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SURVEILLANCE OF SITE A AND PLOT M

Report for 1991

by

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Environment and Waste Management Programs

May 1992

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ABSTRACT

The results of the environmental surveillance program conducted at Site A/Plot M in the Palos Forest Preserve area for CY 1991 are presented. The surveillance program is the ongoing remedial action that resulted from the 1976-1978 radiological characterization of the site. That study determined that very low levels of hydrogen-3 (as tritiated water) had migrated from the burial ground and were present in two nearby hand-pumped picnic wells. The current program consists of sample collection and analysis of air, surface and subsurface water, and bottom sediment. The results of the analyses are used to 1) determine the migration pathway of water from the burial ground (Plot M) to the hand-pumped picnic wells, 2) establish if buried radionuclides other than hydrogen-3 have migrated, and 3) generally characterize the radiological environment of the area. Hydrogen-3 in the Red Gate Woods picnic wells was still detected this year, but the average and maximum concentrations were significantly less than found earlier. Tritiated water continues to be detected in a number of wells, boreholes, dolomite holes, and a surface stream. For many years it was the only radionuclide found to have migrated in measurable quantities. Analyses since 1984 have indicated the presence of low levels of strontium-90 in water from a number of boreholes next to Plot M. The available data does not allow a firm conclusion as to whether the presence of this nuclide represents recent migration or movement that may have occurred before Plot M was capped. The results of the surveillance program continue to indicate that the radioactivity remaining at Site A/Plot M does not endanger the health or safety of the public visiting the site or those living in the vicinity.

1.0 INTRODUCTION AND MONITORING

1.1 Site History

This report presents and discusses the surveillance data obtained during CY 1991. The surveillance program is the ongoing remedial action that resulted from the 1976-1978 radiological characterization of the former site of Argonne National Laboratory and its predecessor, the University of Chicago's Metallurgical Laboratory, which was part of the World War II Manhattan Engineer District Project, in the Palos Park Forest Preserve southwest of Chicago, IL. The Laboratory used two locations in the Forest Preserve: Site A, a 19-acre area that contained experimental laboratories and nuclear reactor facilities; and Plot M, a 150 ft x 140 ft area used for the burial of radioactive waste. These locations are shown in Figures 1.1 and 1.2. To assist in understanding this report, reference should be made to the previous comprehensive reports on this subject,^{1,2} which provide greater detail and illustrations on sampling locations and descriptive material and give the results through 1981, and to the annual reports for 1982,³ 1983,⁴ 1984,⁵ 1985,⁶ 1986,⁷ 1987,⁸ 1988,⁹ 1989,¹⁰ and 1990.¹¹ Earlier data will not be repeated in this report, but reference will be made to some of the results.

Operations at Site A began in 1943 and ceased in 1954. Among the research programs carried out at Site A were reactor physics studies, fission product separations, tritium recovery from irradiated lithium, and studies of the metabolism of radionuclides in laboratory animals. Radioactive waste and radioactively-contaminated laboratory articles from these studies were buried in Plot M. At the termination of the programs, the reactor fuel and heavy water, used for neutron moderation and reactor cooling, were removed and shipped to Oak Ridge National Laboratory. The biological shield for the CP-3 reactor, together with various pipes, valves, and building debris, were buried in place in 1956.

Burial of radioactive waste at Plot M began in 1943 or 1944 and was discontinued in 1949. Waste was buried in six-foot deep trenches and covered with soil until 1948, after which, burial took place in steel bins.

Figure 1.1 Location of Palos Forest Preserve on Chicago-Area Map

Figure 1.2 Palos Forest Preserve Showing Location of Site A/Plot M Dolomite Holes and Picnic Wells

The steel bins were removed in 1949 and sent to Oak Ridge National Laboratory for disposal, but the waste buried in trenches was allowed to remain in place. Both the Site A and Plot M areas were decommissioned in 1956. Concrete sidewalls, eight feet deep, were poured around the perimeter of the burial area and a one-foot thick reinforced concrete slab was poured over the top. The concrete slab was covered with soil and seeded with grass.

In 1973, elevated levels of hydrogen-3 (as tritiated water) were detected in two nearby hand-pumped picnic wells (#5167 and #5159) and the hydrogen-3 was found to be migrating from the burial plot into the surrounding soil and aquifers. As a result, a radiological survey of the entire Palos Park site was conducted with special emphasis on the Site A and Plot M areas.¹

The terminology used in previous reports is continued. A hole drilled and completed into the glacial till is called a borehole. The soil samples obtained from the borehole are called soil cores. Some boreholes have been cased and screened to form monitoring wells. Water from such wells is called borehole water. Test wells drilled into the dolomite bedrock are called dolomite holes or deep holes. Water from such wells is called dolomite water. The hand-pumped picnic wells, which are completed into or close to the dolomite bedrock, are called wells or picnic wells. They are identified by a location name or well number. Except for well #5160, these were in existence before this radiological and hydrological study of the area was begun.

The results of radioactivity measurements are expressed in this report in terms of picocuries per liter (pCi/L) and nanocuries per liter (nCi/L) for water, picocuries per cubic meter (pCi/m³) for air, and picocuries per gram (pCi/g) of the oven-dried (110°C) weight for sediment samples. Radiation effective dose equivalent calculations are reported in units of millirem (mrem) or millirem per year (mrem/y). The use of the term dose throughout this report means effective dose equivalent. Other abbreviations of units are defined in the text.

1.2 Site Characteristics

Geologically, Plot M is constructed on a moraine upland which is dissected by two valleys, the Des Plaines River valley to the north and the Calumet Sag valley to the south. The upland is characterized by rolling terrain with poorly developed drainage. Streams are intermittent and drain internally or flow to one of the valleys. The area is underlain by glacial till or drift, dolomite, and other sedimentary rocks. The uppermost bedrock is Silurian dolomite, into which both the picnic wells and some of the monitoring wells are placed, as described in the text. The dolomite bedrock is about 200 feet thick. The overlying glacial till has a thickness that ranges from 165 feet at Site A to zero at the Des Plaines River and Calumet Sag Canal, and some of the monitoring wells terminate in this layer. The depth to bedrock at Plot M is about 130 feet. Hydrologically, the surface water consists of ponds and intermittent streams. When there is sufficient water, the intermittent stream that drains Plot M flows from the highest point near Site A, past Plot M, then continues near the Red Gate Woods well (Fig. 1.2) and discharges into the Illinois and Michigan Canal. The groundwater in the glacial till and dolomite forms two distinct flow systems. The flow in the drift is controlled principally by topography. The flow in the dolomite, which is recharged by groundwater from the glacial till, is controlled by two discharge areas, the Des Plaines River to the north and the Calumet Sag Canal to the south. Water usage in the area is confined to the hand-pumped picnic wells. These are open to the dolomite and are principally used in the warmer seasons.

