RADIONUCLIDES IN GROUND WATER AT THE IDAHO NATIONAL ENGINEERING LABORATORY, IDAHO

by LeRoy L. Knobel and Larry J. Mann

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CONVERSION FACTORS

For readers who prefer to use International System units, conversion factors for terms used in this report are listed below.

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
gallon (gal)	3.785	liter
square mile (mi^2)	2.590	square kilometer
microcuries per milliliter ($\mu Ci/mL$)	$3.7X10^8$	becquerel per liter
millirem	0.01	millisievert

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ABSTRACT

Sampling for radionuclides in ground water was conducted at the Idaho National Engineering Laboratory during September to November 1987. Water samples from 80 wells that obtain water from the Snake River Plain aquifer and 1 well that obtains water from a shallow, discontinuous perched-water body at the Radioactive Waste Management Complex were collected and analyzed for tritium, strontium-90, plutonium-238, plutonium-239, -240 (undivided), americium-241, cesium-137, cobalt-60, and potassium-40--a naturally occurring radionuclide. The ground-water samples were analyzed at the U.S. Department of Energy's Radiological and Environmental Sciences Laboratory at the Idaho National Engineering Laboratory in Idaho. Methods used to collect the water samples and quality assurance instituted for the sampling program are described in detail.

Tritium and strontium-90 concentrations ranged from below the reporting level to $80.6 \pm 1.5 \times 10^{-6}$ and $193 \pm 5 \times 10^{-8}$ μCi/mL, respectively. Water from a disposal well at Test Area North--which has not been used to dispose of waste water since September 1972--contained $122 \pm 9 \times 10^{-11}$ μCi/mL of plutonium-238, $500 \pm 20 \times 10^{-11}$ μCi/mL of plutonium-239, -240 (undivided), $21 \pm 4 \times 10^{-11}$ μCi/mL of americium-241, and $750 \pm 20 \times 10^{-8}$ μCi/mL of cesium-137; the presence of these radionuclides was verified by resampling and reanalysis. The disposal well had $8.9 \pm 0.9 \times 10^{-7}$ μCi/mL of cobalt-60 on October 28, 1987, but cobalt-60 was not detected when the well was resampled on January 11, 1988. Potassium-40 concentrations were less than the reporting level in all wells.

INTRODUCTION

The INEL (Idaho National Engineering Laboratory) includes about 890 mi^2 of the eastern Snake River Plain in southeastern Idaho (fig. 1). The INEL was established in 1949 and is used by the U.S. Department of Energy to test different types of nuclear reactors. The INEL is one of the main centers in the United States for developing peacetime uses of atomic energy, nuclear safety research, defense programs and development of advanced energy concepts.

During September to November 1987, a sampling program was conducted to document the concentration of radionuclides in ground water at the INEL. Water samples were collected from 30 production wells and 51 ground-water quality monitoring wells; 80 of these wells obtain water from the Snake River Plain aquifer and 1 obtains water from a perched-water zone. Radionuclides historically have been produced in conjunction with the operation of nuclear reactors and the processing of nuclear fuel. In addition, low-level and transuranic radioactive material have been disposed of or stored at the RWMC (Radioactive Waste Management Complex) near the southern boundary of the INEL (fig. 1). This report describes the methods used to collect the water samples and the quality assurance instituted for the sampling program and summarizes the concentrations of radionuclides in the water samples. The sampling program was conducted by the U.S. Geological Survey in cooperation with the U.S. Department of Energy.

Geohydrologic Setting

The eastern Snake River Plain is a northeast trending structural basin about 200 mi long and 50 to 70 mi wide. The plain is underlain by a layered sequence of basaltic lava flows and cinder beds intercalated with alluvium and lake bed sedimentary deposits. Individual flows range from 10 to 50 ft in thickness, although the average thickness may be from 20 to 25 ft (Mundorff and others, 1964, p. 143). The sedimentary deposits consist mainly of lenticular beds of sand, silt and clay with lesser amounts of gravel. Locally, rhyolitic lava flows and tuffs are exposed at the land

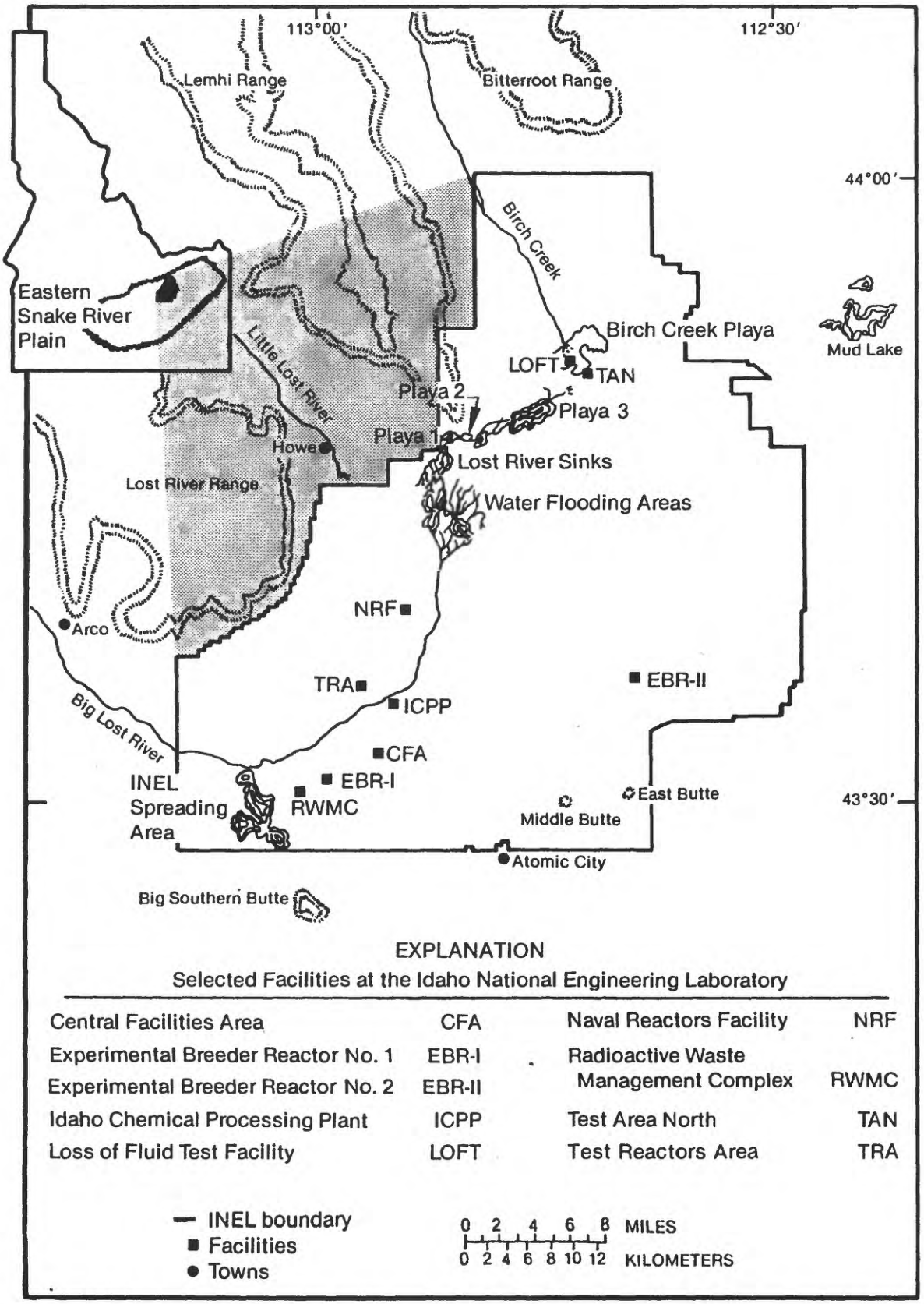

Figure 1.--Location of the Idaho National Engineering Laboratory and selected facilities.

surface or occur at depth. The basaltic lava flows and intercalated sedimentary deposits combine to form the Snake River Plain aquifer, which is the main source of ground water on the plain. The depth to water in the aquifer ranges from about 200 ft in the northern part of the INEL to more than 900 ft in the southern part.

The INEL obtains its entire water supply from the aquifer. Aqueous chemical and radioactive wastes--fission and activation products--generated at the INEL were discharged to ponds and wells from 1952 to 1983. Since 1983, most of the aqueous wastes have been discharged to unlined infiltration ponds. Many of the waste constituents enter the aquifer indirectly following percolation through the unsaturated zone (Lewis and Jensen, 1984, p. 17); prior to 1984, much of the waste was injected directly into the aquifer using deep wells.

Previous Investigations

The U.S. Geological Survey has conducted geologic, hydrologic and water-quality investigations at the INEL since it was selected as a reactor testing area in 1949. Ground-water quality studies routinely include selected common ions, trace elements and radionuclides. Radioactivity in ground water was first investigated in 1955; results of the investigation are reported by Nace (1961, p. 37a). The study was limited to detection of alpha- and beta-activity. Slight beta-contamination was observed in perched ground water beneath the Materials Test Reactor disposal pond at the TRA (fig. 1), although the individual beta-emitters were not identified. Subsequent studies have slowly expanded in scope to include an increasing number of radionuclides. Table 1 summarizes the first description of radionuclides or radioactivity in various U.S. Geological Survey reports by year of publication and author.

