water from the RNM-1 and -2S sites included filtration of water through 293-mm-diam Nuclepore filters to determine whether particulates were present in pumped water samples. A 300-ℓ volume of water from the RNM-1 hole was filtered through 0.4-μm pore size filters, and 3770 ℓ from RNM-2S was filtered through 0.05-μm pore size filters. Particulates on these filters were analyzed by scanning electron microscope (SEM). They contained a variety of different elemental compositions; silicon was generally the predominant element. Particle diameters ranged from tens of micrometers to <0.001 μm (the instrument's limit of resolution).

TABLE VII

COMPARISON OF ^{90}Sr, ^{137}Cs, AND TRITIUM CONCENTRATIONS IN RNM-1 WATER

Entry	Date	Water Volume[a] (10^6 m^3)	Concentration[b]			Atom Ratio (x 10^4)	
			T (10^9 atoms/mℓ)	^{90}Sr (10^6 atoms/mℓ)	^{137}Cs (10^6 atoms/mℓ)	^{90}Sr/T	^{137}Cs/T
Original-Zone IV	08/08/75	0	3100	130	23	0.4	0.07
Original-Zone V	08/14/75	0	790	5.5	4.6	0.07	0.06
Zone IV + V	10/04/77	1.17	66	22	5.5	3	0.8
Zone IV + V	11/30/77	1.34	41	13	11	3	3
Zone IV + V	09/04/79	3.50	5.4	4.4	2.3	8	4
Zone IV + V	10/05/81	5.89	3.0	1.5	1.3 (0.81)[c]	5	4 (3)[c]
Zone IV + V	04/01/82	6.48	1.6	1.3	1.5 (0.68)[c]	8	9 (4)[c]
Zone IV + V	04/06/83	7.67	0.70	--	-- (0.54)[c]	-	- (8)[c]

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[a] Total volume of water removed from RNM-2S by indicated date.

[b] Values corrected to Cambric zero time.

[c] Values in parentheses are based on gamma-spectral analyses of 55-gal. (evaporated) samples.

TABLE VIII
COMPARISON OF ^{85}Kr AND TRITIUM CONCENTRATIONS IN RNM-1 WATER

		Water Volume[a]	Concentration[b]		^{85}Kr/T Atom Ratio	
Entry	Date	(10^6 m^3)	T (10^9 atoms/mℓ)	^{85}Kr (10^6 atoms/mℓ)	(x 10^4)	R[c]
Original-Zone IV	08/08/75	0	3100	570	1.8	1.5
Original-Zone V	08/14/75	0	790	110	1.4	1.2
Zone IV + V	10/04/77	1.17	66	610	92	75
Zone IV + V	11/30/77	1.34	41	49	12	10
Zone IV + V	09/04/79	3.50	5.4	4.6	8.5	7
Zone IV + V	10/05/81	5.89	3.0	1.5	5.0	4
Zone IV + V	04/01/82	6.48	1.6	0.55	3.3	3
Zone IV + V	04/06/83	7.67	0.70	0.24	3.4	3

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[a] Total volume of water removed from RNM-2S by indicated date.

[b] Values corrected to Cambric zero time.

[c] Measured ^{85}Kr/T divided by ^{85}Kr/T calculated for Cambric (1.22×10^{-4}).

TABLE IX
^{129}I CONCENTRATIONS IN RNM-1 WATERS

Sample	^{129}I Concentration (atoms/mℓ)	Method	^{129}I/T Atom Ratio
B12	$(1.53 \pm 0.18) \times 10^{11}$	NAA	1.31×10^{-3}
B12	$(1.30 \pm 0.14) \times 10^{11}$	TAMS	1.11×10^{-3}
C66	$(2.13 \pm 0.25) \times 10^{11}$	NAA	1.22×10^{-3}
C66	$(2.15 \pm 0.26) \times 10^{11}$	TAMS	1.24×10^{-3}
D13	$(8.7 \pm 1.0) \times 10^{10}$	NAA	6.3×10^{-4}
D16	$(8.6 \pm 1.0) \times 10^{10}$	NAA	6.2×10^{-4}
D16	$(5.9 \pm 0.7) \mathrm{X}\ 10^{10}$	TAMS	4.2×10^{-4}
E18	$(1.24 \pm 0.15) \times 10^{8}$	NAA	4.2×10^{-5}
E30	$(1.16 \pm 0.15) \times 10^{8}$	NAA	4.0×10^{-5}
E30	$(1.24 \pm 0.15) \times 10^{8}$	TAMS	4.3×10^{-5}
F16	$(6.9 \pm 1.9) \times 10^{7}$	NAA	6.8×10^{-5}
F16	$(3.6 \pm 0.4) \times 10^{7}$	TAMS	3.6×10^{-5}
H14[a]	$(5.4 \pm 0.6) \times 10^{6}$	TAMS	8.7×10^{-5}
J9[b]	$(5.9 \pm 0.7) \times 10^{6}$	TAMS	1.4×10^{-4}