The climate is that of the upper Mississippi Valley, as moderated by Lake Michigan, and is characterized by cold winters and hot summers. Precipitation averages about 33 inches annually. The largest rainfalls occur between April and September. The average monthly temperature ranges from 21°F in January to 73°F in July. Approximately 7.9 million people reside within 50 miles of the site; the population within a five-mile radius is about 150,000. The only portion of the Forest Preserve in the immediate area of Plot M and Site A that is developed for public use is the Red Gate Woods picnic area (Fig. 1.2), although small numbers of individuals use the more remote areas of the Preserve.

2.0 SUMMARY

The results of the ongoing environmental monitoring and surveillance program at the Palos Park site for CY 1991 are presented in this report. Sample collection and analyses for radioactive and nonradioactive substances were conducted on air, surface and subsurface water, and bottom sediment. Water-vapor samples were collected over the streambed at two locations, one upstream and one downstream of the waste burial Plot M, and analyzed for tritium. Above ambient tritium concentrations were found downstream of the Plot and are attributed to tritiated water leaching from the Plot and evaporating from the stream and transpiration from plants. The maximum dose from tritium in air to a hypothetical individual who spends all of his time at the downstream location would be 0.003 mrem/y, or 0.003% of the applicable U. S. Department of Energy (DOE) Radiation Protection Standard of 100 mrem/y for the general public.¹³

Surface water samples collected from the stream that flows around Plot M showed the same tritiated water concentration pattern seen in the past. Concentrations were at the ambient level (< 0.2 nCi/L) upstream of the Plot, increased to 90-230 nCi/L at the seep adjacent to the Plot, then decreased to 10-20 nCi/L further downstream. Other radiochemical analyses of water and stream-bed sediment collected above and below Plot M indicated that there are slightly elevated concentrations of strontium-90 and uranium in water and cesium-137 and plutonium-239 in sediment downstream from Plot M. For both the water and sediment samples, the upstream concentrations were comparable to ambient or fallout levels.

The tritiated water concentrations in the borehole and dolomite hole water follow a pattern consistent with that observed in the past. The tritium concentration was highest in those boreholes nearest Plot M and downgradient of the Plot. Water from ten of 18 boreholes analyzed for strontium-90 contained concentrations greater than the detection limit of 0.25 pCi/L. The elevated strontium-90 levels (up to 10.7 pCi/L) found in some boreholes are probably from the Plot, since concentrations above 0.25 pCi/L have not been observed in the groundwater due to atmospheric fallout from previous nuclear weapons testing, and no other source is known.

Strontium-90 is a relatively mobile radionuclide and its presence in the borehole water is not unexpected and is probably due to migration that occurred before the Plot was capped. The strontium-90 results are consistent with those measured in the past.

Sampling of the forest preserve picnic wells shown in Figure 1.2 continued. The maximum and average concentrations for the last few years for the Red Gate Woods North well (#5160) and the Red Gate Woods well (#5167) are presented in Table 2.1 and illustrated in Figure 2.1. The maximum concentration (0.21 nCi/L) and the annual average (0.05 nCi/L) in the Red Gate Woods well (#5167) are significantly less than in earlier years. The average annual tritium concentration in the well opposite Red Gate Woods (#5159) was 30% higher than the 1990 value and due to low precipitation during most of the summer and lack of dilution. The maximum and minimum concentrations of #5159 were 2.3 nCi/L and 0.6 nCi/L, respectively. The other wells were all less than 0.2 nCi/L. The previous pattern of high tritium concentrations in the winter and low concentrations (less than the detection limit of 0.2 nCi/L) in the summer is not readily apparent. In the calculation of annual averages, all data as measured were retained in the data base and used to compute the average.

If water equal to the Red Gate Woods North well (#5160) average concentration of 0.35 nCi/L were the sole source of water for an individual, the annual dose from tritium would be 0.016 mrem using the DOE dose conversion factor. Although not applicable, compared to the U. S. Environmental Protection Agency (EPA) drinking water limit,¹² this concentration is about 2% of the annual limit of 20 nCi/L. Consumption of one liter of this water would produce a dose of 2.2×10^{-5} mrem. Table 4.3 provides a relative comparison of this calculated dose to natural or accepted sources of radiation.

The results of this program show that the radioactivity remaining at Site A, Plot M, and the Red Gate Woods area does not endanger the health or safety of the public visiting the site or those living in the vicinity. The potential radiation doses are very low relative to the relevant standards.

TABLE 2.1

Annual Maximum and Average Hydrogen-3 Concentrations
in the Red Gate Woods Wells
(Concentrations in nCi/L)

Year	5167 (Original Well)		5160 (Replacement Well)*	
	Maximum	Annual Average	Maximum	Annual Average
1982	9.2	4.8		
1983	3.0	2.2		
1984	2.7	1.2		
1985	2.5	1.0		
1986	3.4	1.3		
1987	3.3	1.6		
1988	0.48	0.18	0.30	0.19
1989	0.46	0.30	0.41	0.27
1990	0.25	0.12	0.52	0.22
1991	0.21	0.05	0.80	0.35

*The replacement well (#5160) was installed in July 1988.

Figure 2.1 Trends in Tritium Concentrations in Red Gate Woods Well (#5167). (Concentrations in nCi/L)

3.0 MONITORING PROGRAM

The program is designed to monitor the elevated hydrogen-3 (as tritiated water) concentrations in some of the picnic wells in the Forest Preserve, determine the migration pathway of water from the burial ground to the wells, establish if other buried radionuclides or waste constituents have migrated, and characterize the radiological and non-radiological pollutant environment of the area. This is accomplished by analyses of water vapor samples and of water from wells, deep holes, boreholes, and surface streams in the area. Samples are collected from biweekly to annually, depending on past results and proximity to Plot M. During CY 1991, 382 samples were collected and 509 radiochemical analyses were performed. For the most part, individual results are presented in the tables, and compared to control, off-site, or upstream results. Where applicable, results are compared to the U. S. Department of Energy Radiation Protection Standard of 100 mrem/y.¹³ The Site A/Plot M program follows the guidance for monitoring at DOE facilities.¹⁴ Although it is recognized that Site A/Plot M is not a DOE facility, the same monitoring principles are applicable to this site.

The uncertainties associated with individual concentrations given in the tables are the statistical counting errors at the 95% confidence level. A few tables of tritium data do not contain these uncertainties. In such cases, the following uncertainties apply:

<u>Concentration (nCi/L)</u>	<u>Uncertainty (% of Conc.)</u>
0.2-1.0	25-5%
1-10	5-1%
> 10	1%

3.1 Air

Water vapor samples were collected over the surface of the stream next to Plot M, since this stream drains tritiated water leached from the Plot, and were analyzed for tritium to estimate the potential exposure from the atmospheric pathway. Samples were collected upstream and downstream of Plot

M and the results are given in Table 3.1. The concentrations were higher below Plot M than above, where the levels were similar to ambient concentrations of tritium in air of 0.20 pCi/m^3 .¹⁵ The spring and fall averages are calculated using the actual measured values even though in many cases, the results are below the detection limit.

