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UC-70

Formerly Utilized MED/AEC Sites Remedial Action Program

Radiological Survey of Site A, Palos Park Forest Preserve, Chicago, Illinois

April 1978

Final Report

Prepared for

U.S. Department of Energy
Assistant Secretary for Environment
Division of Environmental Control Technology
Washington, D.C. 20545

Under
Chicago Operations Office
Contract Number W-31-109-ENG-38

DISCLAIMER

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PREFACE

This series of reports results from a program initiated in 1974 by the Atomic Energy Commission (AEC) for determination of the condition of sites formerly utilized by the Manhattan Engineering District (MED) and the AEC for work involving the handling of radioactive materials. Since the early 1940's, the control of over 100 sites that were no longer required for nuclear programs has been returned to private industry or the public for unrestricted use. A search of MED and AEC records indicated that for some of these sites, documentation was insufficient to determine whether or not the decontamination work done at the time nuclear activities ceased is adequate by current guidelines.

These reports contain the results of surveys of the current radiological condition of these sites. Based upon the findings of the surveys, further evaluation will be made at those sites where radioactivity above natural background is identified to determine whether further measures should be undertaken to assure the protection of the public health and safety.

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RADIOLOGICAL SURVEY OF SITE A AND PLOT M

I. HISTORICAL BACKGROUND

After the successful operation of the first nuclear reactor (CP-1) on December 2, 1942, at the University of Chicago by Dr. Enrico Fermi and his collaborators, it was apparent that it was necessary to move the project since adequate space was not available, the congested city was not a proper location for nuclear research at that stage of its development, and isolation was necessary to preserve secrecy. The U. S. Army Corps of Engineers leased 1,025 acres of land from the Cook County Forest Preserve District to provide a site for the continuing research. The area is illustrated in Figures 1-3. The land was located in the Palos Forest Preserve, which included a golf course, girl scout camp, and other facilities. The area was south and east of Archer Avenue, north of 107th Street, and west of Wolf Road. Only about 20 acres were used. These are indicated as "Site A" and "Plot M" in Figure 2. Site A refers to the 19-acre experimental area which contained the CP-2 and CP-3 reactors and associated buildings and laboratories (Figure 3), while Plot M refers to a one-acre radioactive waste burial site about 2,000 feet north of Site A.

During March of 1943, the CP-1 reactor at the University of Chicago was disassembled, moved to Site A, rebuilt as CP-2, and placed into operation. The reactor was constructed of uranium metal fuel and graphite moderator. On May 15, 1944, CP-3, the first heavy-water cooled and moderated reactor began operation at this site. In 1953, CP-3 was updated, primarily by replacing the normal uranium fuel with enriched uranium, and designated as CP-3'. Both reactors continued operation until 1954. Among the programs carried out at this site during and after World War II were: fission product separations, reactor physics studies, tritium recovery from irradiated lithium, and studies of the metabolism of radionuclides in laboratory animals. In 1947, the present DuPage County site of the Argonne National Laboratory (ANL) was obtained (Figure 1) and by 1949, the first permanent buildings at this location were completed. As the facilities at ANL were completed, the programs were transferred from Site A to ANL.