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[a] Re-entry of Zones IV and V after pumping 1.17×10^{6} m^{3} at RNM-2S.

[b] Re-entry of Zones IV and V after pumping 1.34×10^{6} m^{3} at RNM-2S.

IV. OTHER FIELD STUDIES

A. Hole UE2ce (V. M. Armijo, M. R. Cisneros, W. R. Daniels, J. Drake, G. W. Knobeloch, and S. Maestas)

Earlier attempts to pump water from Well UE2ce near the Nash crater pumped the well dry. A new pump with a lower flow rate was installed, and pumping started again at UE2ce about April 12, 1982, with a flow rate of ~12 gal./minute; by October 1982, the flow rate had decreased to ~9.5 gal./minute. Tritium, ^{90}Sr, and ^{137}Cs analyses by the usual techniques were performed on water samples from UE2ce. No ^{90}Sr or ^{137}Cs was detected (Ref. 5, Sec. IV). Table X shows the results of tritium analyses for FY 1983.

TABLE X

TRITIUM CONCENTRATION IN WATER PUMPED FROM WELL UE2ce

Sample Number	NTS E/S Number	Meter Reading (gal.)	Date	Tritium[a] (nCi/mℓ)
UE2ce-29	17135	2,067,093	10/05/82	15.20
UE2ce-30	17136	2,178,731	10/13/82	15.23
UE2ce-31	17137	2,302,341	10/22/82	15.20
UE2ce-32	17138	2,356,672	10/26/82	15.39
UE2ce-33	17139	2,473,348	11/04/82	14.91
UE2ce-34	17140	2,622,909	11/16/82	14.79
UE2ce-35	17141	2,823,730	12/03/82	14.48
UE2ce-36	17142	2,879,390	12/08/82	14.88
UE2ce-37	17143	2,946,228	12/14/82	14.52
UE2ce-38	17144	3,031,973	12/21/82	15.10
UE2ce-39	17145	3,083,900	12/28/82	15.58
UE2ce-40	17146	3,153,647	01/04/83	15.52
UE2ce-41	17147	3,211,295	01/10/83	15.52
UE2ce-42	17148	3,352,707	01/26/83	16.47
UE2ce-43	17149	3,406,785	02/02/83	16.77
UE2ce-44	17150	3,457,510	02/09/83	17.74
UE2ce-45	17151	3,495,026	02/16/83	20.55
UE2ce-46	17152	3,517,056	02/24/83	21.97
UE2ce-47	17153	3,596,670	03/15/83	17.50
UE2ce-48	17154	3,661,838	03/23/83	16.95
UE2ce-49	17155	3,742,950	03/31/83	16.23
UE2ce-50	17156	3,800,695	06/29/83	29.99
UE2ce-51	17157	3,834,122	07/06/83	24.77
UE2ce-53	17159	3,897,426	07/11/83	19.02
UE2ce-54	17160	3,911,810	07/12/83	18.98
UE2ce-55	17161	3,929,730	07/13/83	18.66
UE2ce-56	17162	3,942,610	07/14/83	18.00
UE2ce-57	17163	4,003,840	07/18/83	17.21
UE2ce-58	17164	4,032,300	07/20/83	16.72
UE2ce-59	17165	4,046,880	07/21/83	15.50
UE2ce-60	17166	4,060,600	07/22/83	15.72

TABLE X (cont)

Sample Number	NTS E/S Number	Meter Reading (gal.)	Date	Tritium[a] (nCi/mℓ)
UE2ce-61	17167	4,206,694	08/02/83	14.50
UE2ce-62	17168	4,279,066	08/16/83	19.99
UE2ce-63	17169	4,353,076	08/26/83	25.09
UE2ce-64	17170	4,356,890	08/31/83	30.14
UE2ce-65	17171	4,434,761	09/08/83	15.22
UE2ce-66	17172	4,525,679	09/16/83	14.76
UE2ce-67	17173	4,570,316	09/20/83	14.44
UE2ce-68	17174	4,654,110	09/29/83	15.26

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[a] Standard deviations of counting data <0.1%.