Although water was not flowing in the stream during some of the sampling periods, above-ambient tritiated water vapor concentrations were observed below the Plot. As was also observed last year, the downstream air concentrations in the fall were lower than the spring values and are due to generally lower tritium stream concentrations in the fall. The dose to a hypothetical individual who breathed air continuously for one year at the maximum concentration of 5.2 pCi/m^3 would be 0.003 mrem or 0.003% of the applicable DOE environmental dose limit of 100 mrem/y . This dose was calculated using the methodology specified in the DOE Order¹³ for determining radiation exposures to members of the public in uncontrolled areas. The total quantity of a radionuclide inhaled, in microcuries (μCi), is obtained by multiplying the air concentration by the general public breathing rate of $8400 \text{ m}^3/\text{y}$.¹⁶ This annual intake is then multiplied by the 50-year Committed Effective Dose Equivalent factor (CEDE) to obtain the dose.¹⁷ The CEDE for tritiated water vapor is $6.3 \times 10^{-5} \text{ rem}/\mu\text{Ci}$ (rem per microcurie).

3.2 Surface Water

Five sets of samples were collected from the stream that flows around Plot M. The sampling locations are shown in Figure 3.1. The samples were analyzed for tritiated water and the results are in Table 3.2. The same concentration pattern in the water flowing around Plot M was observed this year as in the past. Concentrations were low upstream of the Plot, increased as the stream flowed past the Plot, where it received tritiated water that leached out of the burial site, then decreased downstream due to dilution.

Using the methodology prescribed in the DOE guidance,¹³ the committed effective dose equivalent for consumption of water can be calculated. The

TABLE 3.1

Concentrations of Tritiated Water Vapor Above the
Streambed Adjacent to Plot M, 1991
(Concentrations in pCi/m³)

Sampling Period	Location #1* (Upstream)	Location #9* (Downstream)
March 25 to March 28	< 0.2	0.4 ± 0.8
April 1 to April 4	0.2 ± 0.4	1.5 ± 0.5
April 8 to April 11	< 0.2	2.0 ± 0.6
April 15 to April 18	< 0.2	2.9 ± 0.6
April 22 to April 25	< 0.2	5.2 ± 0.5
Spring Average	0.2 ± 0.4	2.4 ± 1.6
September 23 to September 27	0.7 ± 0.6	2.8 ± 0.6
September 30 to October 3	0.3 ± 1.0	2.5 ± 1.0
October 7 to October 10	0.5 ± 0.6	2.1 ± 0.6
October 14 to October 17	0.3 ± 0.4	0.4 ± 0.4
October 21 to October 24	0.2 ± 0.9	0.7 ± 0.9
Fall Average	0.4 ± 0.2	1.7 ± 1.0

*See Figure 3.1

Figure 3.1 Surface Water Sampling Locations Near Plot M

TABLE 3.2
Tritiated Water Content of Stream Next to Plot M, 1991
(Concentrations in nCi/L)

Location Number*	Date Collected				
	February 6	March 20	May 6	October 25	November 15
1	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
2	0.3 ± 0.1	0.5 ± 0.1	0.5 ± 0.1	0.5 ± 0.1	< 0.2
3	28.2 ± 0.3	28.6 ± 0.3	39.2 ± 0.4	24.4 ± 0.3	2.8 ± 0.1
4	31.4 ± 0.3	28.7 ± 0.3	35.1 ± 0.3	19.0 ± 0.3	3.0 ± 0.1
5	33.4 ± 0.3	26.5 ± 0.3	33.6 ± 0.3	13.1 ± 0.2	3.6 ± 0.1
6 (Seep)	227.8 ± 0.9	230.7 ± 0.9	225.3 ± 0.9	-	91.3 ± 0.5
7	45.3 ± 0.4	27.3 ± 0.3	35.5 ± 0.3	12.3 ± 0.2	5.7 ± 0.1
8	12.2 ± 0.2	32.6 ± 0.3	28.1 ± 0.3	4.1 ± 0.1	1.4 ± 0.1
9	38.2 ± 0.4	27.4 ± 0.3	33.1 ± 0.3	10.4 ± 0.2	6.3 ± 0.1
10	35.4 ± 0.3	21.4 ± 0.3	26.0 ± 0.3	7.3 ± 0.2	4.4 ± 0.1
11	28.1 ± 0.3	14.1 ± 0.2	17.9 ± 0.2	5.3 ± 0.2	4.8 ± 0.1
Outfall**	0.2 ± 0.1	< 0.2	3.5 ± 0.1	< 0.2	0.9 ± 0.1

*See Figure 3.1

**I&M Canal

total quantity of an ingested radionuclide is obtained by multiplying the water concentration by the general public water ingestion rate of 730 L/y.¹⁶ This annual intake is then multiplied by the 50-year Committed Effective Dose Equivalent factor (CEDE).¹⁷ The CEDE for tritium in water is 6.3×10^{-5} rem/ μ Ci. If a hypothetical individual used water with the same tritium concentration as found in the seep (Location #6) as his sole source of water, the annual dose based on the maximum 1991 concentration of 231 nCi/L would be about 11 mrem/y and the dose based on the annual average seep concentration of 194 nCi/L would be 9 mrem/y. The DOE dose limit to the public is 100 mrem/y. Using the same calculations for concentrations at Location #9, the maximum concentration of 38.2 nCi/L would produce 1.8 mrem/y and the 1991 average concentration of 23.1 nCi/L would give a dose of 1.1 mrem/y. Consumption of one liter of water with the same annual average concentration as at Location #9 would produce a dose of 0.001 mrem/y.

Large volume (20 liter) water samples were collected on May 6, 1991, and November 15, 1991, from this stream above Plot M at Location #1 and from below Plot M at Location #9. These samples were analyzed for the very low concentrations of other radionuclides that may be present to determine if any detectable amounts had migrated out of Plot M and entered this surface stream. The results are given in Table 3.3. In addition to hydrogen-3, there are slightly elevated concentrations of strontium-90 and uranium at the downstream location. Strontium-90 has been found in the past in Borehole #6 in Figure 3.2, between Plot M and the stream, and its presence in the stream would be another indicator of possible migration of this radionuclide.