Other U.S. Geological Survey reports dealing with radionuclides in ground water include Morris and others (1964); Barraclough, Teasdale, and Jensen (1967); Barraclough, Teasdale, Robertson, and Jensen (1967); Barraclough and others (1982); and Lewis and Jensen (1984; 1985). In the

Table 1.--First description of radionuclides or radioactivity in U.S. Geological Survey Reports, by year of publication and author

Radionuclide or type of radioactivity	Year of first publication	Author(s)
Gross alpha and gross beta	1961	Nace
Tritium	1961	Jones
Gross gamma	1963	Morris and others
Strontium-90	1965	Morris and others
Cesium-137	1974	Robertson and others
Cobalt-60 and Chromium-51	1976	Barraclough and Jensen
Plutonium-238, plutonium-239,-240 (undivided) and americium-241	1976	Barraclough and others
Iodine-129	1981	Barraclough and others

early 1970's when analyses for plutonium and americium began to show scattered positive results the U.S. Department of Energy initiated a study to determine: (a) if reproducible background concentrations could be determined using special sampling and analytical procedures; (b) if positive analytical results could be reproduced for water from a well with low but detectable quantities of plutonium; and (c) if reproducible results on either detectable or nondetectable quantities could be obtained for water samples collected from the Snake River Plain aquifer. The results of that study are summarized by Polzer and others (1976). They concluded that Snake River Plain aquifer mean background concentrations for plutonium-238, plutonium-239, -240 (undivided), and americium-241 were less than $0.08X10^{-11}$, $0.04X10^{-11}$, and $0.10X10^{-11}$ μCi/mL, respectively. Mean concentrations of $0.65\pm0.29X10^{-11}$ μCi/mL for plutonium-238 and $0.24\pm0.19X10^{-11}$ μCi/mL for plutonium-239, -240 (undivided) were positively identified in well 47 (Polzer and others, 1976, p. 8). These concentrations were approximately one to two million times lower than Federal and State of Idaho concentration guides for drinking water for continuous use by the general population (Polzer and others, 1976, p. 8). The U.S. Geological

Survey has published two compilations that include data on radionuclides for the period 1949 through 1982; Bagby and others (1985) and Lewis and others (1985).

Acknowledgments

The authors gratefully acknowledge the many employees of the U.S. Department of Energy and its contractors at the INEL who aided in the sampling program. A large part of the administrative coordination was provided by T.F. Gesell and Isamu Aoki of the Department of Energy's Idaho Operations Office and by J.L. Clark and W.L. Bodily of EG&G Idaho, Inc., a Department of Energy contractor at the INEL. Analytical work was conducted by the Department of Energy's RESL (Radiological and Environmental Sciences Laboratory), Analytical Chemistry Branch--Don B. Martin, Chief--at the INEL. Special thanks are due to Messrs. A.C. Miskin and R.E. Prine, and Ms. D.G. Avery of EG&G for their participation in collecting the water samples and documenting field conditions.

METHODS AND QUALITY ASSURANCE

The methodology used in sampling for radionuclides generally followed the guidelines established by the U.S. Geological Survey (Thatcher and others, 1977; Skougstad and others, 1979; Wood, 1976). Slight modifications were incorporated into the sampling procedure as a result of the recommendations of the analyzing laboratory (D.R. Percival, U.S. Dept. of Energy, oral commun., 1987). The methods used in the field and quality assurance practices are outlined in following sections.

Sample Containers and Preservatives

Sample containers were purchased for the U.S. Geological Survey by a U.S. Department of Energy contract supplier and preservatives were supplied by the RESL. Polyethylene bottles--500-mL and 1000-mL--were used to collect

water samples. Untreated 500-mL samples were collected for tritium analysis. Samples for analyses of other radionuclides were collected in either 500-mL or 1000-mL polyethylene bottles depending on the target radionuclides. Prior to sample collection 10 or 20 mL of reagent-grade hydrochloric acid was added to the appropriate bottle to make a two-percent solution by volume; the acid maintains the radionuclides in solution.

Sampling Locations and Decontamination Procedures

Samples were collected at 81 locations as follows: 28 production wells equipped with sample delivery lines at the well head; 2 production wells equipped with water spigots located downstream from pressure tanks; 50 ground-water quality monitoring wells equipped with dedicated submersible pumps; and 1 well that obtains water from a perched-water zone that required the use of a thief sampling device. The 30 production wells are equipped with dedicated pumps and supply lines that did not require decontamination. To divert excess flow and facilitate sample collection, monitoring wells equipped with dedicated pumps were fitted with a portable discharge line about 2.5 ft long. The discharge line was 1.5 in. I.D. (inside diameter) galvanized-steel pipe equipped with a brass valve to control the flow rate. A galvanized T-joint was inserted into the line between the well head and the control valve and a series of galvanized pipes, a brass valve to control the flow rate of the sampling port, and galvanized connectors were attached to the T-joint to reduce the diameter so that a 9/32 in. I.D. stainless steel delivery pipe could be attached as the sampling point. The 9/32 in. I.D. stainless-steel pipe was bent 90 degrees to facilitate sample collection. All fittings and pipes were rinsed with deionized water before installation at the well head. Subsequent flushing by several hundred to thousands of gallons of water pumped from the well ensured that the portable discharge line was as clean as reasonably possible. The thief sampler used for sampling the well that penetrates the perched-water zone was washed with hot water and detergent and rinsed with deionized water prior to use. A detailed discussion of techniques used for obtaining samples from wells that represent aquifer water chemistry is presented by Claassen (1982).

Sample Collection

To ensure that water representative of the Snake River Plain aquifer was sampled, a volume of water equivalent to a minimum of 3 well-bore volumes was pumped from each well; at most wells, 5 to 10 well-bore volumes were pumped prior to collecting the samples. The diameter of the well bore, rather than the volume of the casing, was used to calculate the minimum volume because of the potentially large difference between the two. In addition, temperature, specific conductance, and pH were monitored during pumping, using methods described by Wood (1976). When these measurements stabilized, indicating probable hydraulic and chemical stability, a water sample was collected using the following protocol:

1. Field person responsible for collecting the water sample wore disposable vinyl gloves and stood upwind from the point of collection.

2. The outside of the sample delivery line was rinsed thoroughly with well water.

3. An empty 500-mL polyethylene bottle was rinsed with well water at least three times and filled with sample for tritium analysis.

4. Depending on the target radionuclides, either a pre-acidified 500-mL or 1000-mL polyethylene bottle was filled with sample. The 500-mL bottle is sufficient for all target radionuclides except plutonium-238, plutonium-239, -240 (undivided), and americium-241. These require an additional 500 mL of sample.

5. The bottles were capped immediately.

6. The exteriors of the bottles were dried, sealed with laboratory film, and labeled.

7. The water samples were stored in a mobile field laboratory until they could be transferred to a secured storage area, where they

remained until they were hand delivered to the laboratory; most of the samples were delivered on November 17, 1987.

Physical conditions at the well during sample collection were recorded in a field logbook and a chain-of-custody record was used to track samples from the time of collection until delivery to the analyzing laboratory. These records are available for inspection at the U.S. Geological Survey Project Office at the INEL.

Reporting of Data

Concentrations of selected radionuclides are reported with an estimated standard deviation, **s**, that is obtained by propagating sources of analytical uncertainty in measurements. The following guidelines for interpreting analytical results are based on an extension of the method described by Currie (1968).

In the analysis for a selected radionuclide, laboratory measurements are made on a target sample and a prepared blank. Instrument signals for the sample and the blank vary randomly. Therefore, it is essential to distinguish between two key aspects of the problem of detection: (1) The instrument signal for the sample must be greater than the signal observed for the blank to make the decision that a selected radionuclide was detected; and (2) an estimation must be made of the minimum radionuclide concentration that will yield a sufficiently large observed signal to make the correct decision for detection or nondetection of that radionuclide most of the time. The first aspect of the problem is a qualitative decision based on an observed signal and a definite criterion for detection. The second aspect of the problem is an intuitive estimation of the detection capabilities of a given measurement process.

In the laboratory, instrument signals must exceed a critical level to make the qualitative decision whether a selected radionuclide was detected. Radionuclide concentrations that equal 1.6**s** meet this criterion; at 1.6**s**, there is a 95 percent probability that the correct decision--not detected--

will be made. Given a large number of samples, up to 5 percent of the samples with measured concentrations greater than or equal to 1.6σ, which were concluded as being detected, might not contain the selected radionuclide. These measurements are referred to as false positives and are errors of the first kind in hypothesis testing.

Once the critical level of 1.6σ has been defined, the minimum detectable concentration may be established. Radionuclide concentrations that equal 3σ represent a measurement at the minimum detectable concentration. For true concentrations of 3σ or greater, there is a 95 percent or more probability of concluding that a selected radionuclide was detected in a sample. Given a large number of samples, up to 5 percent of the samples with measured concentrations greater than or equal to 3σ, which were concluded as being non-detected, could contain the selected radionuclide at the minimum detectable concentration. These measurements are referred to as false negatives and are errors of the second kind in hypothesis testing.

True radionuclide concentrations between 1.6σ and 3σ have larger errors of the second kind. That is, there is a greater than 5 percent probability of false negative results for samples with true concentrations between 1.6σ and 3σ and, although the selected radionuclide might have been detected, such detection may not be considered reliable; at 1.6σ, the probability of a false negative is about 50 percent.