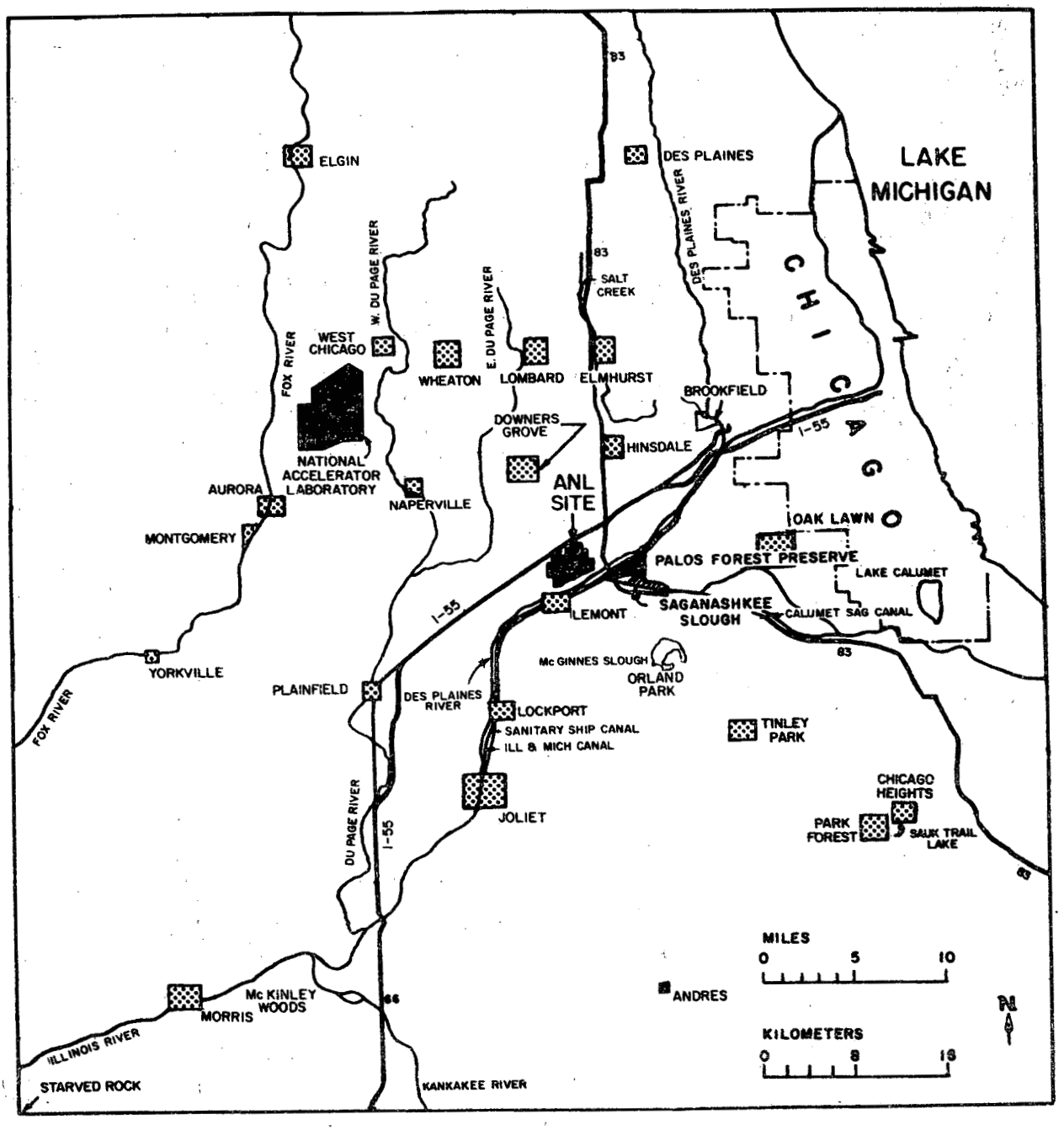


Fig. 1. Location of Palos Forest Preserve on Chicago Area Map.