The tritium concentration generally ranged from 15 to 20 nCi/mℓ, with occasional excursions to 30 nCi/mℓ. This level is well above the maximum permissible concentration[14] for drinking water in a controlled area (3 nCi/mℓ).

B. Hole U20n (W. R. Daniels, J. L. Thompson, G. Bentley, M. R. Cisneros, S. Maestas, A. J. Mitchell, and P. L. Wanek)

The Cheshire device was fired in rhyolite on Pahute Mesa in February 1976 at a depth of 1174 m. Sampling of water from the vicinity of the Cheshire cavity was attempted in late 1976. After about 4000 gal. of water was extracted from Hole U20n, the pump became stuck while being moved, and the sampling program was terminated. The water obtained in earlier samples contained a number of fission products, detectable amounts of plutonium, and tritium (the latter at levels up to 2 μCi/mℓ). It was thought that this water had not been drawn directly from the cavity region, as the tritium content was about an order of magnitude lower than the concentration calculated for the cavity. Interest in conducting radionuclide migration studies at U20n has remained high because the site has a number of favorable features: (1) there is an appropriate source of radionuclides; (2) the rhyolite provides a geologic medium different from that of the Cambric studies; (3) there are relatively transmissive zones in the rhyolite; and (4) the site is within 5 miles of the NTS boundary. In 1981, the obstructing pump was forced to the bottom of the hole, a bridge plug was set above the pump, and when the hole casing was tested it was water tight. In August 1983, the casing was perforated at slant depths from 4202 to 4285 ft (the slant depth of the Cheshire event was slightly over 4100 ft), and a pump was inserted into the hole. On August 7, 1983, pumping began but was terminated after a few minutes because of a generator malfunction. Water collection consisted of three pressurized bottles filled at depth before the pump was inserted and a 55-gal. drum filled just before the pump was turned off. On August 16, 1983, the pump was turned on again but failed to produce water because of a split in the pipe connected to the pump. On September 7, 1983, a new pump was inserted to a slant depth of 3040 ft. It pumped water at approximately 50 gal./minute until it was turned off; about 137,000 gal. had been removed from Hole U20n. On-site analytical work was done by personnel from Los Alamos National Laboratory, Lawrence Livermore National Laboratory and the US Geological Survey. Sample collections for later analysis were made by Los Alamos and Livermore personnel. Reynolds Electrical and Engineering Company provided lithium and tritium analyses within a few hours after the sample was collected.

Much of the analytical work on the Hole U20n samples is in progress, but some preliminary results are available. With the exception of the first sample (taken at 981 gal. pumped), all samples contained lithium in the range 0.13 to 0.16 ppm. The first sample had a lithium content of 0.50 ppm, which probably indicated that the casing had not quite been cleared of the original water, which was spiked with 20 ppm of lithium. The fact that the lithium concentration remained constant considerably above the ambient level of the regional groundwater (0.02 to 0.06 ppm)[15] could be explained if the Cheshire device had contributed to the lithium inventory. This possibility is being checked by running lithium isotopic analyses on the samples. The tritium concentration throughout the pumping period was essentially constant at 0.38 μCi/mℓ, more than an order of magnitude below the expected concentration. Particulates on filters from water samples obtained during the first hours of pumping contained such fission products as ^{137}Cs, ^{106}Ru, and ^{125}Sb. The fission-product content of similar samples collected during the last hours of pumping will be compared. Radionuclides present as dissolved species will be determined by gamma-spectral analyses of evaporated 200-ℓ filtered water samples and by radiochemical techniques applied to filtered water samples. The ^{85}Kr content of samples collected in pressurized bottles at various times during the pumping will be determined. Measured fission product/tritium ratios will be compared with ratios based on calculated yields and with similar ratios determined for the RNM experiment at the Cambric site. These data should give us information on (1) the extent of water movement away from the cavity region and (2) the efficiency of rhyolite as a sorber of fission-product radionuclides.