These guidelines are based on counting statistics alone and do not include systematic or random errors inherent in laboratory procedures. The values, 1.6σ and 3σ, vary slightly with background or blank counts, and with the number of gross counts for individual analyses and for different selected radionuclides. In this report, if the selected radionuclide concentration was less than 3σ the concentration was considered to be below a "reporting level." The use of the critical level, minimum detectable concentration, and reporting level aid the reader in the interpretation of analytical results and do not represent absolute concentrations of radioactivity which may or may not have been detected.

Field Quality Assurance

Field quality assurance instituted for this sampling program included: four blind replicates--duplicate samples with a different sample identification number sent to the same laboratory; two blank samples containing deionized water; and five splits--large sample volumes divided into three equal volumes with the same well-identification number sent to different laboratories. One of the three equal volumes from each split was retained by the U.S. Geological Survey as a backup sample in the event that additional laboratory analyses were needed. Ground-water and quality-assurance samples were analyzed by RESL using methods described by Bodnar and Percival (1982). One of the three equal volumes for each of the five split samples were analyzed by EG&G's RML (Radioactivity Measurements Laboratory) located at the Test Reactors Area (fig. 1), using methods similar to those used by RESL (Bodnar and Percival, 1982; D.H. Meikrantz, EG&G Idaho, Inc., oral commun., 1988).

In October 1987, two blank samples that were prepared with deionized water contained reportable concentrations of tritium; all other radionuclide concentrations in the blank samples were less than the reporting level. The blank samples were obtained from a deionizing exchange column at the Central Facilities Area, which is supplied by wells CFA-1 and CFA-2. In October 1987, wells CFA-1 and CFA-2 contained $32.1 \pm 0.8 \times 10^{-6}$ and $21.1 \pm 0.7 \times 10^{-6}$ μCi/mL of tritium, respectively.

The split samples were from wells 87, 88, 89, 90 and the RWMC production well. Two of the three equal volumes for each of the five splits were analyzed for strontium-90 by two different laboratories and the independent results were within the analytical uncertainty of the measurement; however, the RML split for well 88 had a small but reportable concentration--$0.6 \pm 0.2 \times 10^{-8}$ μCi/mL. Because of the general agreement of results from the two laboratories for the split samples, two out of the five equal volumes--from wells 88 and 89--that were retained as backup samples were provided to RESL for additional analyses for cesium-137. The remaining backup samples were discarded after the analytical results had been obtained from the laboratories and reviewed by the authors.

CONCENTRATIONS OF RADIONUCLIDES IN GROUND WATER

Eighty wells that obtain water from the Snake River Plain aquifer at the INEL and that are equipped with dedicated submersible pumps were sampled for radionuclides. Well 92, which obtains water from a shallow, discontinuous perched-water zone at the RWMC, was sampled with a thief sampler. The eight radionuclides for which analyses were obtained and the number of wells sampled are shown on table 2. The locations of wells that were sampled are shown on figures 2 and 3. The concentrations of the eight radionuclides in ground-water and quality-assurance samples are included in table 3 at the end of this report. Four wells that showed reportable concentrations of one or more radionuclides other than tritium or strontium-90, were resampled. The results of those analyses are also included in table 3--see wells 88 and 89, CFA-1 and the TAN Disposal well. Only the TAN Disposal well--which has not been used to dispose of waste water since September 1972--showed reportable concentrations of radionuclides in the follow-up sampling.

Environmental standards, regulations, and permits applicable, in whole or in part, on the INEL or at the INEL boundary have been discussed by Chew and Mitchell (1988, p. 33-35). Selected derived concentration guides for radiation protection, based on an interim standard in effect for U.S. Department of Energy facilities of 100 millirem per year effective dose equivalent, are reported by Chew and Mitchell (1988, table X). The derived concentration guides for the radionuclides discussed in this report are listed in table 2. The guides follow the recommendations of the International Commission on Radiological Protection. The derived concentration guide for potassium-40 was provided by M.L. Walker (U.S. Department of Energy, written commun., 1988). For comparison, the U.S. Environmental Protection Agency maximum contaminant level for manmade radionuclides in community drinking water systems is based on a 4 millirem per year total body or organ dose equivalent.

Table 2.--Radionuclides for which analyses were obtained for ground-water samples

Radionuclide	Number of wells sampled for specified radionuclide	Derived concentration guides for radiation protection (μCi/mL)[1]
Tritium	81	$2000X10^{-6}$
Strontium-90	58	$100X10^{-8}$
Plutonium-238	45	$4000X10^{-11}$
Plutonium-239, -240 (undivided)	45	$3000X10^{-11}$
Americium-241	44	$3000X10^{-11}$
[2]Cesium-137	[3]47	$300X10^{-8}$
[2]Cobalt-60	[3] 1	$50X10^{-7}$
[2]Potassium-40	[3] 2	$70X10^{-7}$

[1]The U.S. Department of Energy derived concentration guides are based on an effective dose equivalent of 100 millirem per year (Chew and Mitchell, 1988, p. 32-35). For comparison, the U.S. Environmental Protection Agency maximum contaminant level for manmade radionuclides in community drinking water systems is 4 millirem per year total body or organ dose equivalent. New concentrations, based on 4 millirem per year effective dose equivalent have been proposed.

[2]Lithium-drifted germanium detectors are used to determine the concentrations of various radioactive nuclides by the detection of characteristic gamma-emissions (Bodnar and Percival, 1982). Samples from 47 wells were analyzed by gamma spectrometry.

[3]Number of samples for which analytical results for gamma-emitters were reported by RESL.

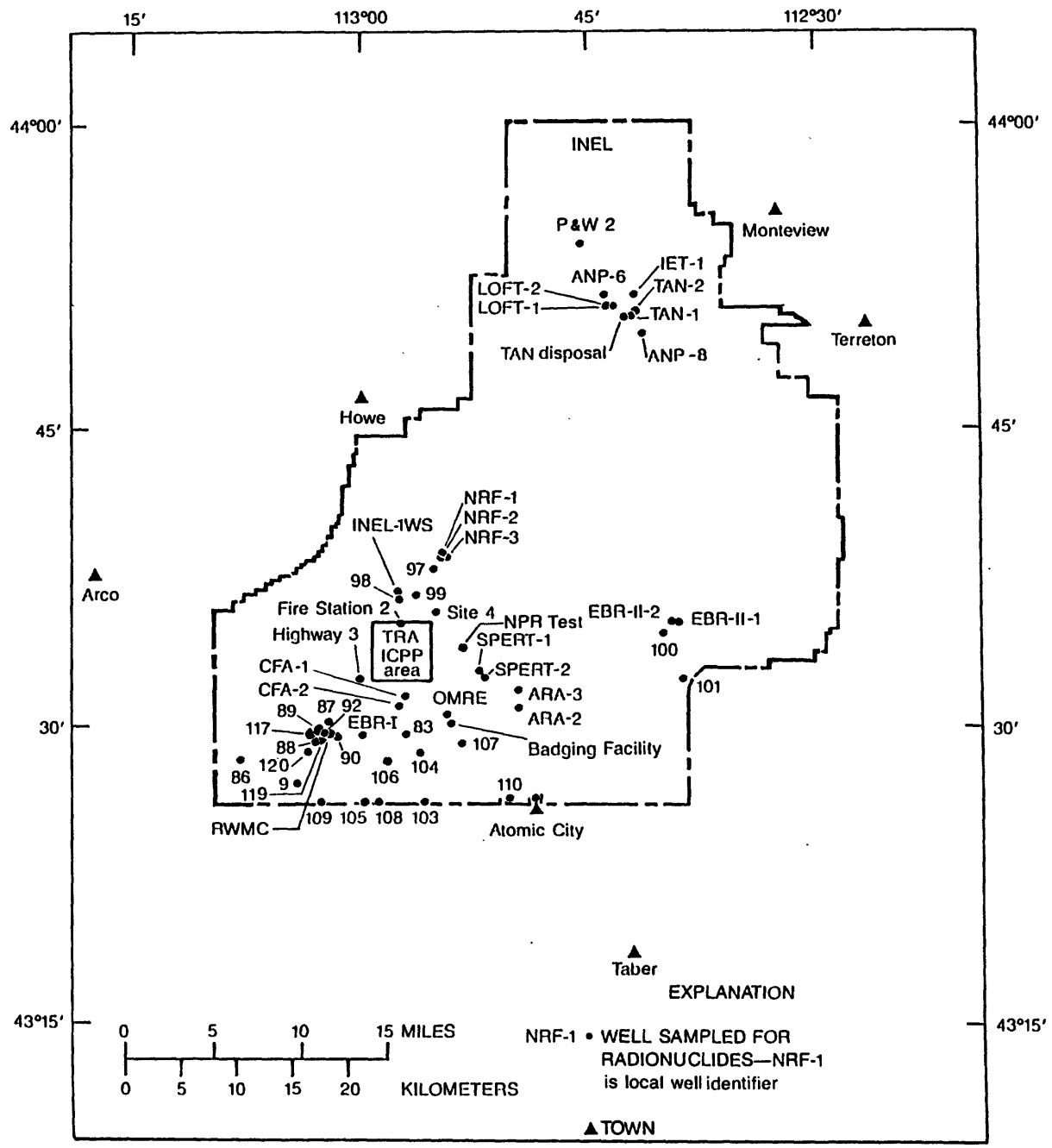

Figure 2.--Locations of wells sampled for selected radionuclides, September to November 1987.