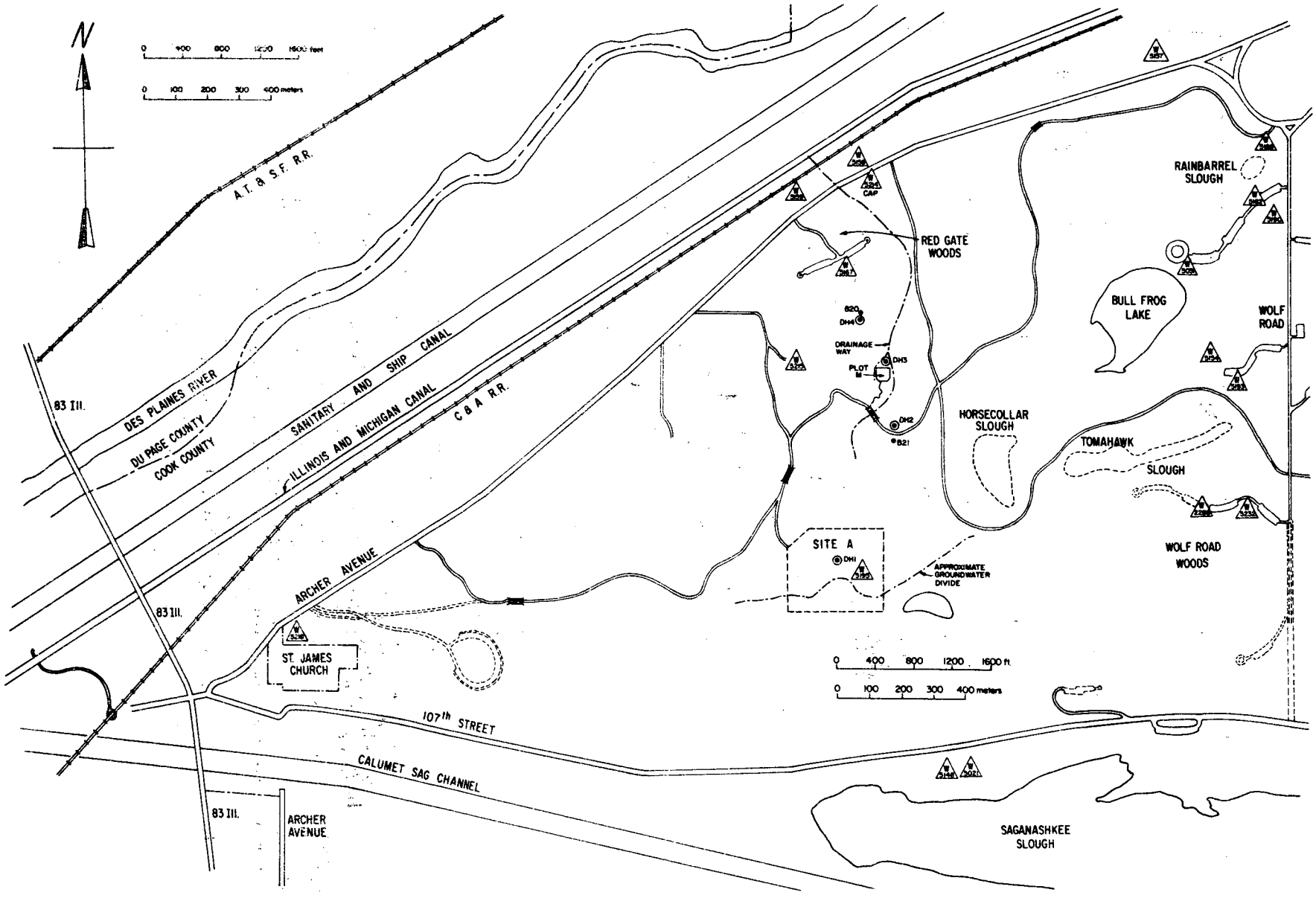
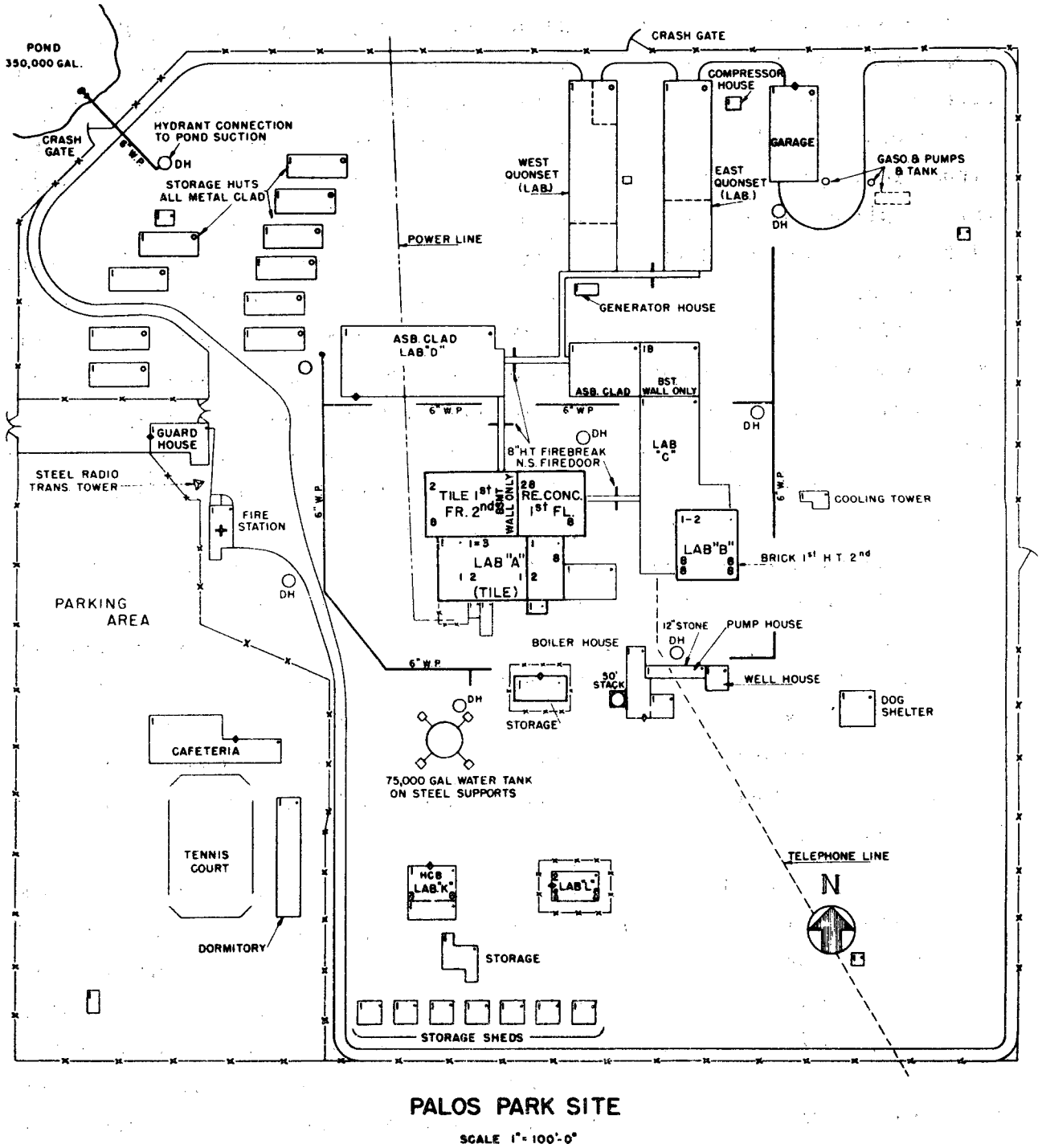