3.3 Subsurface Water

3.3.1 Borehole Water

A number of the boreholes drilled in the Plot M area (Fig. 3.2) were cased with plastic pipe and screens were installed (piezometers) to serve as sampling points within the glacial till. Water samples were collected and water level measurements were made in these boreholes approximately bi-monthly, weather permitting. Each borehole was emptied of water and allowed

TABLE 3.3

Radioactivity Content of Stream Next to Plot M, 1991
(Concentrations in pCi/L)

	Date Collected	Location #1* (Upstream)	Location #9* (Downstream)
Total Alpha**	May 6	3.57 ± 0.32	0.97 ± 0.23
	November 15	0.26 ± 0.11	0.51 ± 0.15
Total Beta**	May 6	11.99 ± 0.31	6.20 ± 0.28
	November 15	3.47 ± 0.17	4.69 ± 0.19
Hydrogen-3	May 6	< 200	3.31x10 ⁴ ± 371
	November 15	< 200	6.37x10 ³ ± 191
Strontium-90	May 6	0.98 ± 0.06	1.35 ± 0.07
	November 15	0.41 ± 0.02	0.82 ± 0.03
Uranium-234	May 6	0.74 ± 0.12	0.73 ± 0.15
	November 15	0.16 ± 0.06	0.38 ± 0.08
Uranium-238	May 6	0.58 ± 0.10	0.89 ± 0.16
	November 15	0.06 ± 0.03	0.24 ± 0.06
Neptunium-237	May 6	-	-
	November 15	< 0.001	< 0.001
Plutonium-238	May 6	-	-
	November 15	< 0.001	< 0.001
Plutonium-239	May 6	-	-
	November 15	0.001 ± 0.001	< 0.001
Americium-241	May 6	-	-
	November 15	< 0.001	< 0.001
Curium-242 and/or Californium-249	May 6	-	-
	November 15	< 0.001	< 0.001
Curium-244 and/or Californium-252	May 6	-	-
	November 15	< 0.001	< 0.001

*See Figure 3.1

**Non-volatile

Figure 3.2 Map of Plot M Palos Site Showing Topography, Intermittent Stream, and Borehole Locations

to recharge before sampling. The shallow boreholes responded to the spring precipitation as indicated by an increase in water levels followed by a drop during summer and fall when moisture was used for plant growth. The water levels in the deeper boreholes (> 100 ft) were relatively constant throughout the year. As in past years, some boreholes were occasionally dry.

All the water samples were analyzed for tritiated water and the results are collected in Table 3.4. Borehole #11 contains a nest of piezometers at three depths; 39 feet, 68 feet, and 124 feet. The principal purpose of this arrangement is to obtain water level measurements at different depths to determine the vertical gradient of the hydraulic head.

The tritium concentrations varied widely as in past years. In 1988, tritium concentration in Borehole #2 increased by about a factor of ten near the end of the year. The concentration remained at this level through the first two sampling periods in 1989 and then decreased to the former level. About the same time the tritium concentration in Borehole #2 was decreasing, the concentration in Borehole #4 was increasing by about a factor of four. During 1990 and 1991, the concentration in Borehole #4 remained elevated, but the concentration in Borehole #5 did not consistently increase. In addition, Boreholes #6, #9, and #26 show low concentrations in the spring, probably due to dilution by precipitation recharge, and higher concentrations later in the year.

In the 40-foot deep boreholes, low tritium concentrations correlate with high water levels, apparently a dilution phenomenon. The measured water levels in the boreholes are in Table 3.5. Since the measurement of the water levels is made relative to a benchmark at the top of the well casing, a decrease in numerical value indicates a rise in water level and dilution of the tritiated water. Higher tritiated water concentrations correlate with higher tritium concentrations in the soil cores obtained when the boreholes were constructed.

A DOE Tiger Team that evaluated the Argonne National Laboratory-East environment, safety, and health programs in the fall of 1990 also reviewed the Site A/Plot M monitoring program. The Tiger Team found that the sample

TABLE 3.4

Hydrogen-3 Content in Borehole Water Samples, 1991
(Concentrations in nCi/L)

Borehole Number	Depth (ft)	Date Collected						
		May 8	May 9	July 12	August 29	October 17	November 27	
1	40	1519	1608	2076	1907	1525	1611	
2	40	217	274	452	588	433	172	
3	40	3252	3247	3231	3224	3166	3129	
4	40	1564	1945	1912	1567	1290	1835	
5	40	91.8	131	63.3	55.3	53.5	56.0	
6	40	8.6	34.3	476	352	276	16.2	
8	40	< 0.2	1.1	3.9	0.3	< 0.2	< 0.2	
9	40*	155	1.61×10^4	1.77×10^4	1.58×10^4	1.58×10^4	1101	
10	40*	26.5	3808	3658	Dry	Dry	1743	
11	39	24.3	455	1384	1446	1246	324	
11	68	1.12×10^4	1.10×10^4	1.61×10^4	1.61×10^4	Dry	7508	
11	124	37.0	53.1	6.0	2.0	5.6	6.7	
24	126	174	14.2	49.0	Dry	71.2	5.5	
26	60	20.8	259	718	847	860	9.8	
28	60	178	177	158	164	Dry	Dry	
35	110	4752	297	134	148	149	172	
36	127	349	363	435	446	228	183	
40	25	- 276	-	227	242	397	672	

* Slant hole drilled at 45° to a depth of 40 ft below the surface.

TABLE 3.5

Water Level Measurements in Boreholes Near Plot M, 1991
(Units of feet below the benchmark at the top of the well)

Borehole Number	Depth (ft)	Date Measured				
		May 8	July 12	August 29	October 17	November 27
1	40	26.94	29.41	35.48	37.87	38.05
2	40	15.86	23.19	28.66	31.55	21.74
3	40	25.37	29.75	35.91	37.78	38.02
4	40	8.28	12.66	18.71	22.35	17.86
5	40	18.43	21.98	26.86	30.98	31.15
6	40	8.65	20.32	30.94	36.19	8.30
8	40	25.78	35.37	35.65	35.93	35.20
11	39	15.31	22.64	28.21	31.32	21.11
11	68	41.22	37.33	43.36	59.48	60.76
11	124	104.00*	103.60	104.29	114.41	104.25
24	125	81.05	84.39	113.55	113.54	81.35
26	60	37.67	38.00	42.67	45.78	41.75
28	60	57.74	55.71	57.29	57.80	57.56
35	110	92.98	92.55	93.15	93.00	93.16
36	127	103.33	103.69	104.46	104.65	104.43
40	25	0.00	4.82	8.50	10.75	0.00

*Surface water in security casing.

collection method for the boreholes was inconsistent with the EPA guidance. The EPA protocols require that a monitoring well be purged and a sample collected within the first two hours or the sample may not be representative of the groundwater.

Geological conditions at Plot M make it very difficult to follow the EPA guidance. Many of the monitoring wells at Plot M have been placed in clay-rich units with very low permeability. Recharge to these monitoring wells over a two-hour period will be insufficient to obtain an appropriate volume (up to one gallon) of water to conduct the analytical tests. The EPA criteria applies to situations where sensitive constituents such as volatile organic chemicals are of concern. Groundwater analyses at Plot M are for radioactive constituents, especially tritium which is less sensitive to chemical or physical loss from the groundwater than the volatile organic chemicals.