V. LABORATORY STUDIES

A. Determination of Anionic Species of Radionuclides (R. S. Rundberg)

BioRad AG1-8X resin has extremely high adsorption coefficients for both pertechnetate and perruthenate. Ruthenium tracer exists as more than one species and, thus, gives significantly lower distribution coefficients if measured by the batch technique. Column experiments were run with ruthenium tracer; 80% adsorbed with a distribution coefficient of 88 000 mℓ/g. This species is assumed to be perruthenate. Desorption experiments were performed to help design a stripping procedure. Nitric acid is the best stripping anion for perruthenate but is also an oxidizer that volatilizes the ruthenium if the strip solution is concentrated by boiling down.

A 1-m by 10-cm-diam column containing AG1-8X resin 20 to 50 mesh was placed in Well RNM-2S and water was sampled for 28 days. A total volume of 5488 gal. passed through the column. If any ruthenium in the RNM water is in the perruthenate form, it will be adsorbed in the upper one-third of the column. An attempt was made to remove a portion of the perruthenate by using HI under controlled redox conditions, but the experiment was thwarted by equipment problems. The strip solutions are being analyzed to decide if this procedure is worth pursuing.

B. Elemental and Mineralogical Analyses of Samples from RNM-1 Alluvium
(S. R. Garcia, S. Levy, P. Q. Oliver, and K. Wolfsberg)

Samples taken from RNM-1 were analyzed by neutron activation for their elemental composition and by x-ray diffraction (XRD) for their mineralogy. The results are given in Tables XI and XII.

TABLE XI

ELEMENTAL ANALYSES OF RNM SAMPLES

Element	Isotope Produced	RNM-27 (225 m depth)	RNM-30 (242 m depth)
Na	Na-24	20200 ± 700	19600 ± 600
Mg	Mg-27	7300 ± 900	12000 ± 1000
Al	Al-28	78000 ± 3000	78000 ± 3000
Cl	Cl-38	150 ± 40	< 110
K	K-42	33000 ± 2000	26000 ± 2000
Ca	Ca-49	23000 ± 2000	27000 ± 2000
Ti	Ti-51	2700 ± 200	3100 ± 200
V	V-52	63 ± 4	73 ± 5
Mn	Mn-56	590 ± 30	690 ± 30
Cu	Cu-66	< 200	< 200
Sr	Sr-87	480 ± 90	510 ± 80
I	I-128	< 10	< 20
Ba	Ba-139	1100 ± 100	1100 ± 100
Dy	Dy-165	5.1 ± 0.4	5.0 ± 0.3
U	U-235	3.7 ± 0.1	3.4 ± 0.1
Na	Na-24	20200 ± 600	18700 ± 500
K	K-42	33000 ± 2000	29000 ± 2000
Ga	Ga-72	< 20	< 30
As	As-76	5.1 ± 0.5	4.1 ± 0.5
Br	Br-82	< 2	< 2
Sb	Sb-122	< 0.5	< 0.5
Ba	Ba-131	900 ± 200	800 ± 200
La	La-140	56 ± 2	63 ± 2
Sm	Sm-153	< 7	6.5 ± 0.3
Yb	Yb-175	2.6 ± 0.3	1.9 ± 0.2
Lu	Lu-177	0.42 ± 0.06	0.36 ± 0.05
W	W-187	< 2	< 2
Au	Au-198	< 0.01	< 0.01
U	U-239	< 6	5.6 ± 0.7
Sc	Sc-46	6.9 ± 0.2	7.2 ± 0.2
Cr	Cr-51	25 ± 3	32 ± 3
Fe	Fe-59	38000 ± 1000	38000 ± 1000
Co	Co-60	6.8 ± 0.3	8.2 ± 0.4
Zn	Zn-65	80 ± 10	38 ± 7
Se	Se-75	ND	ND
Rb	Rb-86	127 ± 8	99 ± 6
Sb	Sb-124	< 0.3	< 0.2
Cs	Cs-134	4.4 ± 0.4	3.6 ± 0.3
Ba	Ba-131	1100 ± 100	820 ± 90
Ce	Ce-141	108 ± 5	104 ± 4
Eu	Eu-152	1.08 ± 0.06	1.10 ± 0.06
Tb	Tb-160	0.6 ± 0.1	0.33 ± 0.08
Yb	Yb-169	2.7 ± 0.2	2.6 ± 0.1
Lu	Lu-177	0.36 ± 0.04	0.32 ± 0.04
Hf	Hf-181	5.9 ± 0.6	5.5 ± 0.5
Ta	Ta-182	1.2 ± 0.1	0.8 ± 0.1
Th	Th-233	17.6 ± 0.8	15.3 ± 0.7