Fig. 2. Palos Forest Preserve. Legend: △ - forest preserve wells; ◎ DH - holes drilled into dolomite bedrock; • B - borings into the soil overburden.



PALOS PARK SITE

SCALE 1" = 100'-0"

Fig. 3. Plan of Site A Laboratory

As a result of a revised lease agreement with the Cook County Forest Preserve District, it was necessary to completely evacuate the Site A/Plot M area by June 30, 1956. As part of the revised lease, it was necessary for the Government to "remove, destroy, or render harmless any or all installations, structures, appurtenances, materials, or conditions of the ground or terrain which shall be dangerous, perilous, or hazardous in nature or which, if permitted to remain, would interfere with the full use and enjoyment of the said premises by the public as a part of the Forest Preserve District." In the spring of 1955, work to comply with these requirements was begun. As programs were moved to ANL, the empty buildings were surveyed, decontaminated if necessary, and razed. The buildings housing CP-2 and CP-3' were the only areas requiring extensive decontamination. The reactors were dismantled, the heavy water was removed, and the fuel shipped to Oak Ridge National Laboratory for reprocessing. The tank which had contained the heavy water in the CP-3' reactor was filled with concrete. The space between the tank and the biological shield was also filled with concrete into which was dumped hardware, piping, and miscellaneous contaminated items. A 40-foot deep excavation was dug next to the CP-3' containment shell, and with the use of explosives, the reactor shell was tumbled into the pit. The shell was covered with CP-2 and CP-3' building rubble and then dirt. After demolition was completed at Site A, the area was graded and an inscribed granite marker placed near the location of the buried reactor.

Plot M was used for the burial of low-level radioactive waste both from the University of Chicago Metallurgical Laboratory and Site A operations. The first recorded use of this site as a radioactive waste burial ground was in early 1943. During the first several years of operations, active materials, both solid and liquid, in glass or metal containers were placed in the bottom of the six-foot deep trenches. Sufficient soil was used to cover the material to reduce the radiation to acceptable levels. Additional active material was placed on top of the original and also covered. This procedure was continued until the trench was full. Sometime prior to July 6, 1948, possibly early in 1948, material was placed into steel bins, which were placed in the trenches and covered with soil. The burial area eventually covered an area 150 feet by 140 feet. No precise inventory of the buried material was kept. The early

records gave little indication of the identity and quantity of specific nuclides involved.

Beginning on May 24, 1949, the bins were removed to search for some missing uranium-235, which was found. The bins were not reburied, but shipped to the present ANL site. After this work was completed on June 10, 1949, burial at Plot M was discontinued and the Plot was covered with additional soil and seeded with a grass cover.