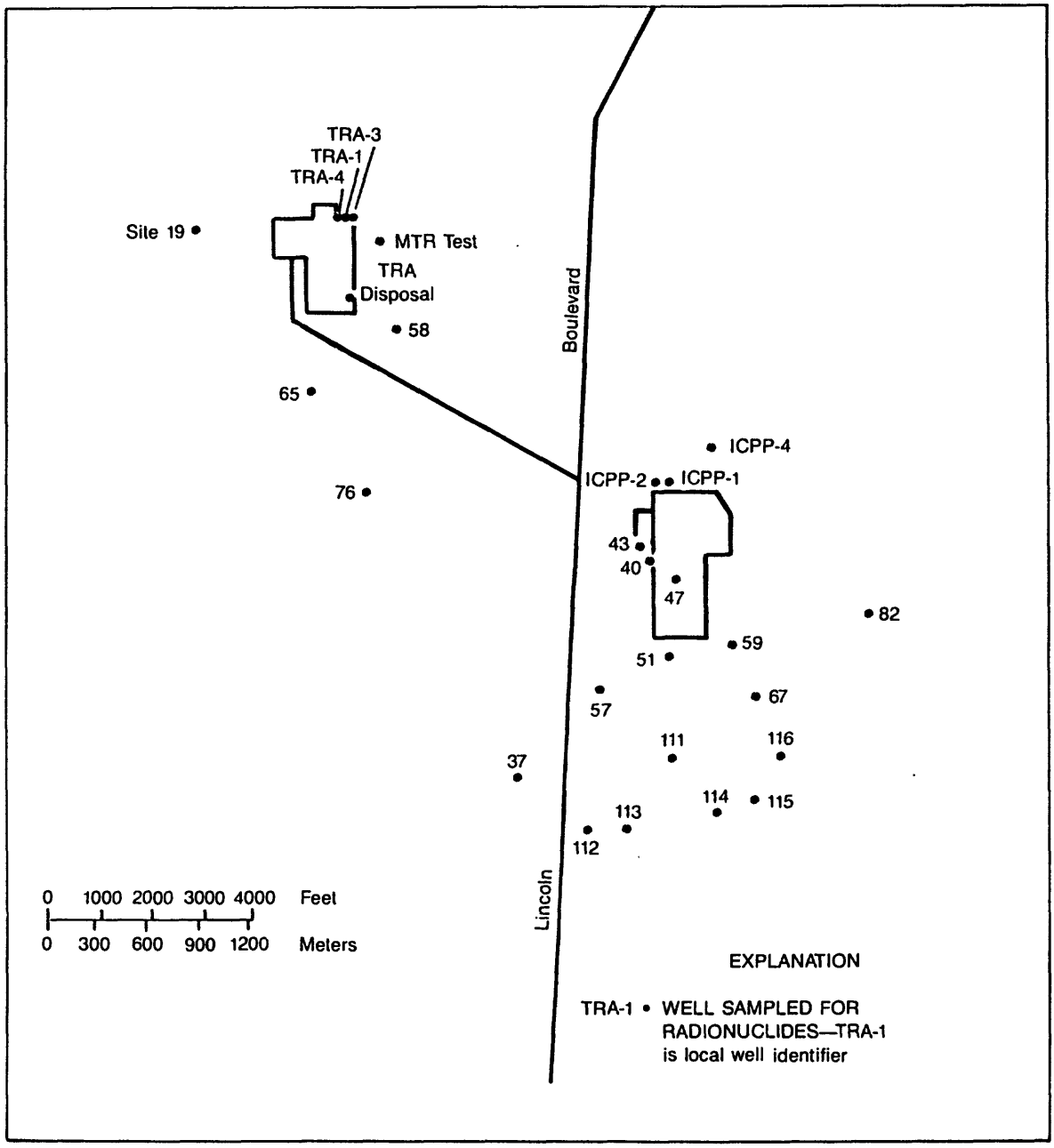

Figure 3.--Locations of wells sampled for selected radionuclides in the TRA-ICPP area, September to November 1987.

Tritium

The distribution of tritium at the INEL has been extensively studied by the U.S. Geological Survey. Jones (1961, figs. 58 and 70) shows the areal distribution of tritium at the ICPP (fig. 1) and at the Materials Test Reactor area near the TRA (fig. 1). More recent summaries of tritium distribution at the INEL are given by Barraclough and others (1982) for the period 1974 to 1978 and by Lewis and Jensen (1985) for the period 1979 to 1981.

During the September to November 1987 sampling program tritium concentrations ranged from less than the reporting level to $80.6 \pm 1.5 \times 10^{-6}$ μCi/mL (table 3). The smallest reportable concentration of tritium was $0.9 \pm 0.3 \times 10^{-6}$ μCi/mL. Except for the TAN Disposal well, all reportable concentrations of tritium are either in or to the south of the ICPP and TRA areas. The southernmost occurrence of tritium is at well 106. The locations of the wells with reportable tritium concentrations are shown on figures 4 and 5.

Strontium-90

Concentrations of strontium-90 were tabulated by Morris and others (1965, table 3) for the period December 1963 to January 1965. Since then, strontium-90 has been described in several reports; recent examples are Barraclough and others (1982) for the period 1974 to 1978 and Lewis and Jensen (1985) for the period 1979 to 1981.

The range of strontium-90 concentrations found in the samples collected during September to November 1987 is from less than the reporting level to $193 \pm 5 \times 10^{-8}$ μCi/mL (table 3). The smallest reportable concentration for strontium-90 is $0.6 \pm 0.2 \times 10^{-8}$ μCi/mL. Except for the TAN Disposal well and wells 87 and 89, strontium-90 concentrations that are greater than the reporting level are geographically situated in and just south of the ICPP. The locations of the wells with reportable strontium-90 concentrations for the September to November 1987 samples along with their concentrations are shown on figures 6 and 7.

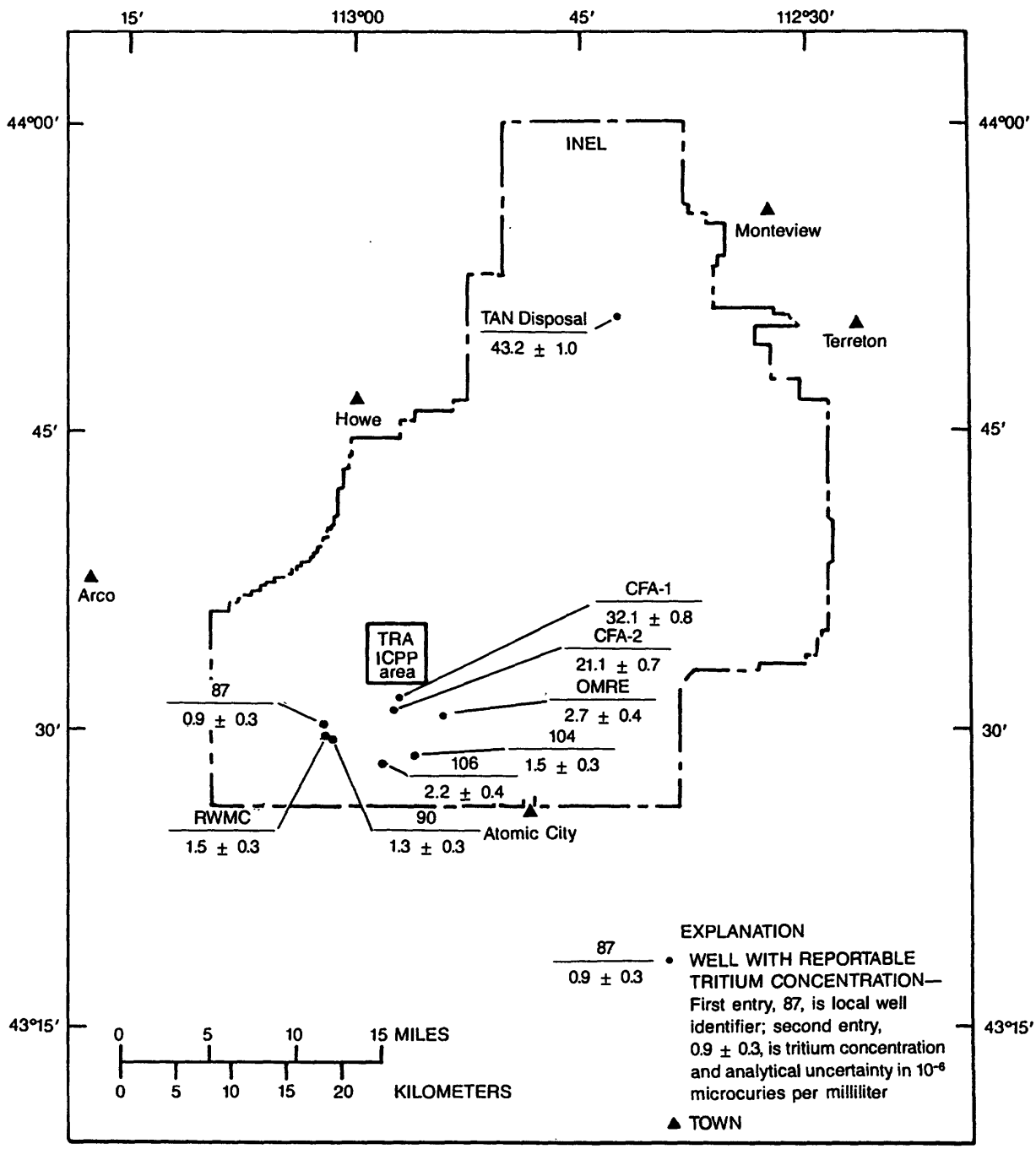

Figure 4.--Locations of wells with tritium concentrations above the reporting level, September to November 1987.