In order to determine if the results were significantly different when using the EPA guidance, the set of samples collected on May 8, 1991, was done without purging the monitoring wells. The wells were then purged and another set of samples was collected as soon as a sufficient volume of water was available. This recharge took between minutes and several days, depending on the monitoring well. The results of the tritium analyses are listed in Table 3.4. The before purging set is the May 8, 1991 data and the after purging set is the May 9, 1991 data. All other samples were collected after purging.

The tritium data obtained from the groundwater samples before and after purging each monitoring well were compared using the same techniques that were applied to a similar study last year.¹¹ Six boreholes showed significant differences, greater than an order of magnitude, in the tritium concentration before and after purging. The are: Boreholes #9, #10, #11(39'), #24, #26, and #35. Since the agreement is substantially less than last year's study, it will probably be necessary to conduct the purge study again. However, the EPA sampling protocol was applied for all sampling during 1991, if appropriate.

As part of a search for radionuclides other than tritium in the borehole monitoring wells, sets of large volume water samples were collected to obtain greater sensitivity in the analysis. One set of samples was collected in early July 1991, and another set was collected November-December 1991. Samples were collected from all boreholes that yielded sufficient water for analysis. All samples were analyzed for strontium-90 and the results are shown in Table 3.6. Strontium-90 concentrations greater than the detection limit of 0.25 pCi/L were found in ten of the 18 sampled boreholes. Levels above 0.25 pCi/L would not be expected in this water from fallout, and no other source is known. The highest strontium-90 concentrations were found in water from Borehole #11 at 68 ft (10.7 pCi/L). The highest concentration found in 1990 was 6.6 pCi/L in Borehole #9, while Borehole #11(68') was 4.4 pCi/L. This borehole water also has of the highest tritium concentrations. It should be noted that the borehole with one of the higher strontium-90 concentrations (Borehole #6) is between the buried waste and the stream that flows around Plot M. These data indicate small but measurable amounts of strontium-90 have migrated from the waste into the surrounding glacial till. As seen in Table 3.3, measurable strontium-90 concentrations were also found in the stream water below the Plot.

3.3.2 Dolomite Hole Water

At the present time, 17 wells are cased into the dolomite zone to monitor the movement of any radionuclides in this aquifer. Most of the dolomite holes are located north of Plot M and east of the Red Gate Woods wells (#5160 and #5167), as shown in Figures 1.2 and/or 3.3. Water was collected from the dolomite holes quarterly. All samples were analyzed for tritiated water and the results are in Table 3.7. Water levels were also measured in the dolomite holes and these measurements are in Table 3.8. Since the four dolomite holes, DH 11 to DH 14, are located close to each other, the water level was only measured in DH 11 and assumed to be representative of the four. Two of the wells, DH 13 and DH 14, were not available for sampling during most of the year. The DH 13 well was vandalized and filled with debris, while DH 14 contained USGS equipment that made the well inaccessible for sampling.

TABLE 3.6

Radiochemical Analyses of Borehole Water Samples Near Plot M, 1991
(Concentrations in pCi/L)

Borehole*	Date Collected	Strontium-90
1 (40')	July 2	0.33 ± 0.04
	November 27	0.36 ± 0.09
2 (40')	July 2	0.48 ± 0.04
	November 27	0.41 ± 0.04
3 (40')	July 2	< 0.25
	November 27	< 0.25
4 (40')	July 2	< 0.25
	November 27	< 0.25
5 (40')	July 2	< 0.25
	November 27	< 0.25
6 (40')	July 2	7.54 ± 0.08
	November 27	4.07 ± 0.16
8 (40')	July 2	< 0.25
	November 27	< 0.25
9 (40')	July 2	8.52 ± 0.08
	November 27	8.15 ± 0.12
10 (40')	July 2	< 0.25
	November 27	< 0.25
11 (39')	July 2	3.21 ± 0.15
	November 27	2.46 ± 0.07
11 (68')	July 21	10.71 ± 0.13
	November 27	5.79 ± 0.10
11 (124')	July 2	< 0.25
	November 27	< 0.25
24 (125')	July 2	I**
	November 27	0.34 ± 0.06
26 (60')	July 2	1.03 ± 0.10
	November 27	1.51 ± 0.06
28 (60')	July 2	I**
	November 27	Dry
35 (110')	July 2	0.50 ± 0.09
	November 27	0.51 ± 0.03
36 (127')	July 2	< 0.25
	November 27	< 0.25
40 (25')	July 2	3.16 ± 0.04
	November 27	3.09 ± 0.08

*See Figure 3.1.

**Insufficient amount of water collected to run analysis.

Figure 3.3 Locations of Dolomite Holes North of Plot M

TABLE 3.7

Tritium in Site A/Plot M Dolomite Holes, 1991
(Concentrations in nCi/L)

Dolomite Hole Number	Date Collected			
	March 20	June 13	August 21	November 19
1	< 0.2	-	< 0.2	< 0.2
2	< 0.2	-	< 0.2	< 0.2
3	1.5	-	1.8	1.6
4	< 0.2	-	< 0.2	< 0.2
5	< 0.2	< 0.2	< 0.2	< 0.2
6	1.7	1.8	1.0	1.8
7	< 0.2	< 0.2	< 0.2	< 0.2
8	< 0.2	< 0.2	< 0.2	< 0.2
9	4.8	4.1	3.9	2.3
10	5.4	5.2	5.2	4.5
11	4.4	4.4	4.4	4.2
12	6.0	6.2	5.9	5.7
13	2.1	-	-	-
14	-	-	-	5.8
15	3.2	3.8	3.8	3.3
16	< 0.2	< 0.2	< 0.2	< 0.2
17	1.5	1.4	1.6	1.4

TABLE 3.8

Water Level Measurements in Dolomite Holes Near Plot M, 1991
 (Units of feet below the benchmark at the top of the well)

Dolomite Hole Number	Date Measured			
	March 20	June 13	August 21	November 19
1	159.61	-	161.41	161.06
2	137.55	-	139.75	139.44
3	96.23	-	98.54	97.98
4	91.40	-	93.56	93.14
5	76.52	76.89	79.71	78.14
6	73.45	73.91	75.65	75.10
7	80.72	80.02	81.64	81.60
8	73.44	73.05	74.20	73.93
9	71.77	71.75	73.07	73.02
10	63.16	63.70	65.17	64.77
11	74.25	74.78	76.20	75.78
15	78.03	78.58	79.97	79.59
16	74.02	74.49	76.18	75.65
17	73.05	73.55	75.21	74.69

A study was conducted to determine if any chemical constituents used or generated at Site A and/or buried at Plot M entered the environment and migrated into the dolomite water. Samples were collected on August 21, 1991, from DH 1, DH 2, DH 3, and DH 4 (see Figure 1.2). These samples were analyzed for the target compound list of constituents, i.e., metals, volatile organic compounds, semi-volatile organic compounds, and PCB/pesticides. The only constituents identified were about 700 ppb of acetone and 140 ppb of methyl ethyl ketone in DH 1. These ketones are known to be very mobile. There are no USEPA drinking water limits for either of these compounds.