Plot M remained in this condition until the spring of 1956, when an inverted concrete box was constructed to cover the entire burial plot. The concrete sidewalls were extended eight feet into the ground and a one-foot thick concrete slab was placed over the entire area. The concrete was covered with two feet of soil, grass was seeded, and an inscribed granite marker was placed in the center of Plot M. The purpose of the concrete barrier was to protect the contents and impede the flow of water through the buried radioactive materials. The decision to decommission the Plot in this way was made after considering alternative methods, including removal of the contents of the burial plot.

By summer of 1956, all demolition and restoration work was complete at both Site A and Plot M. A radioactivity survey of the site indicated no detectable surface contamination. All personnel were removed and the sites were turned over to the Cook County Forest Preserve District.

II. PRIOR ENVIRONMENTAL SURVEILLANCE

There is no record of an organized environmental radioactivity monitoring program during the early operations at Site A/Plot M. Monitoring was accomplished with the use of various portable survey meters, particularly at the time of burial of active material at Plot M. Some environmental samples were collected between 1948 and 1950, primarily plants (tree branches) and animals, but these were not analyzed. A compilation of environmental sampling conducted prior to the present survey is summarized in Table 1.

TABLE 1

Summary of Site A/Plot M Environmental Sampling, 1948-1975

Year	No. of Samples	Type of Samples	Type of Analysis*
1948 to 1950	27	Mostly Plants and Animals	Not Analyzed
1952	1	Surface Water	Total α & β
1954	12	Surface Water	Total α & β, one for U, Ra, Th, Pu
	12	Bottom Sediment	Total α & β
	20	Soil Cores	Total α & β
1955	4	Surface Water	Total α & β
	4	Bottom Sediment	Total α & β
	5	Soil Cores	Total α & β
1958	1	Surface Water	Total α & β
	1	Bottom Sediment	Total α & β
	4	Soil Cores	Total α & β
1960	1	Bottom Sediment	Total α & β
	4	Soil Cores	Total α & β, one for U, ^{137}Cs, & ^{90}Sr
	1	Plant	Total α & β, U
1961	1	Bottom Sediment	Total α & β
	5	Soil Cores	Total α & β
1963	3	Soil Cores	Total α & β, one for U
	2	Surface Soils	Total α & β, one for U, ^{137}Cs, & ^{90}Sr
1964	38	Bottom Sediment and Surface Soils	Total α & β, one for U, five by γ-ray spectrometry
1965	1	Surface Water	Total α & β
	4	Bottom Sediment	Total α & β
	8	Surface Soils	Total α & β
1966	1	Well Water	Total α & β
1969	8	Soil Cores	Total α & β
	8	Surface Soils	Total α & β
	2	Plants	Total α & β

TABLE 1 (contd)

Year	No. of Samples	Type of Samples	Type of Analysis*
1971	4	Bottom Sediment	Total α & β
	24	Surface Soils	Total α & β
	8	Soil Cores	Total α & β
1973	6	Well Water	Total α & β, & ^{3}H
	4	Bottom Sediment	Total α & β, Pu, U, & Th
	4	Soil Cores	Total α & β
	6	Surface Soils	Total α & β, Pu, U, & Th
1974	21	Well Water	^{3}H, one for Pu & U
1975	56	Well Water	^{3}H, one for Am, Pu, U, & ^{90}Sr
	3	Surface Water	^{3}H
	4	Bottom Sediment	Total α & β, Pu, U(α), & Th
	5	Soil Cores	Total α & β, Pu, U(α), & Th, one for ^{3}H
	6	Surface Soils	Total α & β, Pu, U(α), & Th

*Total α and β activity is the nonvolatile activity only. Tritiated water is not included in this analysis.

An environmental monitoring program for Plot M was established in 1954 based on the recommendation of Mr. William Drescher of the Madison, Wisconsin office of the U. S. Geological Survey (USGS), who had been retained by the Laboratory as a consultant on the hydrological aspects of the Plot M area. The stream sampling program consisted of collecting water and bottom sediment at four locations from an intermittent stream that flows around and drains the Plot M area. These locations are illustrated in Figure 4. In addition, surface soil and soil core samples were taken from the Plot M vicinity to whatever depth could be reached using a hand auger.

Samples were first collected in the spring of 1954 and additional samples were collected in subsequent years as shown in Tables 2 to 5. The results for the water and bottom sediment samples (Tables 2 and 3) showed that no radioactive material detected by the measurement procedures used could be attributed to Laboratory operations at Plot M. The concentrations fell within the range found for other samples collected throughout the Chicago area. All alpha activities were normal. Some of the beta activities were higher than normal, up to about 100 pCi/l or g, due to fallout from atmospheric nuclear tests. Normal activities are about 0.1-3 pCi/l (alpha) and 5-10 pCi/l (beta) in water and 15-30 pCi/g (alpha) and 50-80 pCi/g (beta) in bottom sediment and soil.