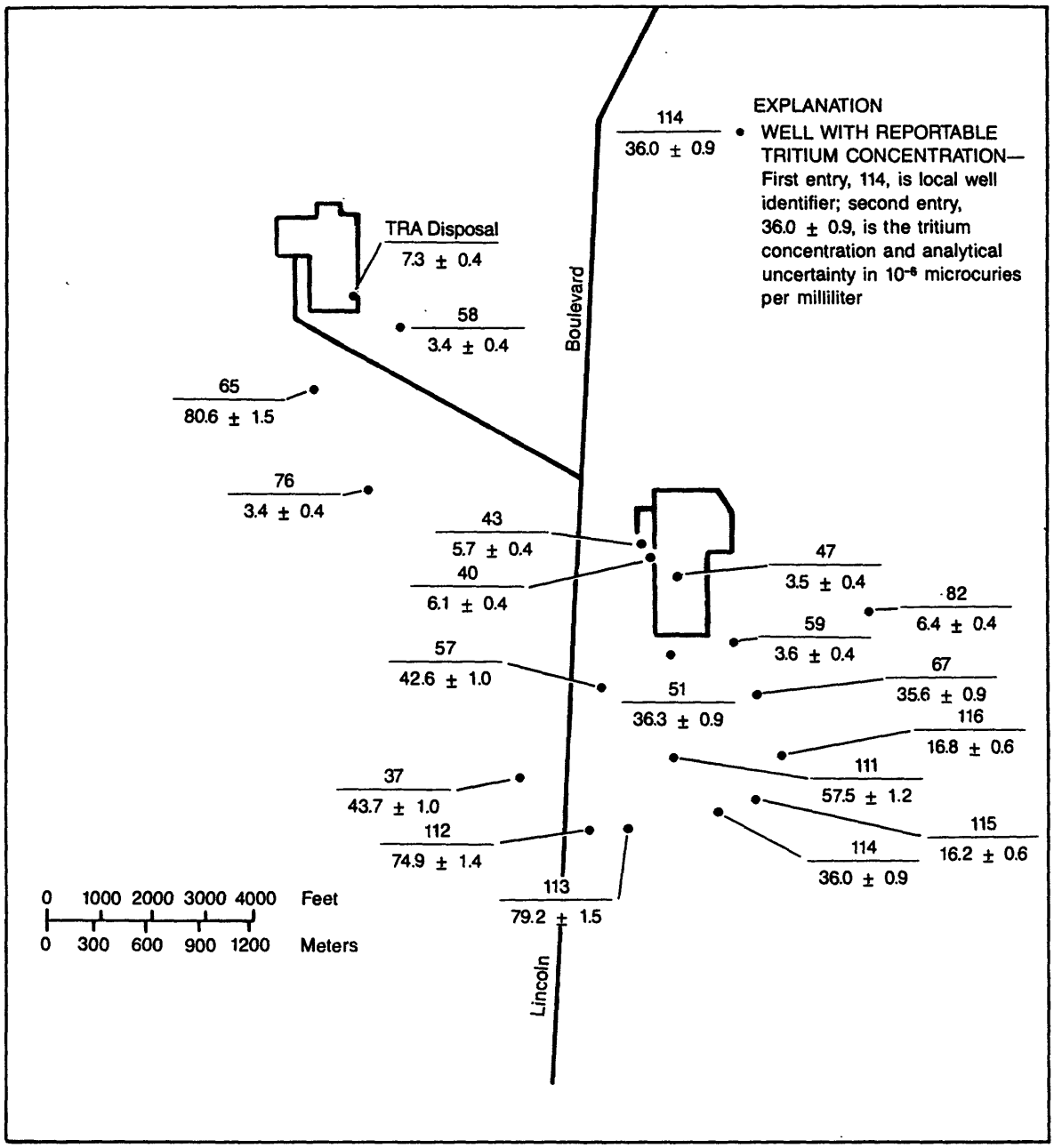

Figure 5.--Locations of wells with tritium concentrations above the reporting level in the TRA-ICPP area, September to November 1987.

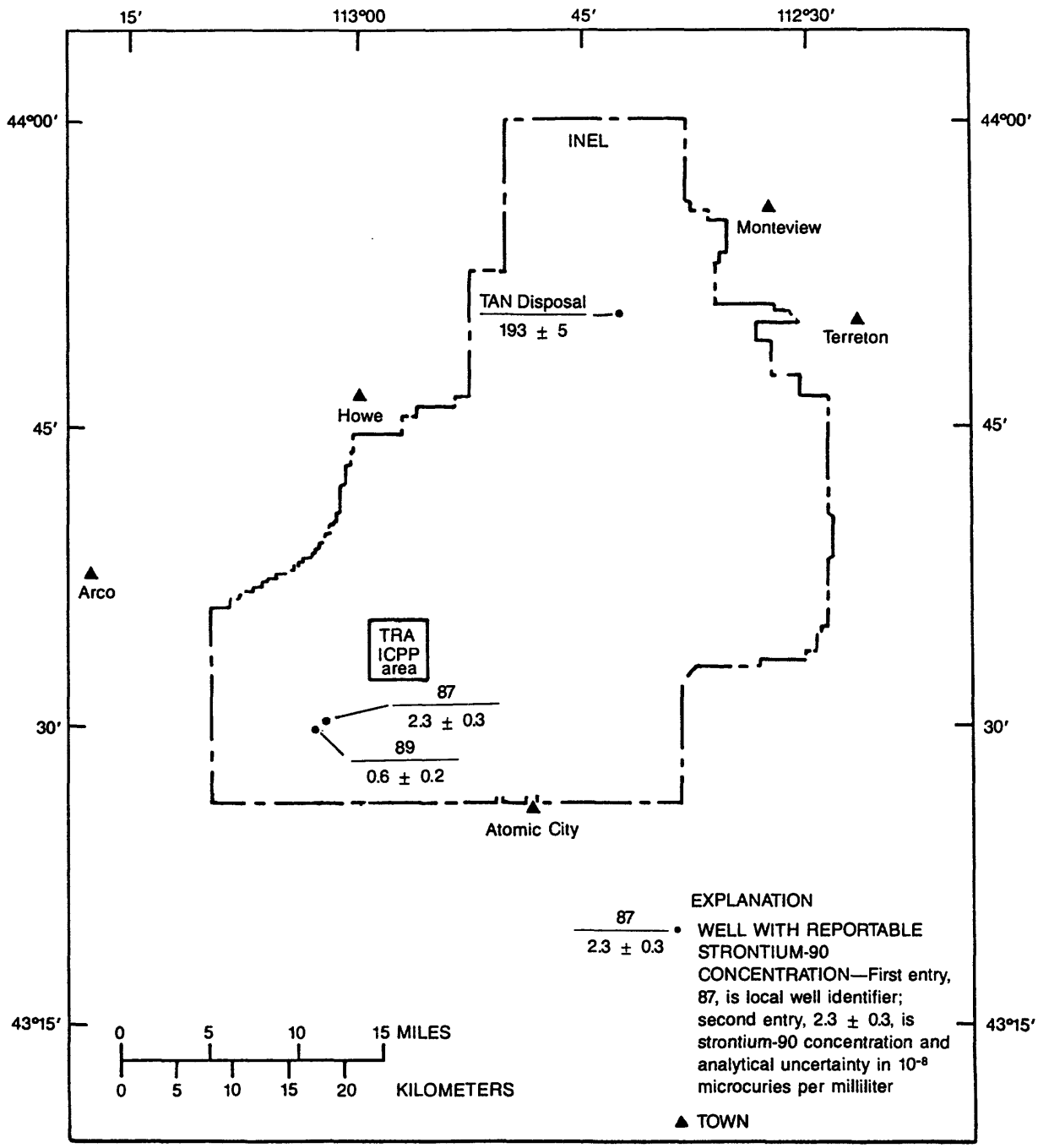

Figure 6.--Locations of wells with strontium-90 concentrations above the reporting level, September to November 1987.