The results of the tritiated water analysis of the dolomite holes are consistent with concentrations measured in the past. In all, ten of the dolomite holes had elevated tritiated water concentrations. The highest tritium levels are in the eight dolomite holes, DH 9 to DH 15 and DH 17, which are the furthest north and near the surface stream that flows next to Plot M (see Section 3.2). The distribution of tritium in these wells supports the USGS interpretation¹⁸ that a large tritium plume underlies the stream. The plume has spread downward as well as downgradient resulting in the current configuration of the tritium concentrations in the dolomite.

Four of the dolomite holes have collapsed and water levels in them indicate they are open to glacial drift or till, not dolomite. These wells, which should not be considered as dolomite holes are: DH 6, DH 7, DH 8, and DH 9. However, DH 6 and DH 9 do provide useful tritium concentration data for the glacial drift just above the dolomite contact. The other dolomite hole with elevated tritium is DH 3, which is immediately downgradient from Plot M. Previous analyses of soil core samples indicated the presence of tritium down to the till-dolomite interface at DH 3.

3.3.3 Well Water

In July 1988, a well was installed in the Red Gate Woods picnic area (#5160) to replace the existing well (#5167) as a drinking water supply for visitors to this area. This will be referred to as the Red Gate Woods North well (#5160). This well was to be cased 20 feet into the dolomite to seal off fractures assumed to contain tritiated water. Previous experiments had

indicated that the tritium moved at the till-dolomite interface and in the uppermost fractures in the dolomite. Extending the casing 20 feet into the dolomite and cementing the void between the casing and dolomite was expected to prevent tritium from entering the new well via these fractures. In addition, placement of a new pump mechanism on the new well was expected to eliminate the elevated lead concentrations found occasionally in the old well that resulted from corrosion of the old pump mechanism. The pump mechanism was removed from the old Red Gate Woods well to prevent its use by the public; however, the well was maintained as a sampling location for this monitoring program. In addition, the lower portion of the Red Gate Woods well (#5167) was filled with grout to seal the lower fracture and prevent communication of water with the new well.

Sampling was conducted throughout the year at the forest preserve picnic wells located north of Plot M and shown in Figure 1.2. These wells are located in the same dolomite as the previously discussed dolomite holes. Although sampling at the Guard Post well (#5215) was terminated in the middle of 1988, sampling was reinstated in May 1989 since this location provides a western limit on the tritium plume. All the samples were analyzed for tritiated water and the results are listed in Table 3.9.

The tritium concentrations in wells #5160 and #5167 have decreased to the level where the earlier pattern of high concentrations in the winter and low concentrations in the summer is not readily detectable. This decrease over the past few years is illustrated in Figure 3.4, which is a plot of the tritium concentrations in wells #5160, #5167, and #5159 for the past six years. The maximum tritium concentrations in the Red Gate Woods well (#5167) dropped from 3.3 nCi/L in 1987 to 0.21 nCi/L in 1991, while the average concentration dropped from 1.6 nCi/L in 1987 to 0.05 nCi/L in 1991.

The annual average tritium concentrations are slightly higher in the new well (#5160) compared to the old well (#5167), see Table 2.1. It is speculated that the higher concentrations of tritium in the Red Gate Woods North well (#5160) compared to the Red Gate Woods well (#5167) is due to the fact that it is drilled deeper and intercepts lower fractures in the dolomite that are connected to some of the dolomite holes near the intermittent

TABLE 3.9

Tritiated Water Content of Wells Near Site A/Plot M, 1991
(Concentrations in nCi/L)

	Red Gate North 5160	Red Gate 5167	Opposite Red Gate 5159	330 yds East Red Gate 5158	95th & Archer 5157	Guard Post 5215
January 2	< 0.2	< 0.2	0.78	< 0.2	< 0.2	< 0.2
January 16	< 0.2	< 0.2	0.83	-	-	-
February 6	< 0.2	< 0.2	0.85	< 0.2	< 0.2	< 0.2
February 20	< 0.2	< 0.2	0.87	-	-	-
March 6	< 0.2	< 0.2	0.89	< 0.2	< 0.2	< 0.2
March 20	< 0.2	< 0.2	1.21	-	-	-
April 3	< 0.2	< 0.2	1.19	< 0.2	< 0.2	< 0.2
April 17	< 0.2	< 0.2	1.76	-	-	-
May 1	0.27	< 0.2	1.78	< 0.2	< 0.2	< 0.2
May 15	0.25	< 0.2	1.87	-	-	-
June 5	< 0.2	< 0.2	2.03	< 0.2	< 0.2	< 0.2
June 19	< 0.2	< 0.2	2.23	-	-	-
July 3	< 0.2	< 0.2	2.16	< 0.2	< 0.2	< 0.2
July 17	0.33	< 0.2	2.26	-	-	-
August 7	0.55	< 0.2	2.20	< 0.2	< 0.2	< 0.2
August 21	0.80	< 0.2	2.00	-	-	-
September 4	0.75	< 0.2	1.51	< 0.2	< 0.2	< 0.2
September 18	0.72	< 0.2	1.55	-	-	-
October 2	0.71	< 0.2	1.36	< 0.2	< 0.2	< 0.2
October 16	0.60	< 0.2	1.35	-	-	-
November 6	0.48	< 0.2	1.24	< 0.2	< 0.2	< 0.2
November 21	0.52	< 0.2	0.57	-	-	-
December 4	0.55	< 0.2	0.74	< 0.2	< 0.2	< 0.2
December 18	0.62	0.21	1.19	-	-	-
Average	0.35	0.05	1.43	< 0.2	< 0.2

Figure 3.4 Tritiated Water Concentrations in Red Gate Woods (#5167), Opposite Red Gate Woods (#5159), and Red Gate Woods North (#5160) Wells From 1986 Through 1991

stream, specifically DH 11 through DH 14. The other dolomite holes were not drilled deep enough to intercept this lower fracture. Flow in the dolomite holes is generally downward from the weathered zone to the bottommost fractures. Most of the flow exits the dolomite hole into the major fracture (96-98 feet below the surface), but some bypasses it and flow also occurs at lower fractures (157 feet). This lower fracture is intercepted by well #5160 but not #5167 since this lower fracture (157 feet) was grouted in 1988. The upper fracture (96-98 feet) has been cased off in #5160. Therefore, the tritium present in the lower sections of the deepholes 11 to 14 moves through the lower fracture (157 feet) and is measured in well #5160. The higher annual average and maximum tritium concentration in #5160 compared to previous years is due to a summer 1991 drought that did not provide any precipitation recharge which would dilute the tritium content. This same explanation is applicable to the higher tritium concentrations in well #5159.