TABLE XII
MINERAL ANALYSIS FOR RNM SAMPLES

Sample	Depth (m)[a]	Fraction[b]	Feldspar	Quartz	Smectite	Kaolinite	Mica	Biotite	Hornblende	Clino-ptilolite	Calcite	Other
RNM-10	189	Sand	70-90	10-15						0-5	0-5	
		Silt & Clay	30-50	5-10	30-50	0-5		0-2	0-2	0-5	2-5	
		Whole	60-90	10-15	3-5	0-1		0-1	0-1	0-5	0-5	
RNM-41	320	Whole	60-80	2-10	10-20			0-3	0-2	5-10	2-5	
RNM-65	266	Sand	60-80	5-10	0-10			0-5	0-5	0-5	2-5	
		Silt & Clay	10-30	0-5	60-80	0-5		0-2	0-2	0-2	0-5	
		Whole	50-80	5-10	5-15	0-1		0-5	0-5	0-5	2-5	
RNM-47	299	Sand	40-60	2-5	0-5			0-2		30-40	0-2	
		Silt & Clay	30-50	2-10	10-20	0-5		0-2	0-2	20-30	0-2	
		Whole	30-60	2-6	2-10	0-1		0-2	0-1	30-40	0-2	
RNM-27	225	Whole	70-90	10-15	0-5		0-2		0-2	0-5	0-2	
RNM-33	256	Whole	70-90	5-15				0-2	0-2	0-5		0-2 Muscovite
RNM-30	242	Silt & Clay	10-30	2-5	60-80					0-5	1-2	0-2 Biotite-phlogopite
		Whole	70-90	5-10	0-10				0-2	0-1	0-2	0-2 Biotite-phlogopite, 0-5 Hematite
U3bv	238	Sand	70-90	10-15	0-5		0-2		0-2	0-5	0-5	
		Silt & Clay	20-30	5-10	20-40		0-2			0-2	10-20	
		Whole	60-90	10-15	2-8		0-2		0-2	0-5	1-7	
Bentonite drilling mud whole		Whole	5-20	5-10	70-90		0-2				0-5	2-5 Bentonite, 0-2 unidentified

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[a] Depth of standing water level is 221 m.

[b] See text.

The neutron activation analyses were carried out at the Los Alamos Omega West Reactor.[16] The abundances of some elements are given more than once because the results are grouped by counting times of 20 minutes, 4 days, and 3 weeks after irradiation.

Some of the samples analyzed by XRD were separated into sand (50-µm to 2-µm) or silt plus clay (<50-µm) fractions. In these cases, the mineral properties for the whole sample were calculated from the data for the fractions. Much of the sample material had resided in core shoes for many years, so every effort was made to select alluvial material uncontaminated by drilling mud or rust. In addition to samples derived from the RNM-1 hole, samples of alluvium from Hole U3bv and Bentonite drilling mud were analyzed for mineral content. The sorptive properties of these materials had been evaluated earlier.

The XRD studies were performed using a Siemens D500 diffractometer that provided copper K-alpha radiation. Each sample was run from 2 to 32° two-theta. Diffraction data were collected and processed by the Siemens DIFFRAC V system. The system identified XRD peaks and calculated their d-spacing and integrated intensities.