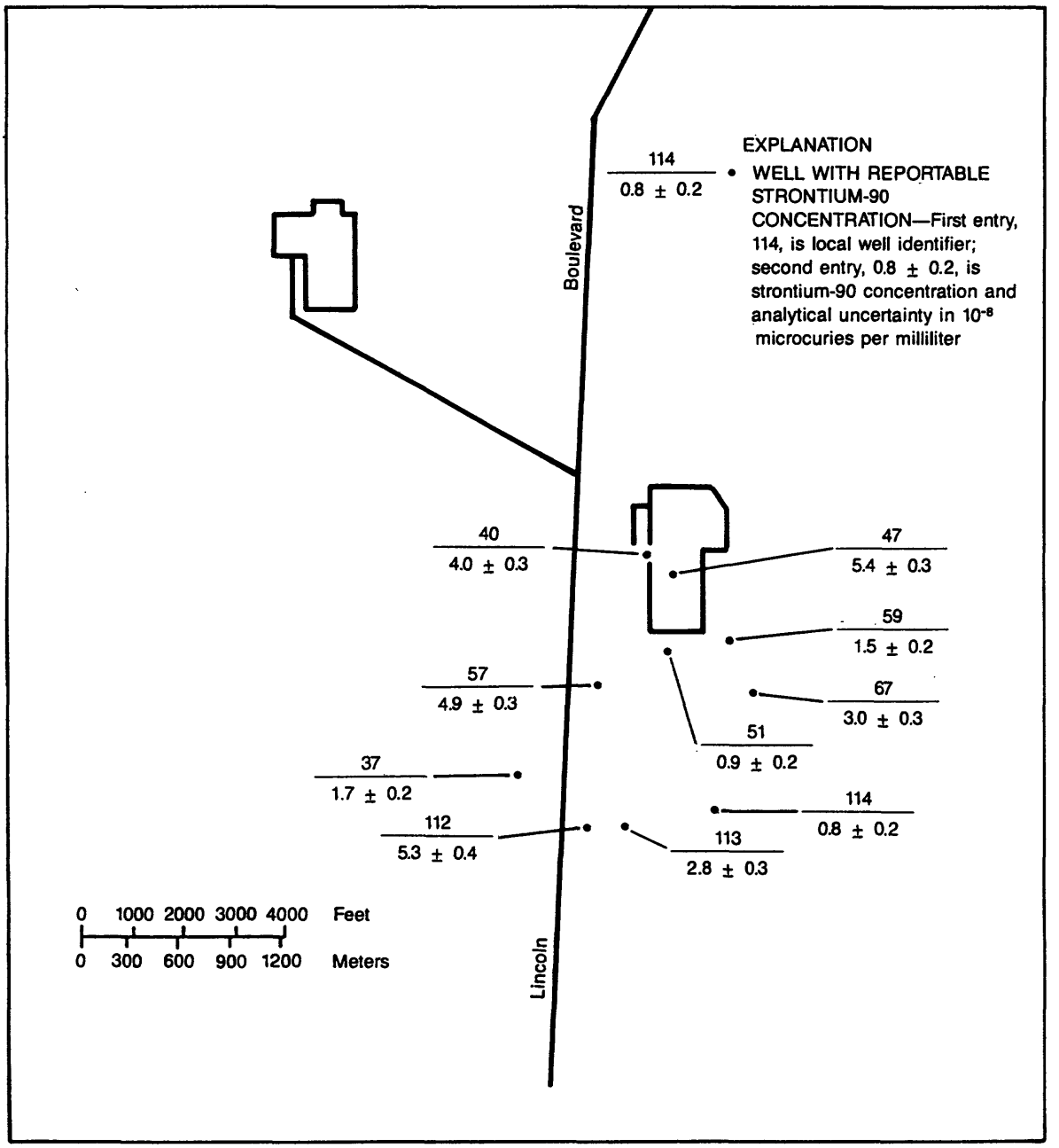

Figure 7.--Locations of wells with strontium-90 concentrations above the reporting level in the TRA-ICPP area, September to November 1987.

Plutonium-238, Plutonium-239, -240 (undivided) and Americium-241

Concentrations of plutonium-238, plutonium-239, -240 (undivided) and americium-241 for samples collected near the RWMC (fig. 1) during the period 1971 to 1974 are tabulated by Barraclough and others (1976, tables III and IV). Lewis and Jensen (1985) summarized the concentrations of plutonium isotopes and americium-241 in ground water at the INEL for the period 1979 to 1981. During the current sampling, water from two wells--CFA-1 and the TAN Disposal well--had concentrations greater than the reporting level for one or more of the three radionuclides. The concentration of plutonium-238 in water collected from CFA-1 on October 15, 1987, was $11 \pm 3X10^{-11}$ μCi/mL (table 3). CFA-1 was resampled on January 5, 1988 and April 19, 1988. The results were $13 \pm 6X10^{-11}$ and $0.14 \pm 0.43X10^{-11}$ μCi/mL, respectively. The cause of the variation between the three samples is unknown, however, the results from both of the later samples are less than the reporting level. The concentrations of plutonium-238, plutonium-239, -240 (undivided) and americium-241 in water collected from the TAN Disposal well on October 28, 1987, were $122 \pm 9X10^{-11}$, $500 \pm 20X10^{-11}$ and $21 \pm 4X10^{-11}$ μCi/mL, respectively (table 3). On January 11, 1988, the well was resampled and the respective concentrations were $18 \pm 5X10^{-11}$, $96 \pm 8X10^{-11}$ and $10 \pm 3X10^{-11}$ μCi/mL. The January 11, 1988, concentrations were smaller than the October 28, 1987, concentrations, however, they are all greater than the reporting level.

Cesium-137, Cobalt-60 and Potassium-40

Gamma spectrometry involves using lithium-drifted germanium detectors to simultaneously determine the concentrations of a variety of radioactive nuclides by the detection of characteristic gamma-emission (Bodnar and Percival, 1982, p. G-2-1). When a gamma spectrometric analysis is requested, RESL currently reports a result for cesium-137, whether or not it is detected, together with any other detectable gamma-emitters. In addition, when analyses for specific gamma-emitters are requested, a result is reported for each.

Early studies of gamma radiation in ground water at the INEL only measured total gamma activity; 725 samples were collected and measured in 1962 (Morris and others, 1963). Morris and others (1964) gave a more detailed description of the distribution of total gamma activity in ground water at the INEL. Studies separating cesium-137 and cobalt-60 from other gamma-emitting isotopes were reported in the 1970's (Robertson and others, 1974; Barraclough and others, 1976). Current studies routinely separate gamma-emitting isotopes.

During September to November 1987, three radionuclides were identified using gamma spectrometry: cesium-137, cobalt-60 and potassium-40 (table 3). Water from the TAN Disposal well contained reportable concentrations of cesium-137 and cobalt-60 on October 28, 1987; $750 \pm 20 \times 10^{-8}$ and $8.9 \pm 0.9 \times 10^{-7}$ μCi/mL, respectively. Subsequent resampling on January 11, 1988, yielded water that contained $306 \pm 12 \times 10^{-8}$ μCi/mL of cesium-137 but cobalt-60 was not detected. The RESL portion of the split samples from wells 88 and 89 contained reportable concentrations of cesium-137; $3.0 \pm 0.9 \times 10^{-8}$ and $2.5 \pm 0.6 \times 10^{-8}$ μCi/mL, respectively. The parts of the split samples that were retained by the U.S. Geological Survey as backup samples, for each of these wells, were analyzed by RESL and cesium-137 was below the reporting level for both. In all instances, potassium-40 concentrations were less than the reporting level--potassium-40 is a naturally occurring radionuclide.

SUMMARY

Sampling for selected radionuclides in ground water at the INEL was conducted by the U.S. Geological Survey during September to November 1987. The sampling was done in cooperation with the U.S. Department of Energy. Water samples from the Snake River Plain aquifer were collected at 80 wells and 1 sample was collected from a discontinuous perched-water zone at the Radioactive Waste Management Complex. The samples were analyzed for tritium, strontium-90, plutonium-238, plutonium-239, -240 (undivided), americium-241 and gamma-emitting isotopes. Gamma emitters identified by gamma spectrometry were cesium-137, cobalt-60 and potassium-40.

A field logbook was maintained to record physical conditions at the well during sample collection and a chain-of-custody record was used to track samples from the time of collection until delivery to the U.S. Department of Energy's Radiological and Environmental Sciences Laboratory for analysis. Methods used to collect water samples and the quality assurance procedures instituted for the sampling program are described in detail.

Tritium concentrations ranged from below the reporting level to $80.6 \pm 1.5 \times 10^{-6}$ μCi/mL. The smallest reportable tritium concentration was $0.9 \pm 0.3 \times 10^{-6}$ μCi/mL. Except for the TAN Disposal well, all reportable concentrations of tritium were either in or to the south of the ICPP and TRA areas.

Strontium-90 concentrations ranged from below the reporting level to $193 \pm 5 \times 10^{-8}$ μCi/mL. The smallest reportable strontium-90 concentration was $0.6 \pm 0.2 \times 10^{-8}$ μCi/mL. Except for the TAN Disposal well and wells 87 and 89, all reportable concentrations of strontium-90 were either in or just south of the ICPP.

The concentration of plutonium-238 in CFA-1 was $11 \pm 3 \times 10^{-11}$ μCi/mL on October 15, 1987. The well was resampled on January 5, 1988 and April 19, 1988. Plutonium-238 concentrations for both later samples were below the reporting level. Water from the TAN Disposal well--which has not been used to dispose of waste water since September 1972--contained $122 \pm 9 \times 10^{-11}$ μCi/mL of plutonium-238, $500 \pm 20 \times 10^{-11}$ μCi/mL of plutonium-239, -240 (undivided) and $21 \pm 4 \times 10^{-11}$ μCi/mL of americium-241 on October 28, 1987; the presence of these radionuclides was verified by resampling and reanalysis.

Cesium-137 and cobalt-60 concentrations in water from the TAN Disposal well were above the reporting level on October 28, 1987; $750 \pm 20 \times 10^{-8}$ and $8.9 \pm 0.9 \times 10^{-7}$ μCi/mL, respectively. Subsequent resampling on January 11, 1988, yielded water that contained $306 \pm 12 \times 10^{-8}$ μCi/mL of cesium-137 but cobalt-60 was not detected. The portions of the split samples from wells 88 and 89, that were analyzed by RESL, contained reportable concentrations of cesium-137, however, when the backup samples from the wells were analyzed

cesium-137 was below the reporting level. In all instances, potassium-40 concentrations were less than the reporting level. Potassium-40 is a naturally occurring radionuclide.