The other wells, although also downgradient from Plot M, are evidently too far from the Plot to show measurable tritium concentrations. Three of the picnic wells; #5159, #5157, and #5158 were not available to the public during the year. The Cook County Forest Preserve District had removed the pump handles due to high fecal coliform concentrations in the well water. A set of picnic well water samples was collected on April 8, 1991, and October 7, 1991, from the wells on the east and south sides of the Palos Forest Preserve. The sampled wells were #5162, #5031, #5188, #5153, #5154, #5226, #5021, #5193, #5232, and #5148 in Figure 1.2. All the tritium results were less than the detection limit of 0.2 nCi/L.

The Red Gate Woods North well (#5160) is the location which provides the greatest potential radiation exposure to the public in 1991. If water equal to the Red Gate Woods North well average concentration of 0.35 nCi/L were the sole source of water for an individual, the annual dose from the tritium would be 0.016 mrem. If an individual consumed one liter of this water, the dose would be 2.2×10^{-5} mrem.

In addition to tritiated water measurements, quarterly sets of water samples from the picnic wells were collected and analyzed for isotopic

uranium. The uranium results are presented in Table 3.10. The range of concentrations is similar to that found previously and are consistent with concentrations of uranium found in well water away from Site A/Plot M.

Samples were collected quarterly from the Red Gate Woods north well (#5160) and analyzed for a number of inorganic constituents. The results are found in Table 3.11. Because this picnic well is used as a drinking water supply, the limits used were the State of Illinois concentrations of chemical constituents in drinking water.¹⁹ The constituents in Table 3.11 that do not have a specific limit are provided for completeness. Although the limits are exceeded for sulfate and manganese, this is probably due to natural levels. These concentrations are not unusual for dolomite water in northeast Illinois. Elevated levels of iron, lead, zinc, and some trace metals may be related to the decomposition of the well pump materials. These concentrations are the highest early in the year when the pumps have received very little use. There is no evidence that the source of the elevated inorganic constituents is from Plot M, since these metals are not found in the deepholes between Plot M and the Red Gate Woods wells.

To attempt to establish that the source of the trace metals, particularly lead, was from the well pump materials, samples were collected from the six picnic wells and four of the deep holes on June 5, 1991, and analyzed for lead. Since both the picnic wells and the deepholes collect water from the same dolomite strata, any difference could be attributed to the pump materials. The lead results are collected in Table 3.12. All the samples from the deepholes have low lead concentrations, below the 50 $\mu\text{g/L}$ State of Illinois drinking water limit, while the picnic wells have elevated levels. This information supports the conclusion that the source of the trace metals is the pump materials.

TABLE 3.10

Uranium Content of Well Water Near Plot M, 1991
(Concentrations in pCi/L)

Well Number	Location	Date Collected			
		February 6	May 1	August 7	November 6
5160	Red Gate Woods North	0.80 ± 0.19	0.17 ± 0.12	0.32 ± 0.17	0.18 ± 0.09
5167	Red Gate Woods	0.26 ± 0.10	0.23 ± 0.10	0.19 ± 0.08	0.28 ± 0.10
5159	Opposite Entrance to Red Gate Woods	0.40 ± 0.14	0.54 ± 0.16	0.44 ± 0.16	0.38 ± 0.12

*See Figure 1.2

TABLE 3.11

Inorganic Constituents in Red Gate Woods North Well Water (#5160), 1991
(Concentrations in mg/L)

Inorganic Constituent	February	May	August	November	Limit**
Arsenic	< 0.004	< 0.004	< 0.004	< 0.004	0.05
Barium	0.0119	0.0218	0.0187	0.0097	1.0
Beryllium*	< 0.2	< 0.2	< 0.2	< 0.2	-
Cadmium	0.0007	0.0004	0.0006	0.0008	0.01
Chloride	36.0	14.0	11.0	11.0	250
Chromium	< 0.003	< 0.003	< 0.003	< 0.003	0.05
Cobalt	0.018	0.020	0.027	0.016	-
Copper	0.239	0.058	0.082	0.031	-
Fluoride	0.126	0.180	0.224	0.062	-
Iron	18.70	15.47	14.86	23.42	-
Lead	0.095	0.027	0.014	0.011	0.05
Manganese	0.408	0.585	0.420	1.273	0.15
Mercury*	< 0.1	< 0.1	< 0.1	< 0.1	2.0
Nickel	< 0.020	0.032	0.040	0.020	-
pH	7.2	7.0	7.1	7.0	-
Silver	< 0.0002	< 0.0002	< 0.0002	< 0.0002	0.05
Sulfate	170	658	886	678	250
Thallium	< 0.004	< 0.004	< 0.004	< 0.004	-
Vanadium	< 0.003	< 0.003	< 0.003	< 0.003	-
Zinc	12.80	8.25	4.58	1.65	-

*Concentrations in $\mu\text{g/L}$.

**State of Illinois concentrations of chemical constituents in drinking water.¹⁹ See text.

TABLE 3.12

Lead Concentrations in Picnic Wells and Deep Holes Collected June 5, 1991
(Concentrations in $\mu\text{g/L}$)

Location	Lead
(Picnic Wells)	
Red Gate North (5160)	11.1
Red Gate (5167)	96.0
Opposite Red Gate (5159)	329.7
300 yds East of Red Gate (5158)	14.3
95th and Archer (5157)	258.2
Guard Post (5215)	62.5
(Deep Holes)	
#10	8.9
#11	7.1
#12	2.0
#16	6.2

3.4 Bottom Sediment

Bottom sediment samples were collected from the stream next to Plot M at Location #1 and Location #9 on May 6, 1991, and on November 15, 1991 (see Figure 3.1). Various radiochemical analyses were performed on these samples and the results are found in Table 3.13. The results are similar at all locations except that the cesium-137 and plutonium-239 are slightly elevated downstream. The concentrations are very low and in some cases similar to fallout levels of these radionuclides. For comparison to concentrations measured in the area away from the impact of any nuclear facilities, see the ANL-E Site Environmental Report for CY 1990.¹⁵

TABLE 3.13

Radioactivity Content of Streambed Next to Plot M, 1991
(Concentrations in pCi/g)