Mineral identifications were made by comparing sample XRD patterns with patterns from the mineral powder diffraction file. Identifications were confirmed by petrographic examinations when possible. Estimates of mineral percentages were made by a combination of the following methods:

(1) use of XRD I/I_{cor} values as described by Hubbard and others,[17]

(2) comparison of sample patterns with patterns for material of known composition, and/or

(3) estimates of mineral proportions from optical examination of the material.

C. Sorptive Properties of NTS Media (F. O. Lawrence, S. D. Knight, B. P. Bayhurst, M. R. Cisneros, K. W. Thomas, and K. Wolfsberg)

There is a continual effort to relate sorptive properties of tuffs to their mineralogies. A previous report[5] contained a discussion of sorption studies by the batch method with particular emphasis on the correlation of sorption ratios with clinoptilolite abundance. During FY 1983, a number of tuffs with varying mineralogies were used in sorption studies, and selenium and radium were added to the suite of elements employed for these studies. A brief summary of this work is given here and some relevant data are presented in Table XIII; more details may be found in Ref. 18.

Barium is a good analogue for radium in sorption studies. This information is useful because radium, with its volatile daughter radon, requires special equipment and procedures to avoid contaminating the laboratory. Sorption data for barium and radium are comparable for glassy, devitrified, and zeolitized tuffs; there are variations of more than 2 orders of magnitude in the sorption ratios for the different types of tuff.

In contrast to barium and radium, selenium showed no clear correlation of sorption with abundances of zeolites, clays, glass, or devitrification minerals. The average value of the sorption ratios, while low, was higher than the values for iodine and technetium. It was not anticipated that selenium, which exists in solution as the anions selenite and selenate, would sorb strongly on tuff. Similarly, the pertechnetate and uranylcarbonate anionic species show little or no tendency to sorb.

The zeolites mordenite and clinoptilolite appear to have an equal capacity to sorb cesium and barium. Strontium, plutonium, and americum sorption ratios do not appear greater for mordenite than for devitrification minerals. It is possible that the calcite present in G-2-723 is responsible for the exceptionally high sorption ratios of europium, plutonium, and americium in that sample. This point will be investigated. Analcime does not appear to enhance sorption of strontium, cesium, or barium. Sorption on glassy tuffs does not correlate with glass content and, instead, may be related to texture. Further examination and description of glassy samples is required. Smectite gives rise to high sorption ratios for cesium and barium, but not for strontium. As the data base expands, it should be possible to establish better correlations between mineral content and sorption ratios for each of the elements of interest.

TABLE XIII

SUMMARY OF SORPTION RATIOS

Sample	Sorption Ratio[a] (mℓ/g) Se	Sr	Tc	Cs	Ba	Eu	Ra	U	Pu	Am
G-1-1292					2100 (300)		1500 (100)			
G-1-1436					150 000 (24 000)		100 000 (30 000)	11 (1)		
G-1-2289	9 (1)				66 000 (9000)		46 000 (20 000)	2.5 (0.1)		
G-1-2363	25 (5)				235 (9)		540 (60)	0		
G-2-547	2 (2)	265 (10)	0	13 300 (1500)	3490 (30)	390 (30)		9.4 (0.1)	1200 (200)	13 000 (110)
G-2-723	19 (2)	290 (40)	0	4100 (600)	3500 (400)	>10 000		2.4 (0.6)	>4500	890 000 (50 000)
G-2-1952	2 (1)	2200 (400)	0	63 300 (1100)	25 000 (4000)	89 (14)		0	76 (4)	1800 (70)
G-2-3933	0 (1)	240 (60)	0.1 (0.06)	2500 (1000)	1700 (500)	1500 (700)		0	1600 (30)	6600 (400)
GU-3-433	15 (3)	61 (6)	0	630 (20)	810 (100)	100 (14)		0	420 (80)	3100 (200)
GU-3-855	10 (4)							10.0 (0.1)		
GU-3-1203	1 (1)							0	410 (70)	920 (60)
GU-3-1301	7 (2)	32 (8)	0.03 (0.004)	160 (40)	570 (60)	75 (12)		0	210 (30)	2000 (40)
GU-3-1436	3 (0)							20 (2)		
GU-3-1531	5 (1)							54 (9)		

Sample	Comments
G-1-1292	Glassy
G-1-1436	Clinoptilolite
G-1-2289	Clinoptilolite
G-1-2363	Devitrified, 5% clay
G-2-547	24% clay
G-2-723	Calcite, glass, 10% clay
G-2-1952	Mordenite, clinoptilolite
G-2-3933	Analcime, 15% clay
GU-3-433	Devitrified
GU-3-855	Devitrified, 2% clay
GU-3-1203	Glass, vitrophyre
GU-3-1301	Glass, 12% clay
GU-3-1436	Glass
GU-3-1531	Devitrified

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[a] Average value for sorption. Numbers in parentheses are standard deviations of the means.