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Table 3

Table 3.--Concentrations of selected radionuclides in ground water

[Analyses by U.S. Department of Energy's RESL (Radiological and Environmental Sciences Laboratory) unless otherwise specified. Analytical results and uncertainties are in μCi/mL (microcuries per milliliter) times the factor shown in the column heading for each radionuclide. One pCi/L (picocurie per liter) equals 10^{9} μCi/mL. Continued on following page.]

Well Identifier	Date Sampled	Tritium (μCi/mL X10^{-6})	Strontium-90 (μCi/mL X10^{-8})	Plutonium-238 (μCi/mL X10^{-11})	Plutonium--239,-240 undivided (μCi/mL X10^{-11})
9	10/05/87	0.1 ± 0.3	--	--	--
37	10/05/87	$^{1}43.7 \pm 1.0$	$^{1}1.7 \pm 0.2$	0 ± 3	0 ± 2
40	10/13/87	$^{1}6.1 \pm 0.4$	$^{1}4.0 \pm 0.3$	3 ± 3	1 ± 2
43	10/05/87	$^{1}5.7 \pm 0.4$	0.11 ± 0.16	1 ± 3	5 ± 3
47	10/26/87	$^{1}3.5 \pm 0.4$	$^{1}5.4 \pm 0.3$	0 ± 2	-0.5 ± 1.5
51	10/13/87	$^{1}36.3 \pm 0.9$	$^{1}0.9 \pm 0.2$	--	--
57	10/09/87	$^{1}42.6 \pm 1.0$	$^{1}4.9 \pm 0.3$	--	--
58	10/08/87	$^{1}3.4 \pm 0.4$	--	--	--
59	10/06/87	$^{1}3.6 \pm 0.4$	$^{1}1.5 \pm 0.2$	--	--
65	10/14/87	$^{1}80.6 \pm 1.5$	-0.11 ± 0.14	--	--
67	10/06/87	$^{1}35.6 \pm 0.9$	$^{1}3.0 \pm 0.3$	--	--
76	10/08/87	$^{1}3.4 \pm 0.4$	0.22 ± 0.17	--	--
82	10/06/87	$^{1}6.4 \pm 0.4$	0.11 ± 0.14	--	--
83	10/14/87	-0.1 ± 0.3	--	--	--
86	10/06/87	$-0.10 \pm .32$	--	--	--
87	09/23/87	0.8 ± 0.3	$^{1}2.3 \pm 0.3$	--	--
	09/30/87	--	$^{1}1.0 \pm 0.2$	--	--
	09/30/87	$^{1}0.9 \pm 0.3$	$^{1}0.70 \pm 0.15$	-1 ± 3	-0.5 ± 1.6

Table 3.--Concentrations of selected radionuclides in ground water-Continued
[Well identifier: see figures 2 and 3 for location of wells; Blank--indicates sample bottle contained deionized water. Remarks: QA--indicates a quality assurance sample; RML indicates the analyses was performed by the Radioactivity Measurements Laboratory operated by EG&G Idaho, Inc. at the INEL.]

Well Identifier	Americium-241 (μCi/mL X10^{-11})	Cesium-137 (μCi/mL X10^{-8})	Cobalt-60 (μCi/mL X10^{-7})	Potassium-40 (μCi/mL X10^{-7})	Remarks
9	--	--	--	--	
37	-2 ± 3	--	--	--	
40	--	6 ± 3	--	--	
43	2 ± 3	0.3 ± 1.6	--	--	
47	-2 ± 3	5 ± 3	--	--	
51	--	--	--	--	
57	--	--	--	--	
58	--	--	--	--	
59	--	--	--	--	
65	--	1 ± 3	--	--	
67	--	--	--	--	
76	--	-1 ± 3	--	--	
82	--	--	--	--	
83	--	--	--	--	
86	--	--	--	--	
87	--	0.8 ± 0.7	--	3.0 ± 1.1	
	--	--	--	--	QA Split-RML
	-8 ± 3	-1.2 ± 1.4	--	--	QA Split-RESL

Table 3.--Concentrations of selected radionuclides in ground water-Continued

Well Identifier	Date Sampled	Tritium (μCi/mL X10^{-6})	Strontium-90 (μCi/mL X10^{-8})	Plutonium-238 (μCi/mL X10^{-11})	Plutonium-239,-240 undivided (μCi/mL X10^{-11})
88	09/22/87	0.0 ± 0.3	-0.09 ± 0.14	-1 ± 3	-0.9 ± 1.6
	09/30/87	--	0.4 ± 0.2	--	--
	09/30/87	0.0 ± 0.3	-0.10 ± 0.16	-1 ± 2	-0.5 ± 1.7
	09/30/87	--	--	--	--
89	09/22/87	-0.3 ± 0.3	0.30 ± 0.17	0 ± 3	0 ± 2
	09/30/87	--	$^{1}0.6 \pm 0.2$	--	--
	09/30/87	-0.12 ± 0.32	0.1 ± 0.2	0 ± 3	2 ± 2
	09/30/87	--	--	--	--
90	09/23/87	$^{1}1.3 \pm 0.3$	0.20 ± 0.16	-3 ± 3	0 ± 2
	09/30/87	--	0.2 ± 0.1	--	--
	09/30/87	$^{1}1.4 \pm 0.3$	-0.02 ± 0.16	1.5 ± 2.8	1 ± 2
92	10/23/87	0.10 ± 0.32	0.09 ± 0.15	1 ± 2	0.4 ± 1.7
97	10/14/87	0.16 ± 0.32	--	--	--
98	10/14/87	0.1 ± 0.3	--	--	--
99	10/14/87	0.0 ± 0.3	--	--	--
100	10/20/87	-0.1 ± 0.3	--	--	--
101	10/20/87	-0.3 ± 0.3	--	--	--
103	09/24/87	-0.2 ± 0.3	--	--	--
104	09/24/87	$^{1}1.5 \pm 0.3$	--	--	--
105	09/28/87	0.0 ± 0.3	--	--	--
	09/28/87	0.0 ± 0.3	--	--	--

Table 3.--Concentrations of selected radionuclides in ground water-Continued

Well Identifier	Americium-241 (μCi/mL X10^{-11})	Cesium-137 (μCi/mL X10^{-8})	Cobalt-60 (μCi/mL X10^{-7})	Potassium-40 (μCi/mL X10^{-7})	Remarks
88	3 ± 3	0 ± 3	--	--	
	--	--	--	--	QA Split-RML
	3 ± 3	$^{1}3.0 \pm 0.9$	--	5 ± 2	QA Split-RESL
	--	-2.3 ± 1.4	--	--	QA Split-Recount
89	1 ± 4	0.0 ± 0.3	--	--	
	--	--	--	--	QA Split-RML
	3 ± 3	$^{1}2.5 \pm 0.6$	--	--	QA Split-RESL
	--	1.1 ± 0.7	--	--	QA Split-Recount
90	1.1 ± 3.3	2 ± 4	--	--	
	--	--	--	--	QA Split-RML
	-3 ± 2	0.7 ± 0.5	--	--	QA Split-RESL
92	5 ± 3	1 ± 4	--	--	Thief Sample
97	--	--	--	--	
98	--	--	--	--	
99	--	--	--	--	
100	--	--	--	--	
101	--	--	--	--	
103	--	--	--	--	
104	--	--	--	--	
105	--	--	--	--	
	--	--	--	--	QA Replicate

Table 3.--Concentrations of selected radionuclides in ground water-Continued

Well Identifier	Date Sampled	Tritium (μCi/mL X10^{-6})	Strontium-90 (μCi/mL X10^{-8})	Plutonium-238 (μCi/mL X10^{-11})	Plutonium-239,-240 undivided (μCi/mL X10^{-11})
106	10/06/87	[1]2.2±0.4	--	--	--
	10/06/87	[1]2.4±0.4	--	--	--
107	10/09/87	-0.2±0.3	--	--	--
108	09/28/87	0.17±0.32	--	--	--
109	10/05/87	-0.2±0.3	--	--	--
110	10/09/87	0.0±0.3	--	--	--
111	09/25/87	[1]57.5±1.2	0.23±0.14	--	--
112	09/25/87	[1]74.9±1.4	[1]5.3±0.4	--	--
113	10/02/87	[1]79.2±1.5	[1]2.8±0.3	--	--
114	10/09/87	[1]36.0±0.9	[1]0.8±0.2	--	--
115	10/09/87	[1]16.2±0.6	0.16±0.14	--	--
116	10/28/87	[1]16.8±0.6	0.01±0.14	--	--
117	10/19/87	0.0±0.3	0.01±0.14	-5±2	0±2
	10/19/87	-0.2±0.3	0.07±0.14	-1±3	0±2
119	11/06/87	0.3±0.3	0.00±0.15	1.4±2.5	-0.9±1.5
120	11/18/87	0.0±0.3	-0.12±0.14	0±2	1±2
ANP-6	10/28/87	-0.2±0.3	0.13±0.16	2±2	1.3±1.8
ANP-8	10/25/87	0.0±0.3	-0.02±0.16	2±3	-1±2
ARA-2	10/28/87	0.0±0.3	0.1±0.2	5±3	2±2
ARA-3	10/28/87	-0.2±0.3	0.1±0.2	1±2	-1.4±1.7
Atomic City	10/29/87	0.1±0.3	--	--	--
Badging Facility	10/24/87	-0.2±0.3	0.22±0.16	1±3	-0.5±1.6