Radionuclide	Date Collected	Location #1* (Upstream)	Location #9* (Downstream)
Potassium-40	May 6	22.32 $\pm$ 0.81	20.54 $\pm$ 0.78
	November 15	18.29 $\pm$ 0.60	18.48 $\pm$ 0.64
Strontium-90	May 6	0.11 $\pm$ 0.01	0.12 $\pm$ 0.01
	November 15	0.15 $\pm$ 0.01	0.15 $\pm$ 0.01
Cesium-137	May 6	0.24 $\pm$ 0.02	0.40 $\pm$ 0.03
	November 15	0.26 $\pm$ 0.02	0.34 $\pm$ 0.02
Radium-226	May 6	2.25 $\pm$ 0.08	2.20 $\pm$ 0.08
	November 15	2.58 $\pm$ 0.09	3.40 $\pm$ 0.09
Thorium-228	May 6	1.33 $\pm$ 0.04	1.27 $\pm$ 0.04
	November 15	1.07 $\pm$ 0.04	1.22 $\pm$ 0.04
Thorium-232	May 6	1.06 $\pm$ 0.10	1.04 $\pm$ 0.10
	November 15	0.88 $\pm$ 0.09	1.09 $\pm$ 0.09
Uranium-234	May 6	1.26 $\pm$ 0.09	1.38 $\pm$ 0.10
	November 15	1.31 $\pm$ 0.09	1.40 $\pm$ 0.09
Uranium-238	May 6	1.39 $\pm$ 0.10	1.47 $\pm$ 0.11
	November 15	1.44 $\pm$ 0.09	1.49 $\pm$ 0.09
Plutonium-238	May 6	< 0.001	< 0.001
	November 15	< 0.001	< 0.001
Plutonium-239	May 6	0.0085 $\pm$ 0.0013	0.0404 $\pm$ 0.0026
	November 15	0.0089 $\pm$ 0.0018	0.0452 $\pm$ 0.0039
Americium-241	May 6	0.0030 $\pm$ 0.0010	0.0053 $\pm$ 0.0013
	November 15	0.0066 $\pm$ 0.0017	0.0042 $\pm$ 0.0020

*See Figure 3.1

4.0 SUMMARY OF POTENTIAL RADIATION DOSE ESTIMATES

If a hypothetical individual were exposed continuously to tritium at various locations, the dose could be estimated. Assuming a person breathed the air at Location #9, drank water from Location #9 or the seep, or drank water from Well 5160 or 5167, the dose from exposure for all of 1991 at the maximum and annual average concentrations is collected in Table 4.1. The exposure to air, drinking water, and surface water employs the DOE methodology and limits.

A more meaningful estimation is for the occasional visitor to the Plot M area. Assuming a visitor spends one hour at Location #9 or drinks one liter of water from the surface stream or picnic wells, the dose from this exposure is estimated and presented in Table 4.2. The total dose received by an occasional visitor is the combination of the separate pathways, breathing air at Location #9 and drinking water from the Red Gate Woods North Well (5160). This dose would be 0.00005 mrem per visit.

In order to put the doses into perspective, comparisons can be made to annual average doses received by the public from natural or accepted sources of radiation. These are listed in Table 4.3. It is obvious that the magnitude of the doses potentially received near Plot M from residual radioactive substances remaining from work conducted in this area are insignificant compared to these sources. Therefore, the monitoring program results have established that radioactivity at Plot M is very low and does not endanger the health or safety of those living in the area or visiting the site.

TABLE 4.1

Dose From Continuous Exposure to Tritium at Selected Locations, 1991

Pathway	Maximum		Annual Avg.	
	Conc.	Dose	Conc.	Dose
Air	5.2 pCi/m ³	0.003 mrem/y	2.0 pCi/m ³	0.001 mrem/y
Surface Water				
Seep	231 nCi/L	11 mrem/y	194 nCi/L	9 mrem/y
Location #9	38 nCi/L	1.8 mrem/y	23 nCi/L	1.1 mrem/y
Well Water				
Red Gate Woods (5160)	0.80 nCi/L	0.037 mrem/y	0.35 nCi/L	0.016 mrem/y
Red Gate Woods (5167)	0.21 nCi/L	0.010 mrem/y	0.05 nCi/L	0.002 mrem/y

TABLE 4.2
Estimates of Exposures to a Casual Visitor to Plot M, 1991

Pathway	Quantity	Maximum Dose	Annual Average
Air	One Hour	0.0000003 mrem	0.0000001 mrem
Surface Water			
Seep	One Liter	0.015 mrem	0.012 mrem
Location #9	One Liter	0.002 mrem	0.001 mrem
Well Water			
Red Gate Woods (5160)	One Liter	0.00005 mrem	0.00002 mrem
Red Gate Woods (5167)	One Liter	0.00001 mrem	0.000003 mrem

TABLE 4.3

Annual Average Dose Equivalent
in the U. S. Population

Source	(mrem)
Natural Sources	
Radon	200
Internal (^{40}K and ^{226}Ra)	39
Cosmic	28
Terrestrial	28
Medical	
Diagnostic X-rays	39
Nuclear Medicine	14
Consumer Products	
Domestic Water Supplies, Building Materials, etc.	10
Occupational (medical radiology, industrial radiography, research, etc.)	1
Nuclear Fuel Cycle	< 1
Fallout	< 1
Other Miscellaneous Sources	< 1
Total	360

*NCRP Report No. 93.²⁰

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6.0 APPENDICES

6.1 Quality Assurance Program

All nuclear instrumentation is calibrated with standardized sources obtained from the U. S. National Institute of Standards and Technology (NIST), if available. If NIST standards were not available for particular nuclides, standards from the Amersham Corporation were used. The equipment is checked prior to the sample measurements with secondary counting standards to insure proper operation. Samples were periodically analyzed in duplicate or with the addition of known amounts of a radionuclide to check precision and accuracy. Intercomparison samples distributed by the Quality Assurance Branch of the EPA are analyzed regularly. In addition, our laboratory participates in the DOE Environmental Measurements Laboratory Quality Assurance Program, a semi-annual distribution of four different sample matrices containing various combinations of radionuclides. The results of our participation in both programs for 1990 are published in ANL-91/3.¹⁵

Many factors enter into an overall quality assurance program other than the analytical quality control discussed above. Representative sampling is of prime importance. Appropriate sampling protocols are followed for each type of sampling being conducted. Water samples are pre-treated in a manner designed to maintain the integrity of the analytical constituent. For example, samples for trace radionuclide analyses are acidified immediately after collection to prevent hydrolytic loss of metal ions and filtered to reduce leaching from suspended solids.

6.2 Applicable Standards

The standard that is relevant to this study is the DOE Order 5400.5 which established a dose limit of 100 mrem/y.¹³ The dose limit and dose calculation methodology is applicable to all media: air, surface water, deep holes, boreholes, and drinking water. The EPA drinking water standard¹² is not applicable to the picnic wells since they do not meet the definition of a public water system. However, the EPA standard of 20 nCi/L for tritium may be useful for some comparison purposes.

6.3 Analytical Methods

The analytical methods used to obtain the data in this report are the same as those described in ANL-91/3.¹⁵

6.4 Acknowledgements

The analytical separations and radiochemical measurements were conducted by the Dosimetry and Analytical Services Section of the ESH Division. A draft of this report was reviewed by Sue Nielson, Andrew Gabel, and Barrett Fritz (DOE-CH), Jacob Sedlet, and members of the ANL staff, who made a number of constructive comments. The dedicated effort of Rita M. Beaver (ANL), who typed and prepared this manuscript is greatly appreciated. Funding to support this program was provided by the Environmental Restoration and Waste Management Program through the U. S. Department of Energy-Chicago Field Office.

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