VI. PUBLICATIONS AND PRESENTATIONS

A number of publications and reports were issued that include, but are not limited to, data from the RNM program.

1. A. E. Ogard, W. R. Daniels, and D. T. Vaniman, Comps., "Research and Development Related to the Nevada Nuclear Waste Storage Investigations, October 1--December 31, 1983," Los Alamos National Laboratory report LA-9666-PR (May 1983).

2. K. Wolfsberg, D. T. Vaniman, and A. E. Ogard, "Research and Development Related to the Nevada Nuclear Waste Storage Investigations, January 1--March 31, 1983," Los Alamos National Laboratory report LA-9793-PR (June 1983).

3. A. E. Ogard, K. Wolfsberg, and D. T. Vaniman, "Research and Development Related to the Nevada Nuclear Waste Storage Investigations, April 1--June 30, 1983," Los Alamos National Laboratory report LA-9846-PR (December 1983).

4. E. A. Bryant and D. T. Vaniman, Comps., "Research and Development Related to the Nevada Nuclear Waste Storage Investigations, July 1--September 31, 1983," Los Alamos National Laboratory report LA-10006-PR (in press).

5. W. R. Daniels, Comp. and Ed., "Laboratory and Field Studies Related to the Radionuclide Migration Project, October 1, 1981--September 30, 1982," Los Alamos National Laboratory report LA-9691-PR (May 1983).

6. D. C. Hoffman, W. R. Daniels, K. Wolfsberg, J. L. Thompson, R. S. Rundberg, S. L. Fraser, and K. S. Daniels, "A Review of a Field Study of Radionuclide Migration from an Underground Nuclear Explosion," International Atomic Energy Agency report IAEA-CN-43/469 (1983).

During FY 1983 there were also oral presentations describing the RNM project to both domestic and international audiences.

1. W. R. Daniels and D. C. Hoffman, "A Field Study of Radionuclide Migration," Institute for Nuclear Chemistry, University of Mainz, West Germany, April 20, 1983.

2. W. R. Daniels and D. C. Hoffman, "Assessment of the Potential for Radionuclide Migration from the Region of a Nuclear Explosion," University of Bern, Switzerland, May 5, 1983.

3. D. C. Hoffman, W. R. Daniels, K. Wolfsberg, J. L. Thompson, R. S. Rundberg, S. L. Fraser, and K. S. Daniels, "A Review of a Field Study of Radionuclide Migration from an Underground Nuclear Explosion," IAEA International Conference on Radioactive Waste Management, Seattle, Washington, May 16-20, 1983.

4. W. R. Daniels and D. C. Hoffman, "A Field Study of Radionuclide Migration from an Underground Nuclear Explosion at the Nevada Test Site," Technical University of Munich, West Germany, May 20, 1983.

5. J. L. Thompson and W. R. Daniels, "Radionuclide Migration Program Update-1983," RNM Committee Meeting, Las Vegas, Nevada, July 12, 1983.

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2. D. C. Hoffman, "A Field Study in Radionuclide Migration," in Radioactive Waste in Geologic Storage, S. Fried, Ed., ACS Symposium Series 100 (American Chemical Society, Washington, DC, 1979), p. 149.

3. W. R. Daniels, Ed., "Laboratory and Field Studies Related to the Radionuclide Migration Project, October 1, 1979--September 30, 1980," Los Alamos National Laboratory report LA-8670-PR (February 1981).

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6. M. L. Wheeler, H. S. Ng, and S. E. Logan, "Selection of a Simulation Model for Analysis of Radionuclide Migration at the RNM Experiment Site, Nevada Test Site, Nevada," Los Alamos Technical Associates report LATA-LSL-29-01 (January 1982).

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