Table 3.--Concentrations of selected radionuclides in ground water-Continued

Well Identifier	Americium-241 (μCi/mL X10^{-11})	Cesium-137 (μCi/mL X10^{-8})	Cobalt-60 (μCi/mL X10^{-7})	Potassium-40 (μCi/mL X10^{-7})	Remarks
106	--	--	--	--	
	--	--	--	--	QA Replicate
107	--	--	--	--	
108	--	--	--	--	
109	--	--	--	--	
110	--	--	--	--	
111	--	--	--	--	
112	--	--	--	--	
113	--	--	--	--	
114	--	--	--	--	
115	--	--	--	--	
116	--	--	--	--	
117	6 ± 3	-1.4 ± 3.6	--	--	
	1.5 ± 3.2	-0.6 ± 1.4	--	--	QA Replicate
119	-3 ± 3	-2 ± 4	--	--	
120	1.1 ± 3.4	1.3 ± 2.6	--	--	
ANP-6	1 ± 3	-1.2 ± 2.2	--	--	
ANP-8	4 ± 3	0 ± 3	--	--	
ARA-2	3 ± 3	4 ± 4	--	--	
ARA-3	7 ± 3	-1.1 ± 3.2	--	--	
Atomic City	--	--	--	--	
Badging Facility	4 ± 3	2 ± 3	--	--	

Table 3.--Concentrations of selected radionuclides in ground water-Continued

Well Identifier	Date Sampled	Tritium (μCi/mL X10^{-6})	Strontium-90 (μCi/mL X10^{-8})	Plutonium-238 (μCi/mL X10^{-11})	Plutonium-239,-240 undivided (μCi/mL X10^{-11})
CFA-1	10/15/87	[1]32.1±0.8	0.13±0.14	[1]11±3	2±2
	01/05/88	[1]32.0±0.8	--	13±6	0±3
	04/19/88	--	--	0.14±0.43	0.12±0.26
CFA-2	10/14/87	[1]21.1±0.7	0.04±0.14	-3±2	-0.9±1.6
EBR-I	10/14/87	-0.10±0.32	0.12±0.15	-1.6±4.1	1±3
EBR-II-1	10/15/87	-0.1±0.3	0.02±0.14	-6±2	-1.4±1.6
EBR-II-2	10/15/87	-0.15±0.32	0.20±0.15	-2±2	-0.5±1.6
Fire Station 2	11/03/87	-0.11±0.32	0.20±0.15	1±2	-0.1±1.6
Highway 3	10/29/87	0.0±0.3	--	--	--
ICPP-1	10/22/87	0.4±0.3	0.22±0.15	0±2	-0.9±1.6
ICPP-2	10/22/87	0.0±0.3	0.10±0.13	-1.4±1.6	-1.4±1.6
ICPP-4	10/22/87	0.0±0.3	0.02±0.14	4±3	-1±2
IET-1	10/27/87	0.0±0.3	0.06±0.15	0±3	1±2
INEL-1WS	10/26/87	-0.2±0.3	--	--	--
LOFT-1	10/25/87	0.0±0.3	-0.04±0.17	-1±3	0.4±1.7
LOFT-2	10/26/87	-0.12±0.32	0.16±0.15	0±3	-1.4±1.7
MTR Test	10/07/87	-0.1±0.3	--	--	--
NPR Test	10/15/87	0.1±0.3	0.19±0.16	2±3	3±2
	10/15/87	-0.1±0.3	0.03±0.14	0±3	-1.8±1.7
NRF-1	10/29/87	0.1±0.3	0.2±0.2	7±3	0±2
NRF-2	10/29/87	0.1±0.3	0.11±0.15	0±2	-1±2
NRF-3	10/29/87	-0.15±0.32	0.06±0.15	1.0±1.9	-1±2

Table 3.--Concentrations of selected radionuclides in ground water-Continued

Well Identifier	Americium-241 (μCi/mL X10^{-11})	Cesium-137 (μCi/mL X10^{-8})	Cobalt-60 (μCi/mL X10^{-7})	Potassium-40 (μCi/mL X10^{-7})	Remarks
CFA-1	-2 ± 3	-1 ± 4	--	--	
	5 ± 4	--	--	--	Resampled
	0.7 ± 0.4	--	--	--	Resampled
CFA-2	-3 ± 3	6 ± 3	--	--	
EBR-I	-2 ± 5	1 ± 4	--	--	
EBR-II-1	2 ± 3	-1.4 ± 3.7	--	--	
EBR-II-2	-5 ± 3	4 ± 3	--	--	
Fire Station 2	3 ± 3	-6 ± 4	--	--	
Highway 3	--	--	--	--	
ICPP-1	1 ± 3	1 ± 3	--	--	
ICPP-2	-4 ± 2	-2 ± 3	--	--	
ICPP-4	3 ± 3	1 ± 3	--	--	
IET-1	1.2 ± 3.0	0.4 ± 1.5	--	--	
INEL-1WS	--	--	--	--	
LOFT-1	3 ± 3	1.2 ± 2.0	--	--	
LOFT-2	-2 ± 4	4 ± 3	--	--	
MTR Test	--	--	--	--	
NPR Test	-4 ± 3	3 ± 4	--	--	
	1 ± 3	-1.4 ± 3.9	--	--	QA Replicate
NRF-1	2 ± 3	0 ± 3	--	--	
NRF-2	4 ± 3	-6 ± 3	--	--	
NRF-3	5 ± 3	-2 ± 4	--	--	

Table 3.--Concentrations of selected radionuclides in ground water-Continued

Well Identifier	Date Sampled	Tritium (μCi/mL X10^{-6})	Strontium-90 (μCi/mL X10^{-8})	Plutonium-238 (μCi/mL X10^{-11})	Plutonium-239,-240 undivided (μCi/mL X10^{-11})
OMRE	10/30/87	[1]2.7±0.4	0.29±0.15	-1±2	0±2
P&W-2	10/16/87	-0.10±0.32	--	--	--
	10/23/87	-0.2±0.3	0.00±0.15	1±3	0±2
RWMC	09/23/87	[1]1.5±0.3	0.24±0.16	--	--
	09/30/87	--	-0.05±0.05	--	--
	09/30/87	[1]1.5±0.3	-0.01±0.14	3±3	0.5±1.7
	10/14/87	[1]1.9±0.4	0.06±0.15	0±3	-4±3
Site 4	11/03/87	0.3±0.3	0.09±0.15	0±3	-0.4±1.7
Site 19	10/07/87	0.1±0.3	--	--	--
SPERT-1	10/24/87	-0.1±0.3	-0.18±0.13	-2±3	0±2
SPERT-2	10/24/87	-0.3±0.3	0.00±0.16	0±3	0.7±1.7
TAN-1	10/23/87	-0.2±0.3	-0.16±0.15	-1±2	-1.4±1.7
TAN-2	10/23/87	-0.1±0.3	-0.10±0.15	2±3	-1.0±1.7
TAN Disposal	10/28/87	[1]43.2±1.0	[1]193±5	[1]122±9	[1]500±20
	01/11/88	[1]41.3±1.0	[1]95±3	[1]18±5	[1]96±8
TRA-1	10/30/87	-0.3±0.3	0.2±0.2	-1±2	-1.0±1.8
TRA-3	10/27/87	0.1±0.3	0.00±0.15	0±3	-1±2
TRA-4	10/30/87	0.0±0.3	0.22±0.15	0±2	0.0±1.6
TRA Disposal	10/28/87	[1]7.3±0.4	--	--	--
Blank	10/07/87	[1]32.1±0.8	-0.11±0.14	-1.1±2.0	0±2
Blank	10/15/87	[1]30.6±0.8	0.06±0.15	5±3	0±2

[1]Indicates a reportable value that is equal to or greater than 3s.

Table 3.--Concentrations of selected radionuclides in ground water-Continued

Well Identifier	Americium-241 (μCi/mL X10^{-11})	Cesium-137 (μCi/mL X10^{-8})	Cobalt-60 (μCi/mL X10^{-7})	Potassium-40 (μCi/mL X10^{-7})	Remarks
OMRE	5 ± 3	-2 ± 2	--	--	
P&W-2	--	--	--	--	
	3 ± 3	0 ± 3	--	--	
RWMC	--	0.6 ± 0.7	--	--	
	--	--	--	--	QA Split-RML
	1.1 ± 3.0	-2.8 ± 1.4	--	--	QA Split-RESL
	-2 ± 5	-3 ± 4	--	--	
Site 4	1 ± 3	0 ± 3	--	--	
Site 19	--	--	--	--	
SPERT-1	5 ± 3	0 ± 3	--	--	
SPERT-2	4 ± 3	0 ± 4	--	--	
TAN-1	6 ± 3	1.1 ± 2.8	--	--	
TAN-2	-1 ± 2	7 ± 3	--	--	
TAN Disposal	$^{1}21 \pm 4$	$^{1}750 \pm 20$	$^{1}8.9 \pm 0.9$	--	
	$^{1}10 \pm 3$	$^{1}306 \pm 12$	--	--	Resampled
TRA-1	5 ± 3	2 ± 4	--	--	
TRA-3	-1.0 ± 2.8	2 ± 4	--	--	
TRA-4	-3 ± 3	0.6 ± 1.4	--	--	
TRA Disposal	--	3 ± 4	--	--	
Blank	8 ± 3	-1.6 ± 3.5	--	--	QA-Deionized Blank
Blank	2 ± 3	5 ± 3	--	--	QA Deionized Blank