The soil samples (Table 4) were collected at various distances up to 275 feet north of Plot M and at depths up to 9.5 feet. Those collected through 1961 were normal, except for the effect of fallout on some of the beta activities. In the fall of 1963, a few surface samples collected 50 feet north of Plot M contained abnormally high alpha and beta activities. Specific radiochemical analyses indicated that these elevated activities were due to uranium.

In 1964, 1965, and 1969, extensive sampling was conducted to delineate the region of surface contamination found in 1963. Analyses for total nonvolatile alpha and beta activities indicated the presence of elevated levels of radioactivity in a few isolated portions of this region, but not a uniform distribution. This above-normal activity was again identified as uranium. Elevated levels were not found in the core samples, which indicated that the material did not come from within the buried area. The cross-hatched area in Figure 4 shows the region in which the above-normal activity levels were found. It was

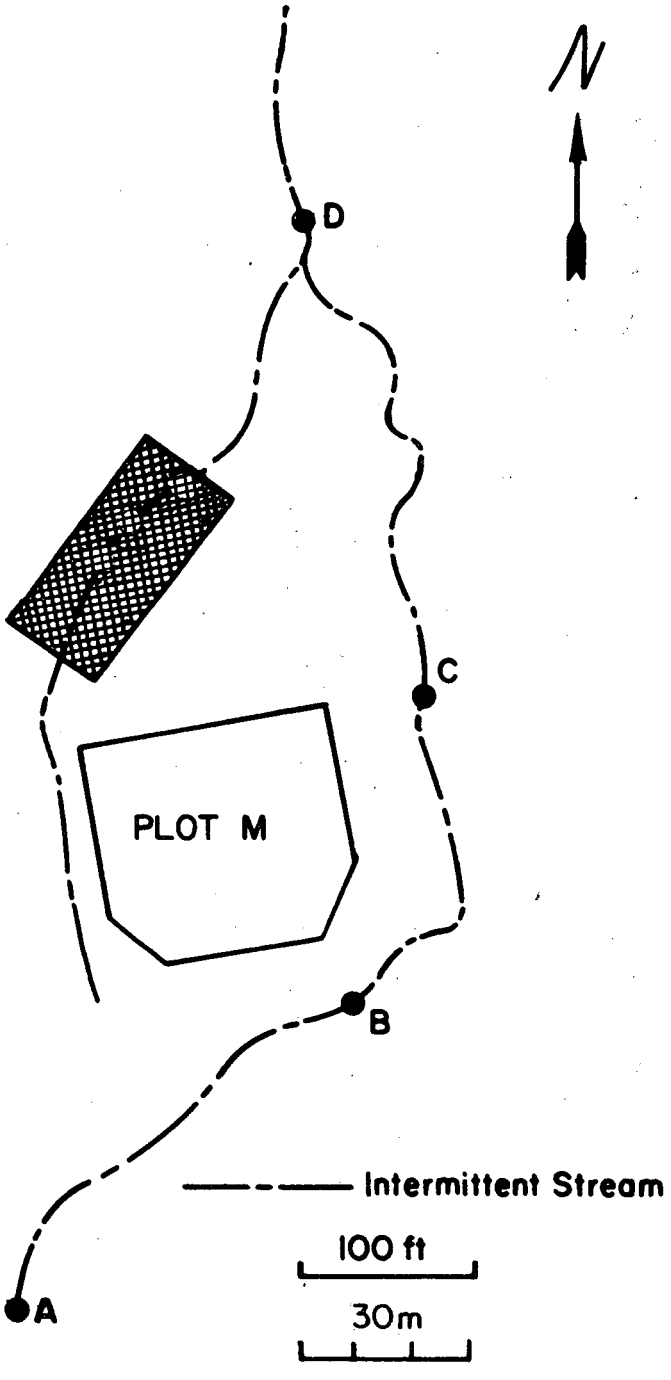


Fig. 4. Plan of Plot M Showing Drainage Streams. Water flow is south to north. A, B, C, and D are the standard stream sampling locations.

TABLE 2

Nonvolatile Radioactivity in Stream Water Near Plot M

(results in pCi/liter)

Year	No. of Samples	Location A		Location B		Location C		Location D	
		Alpha	Beta	Alpha	Beta	Alpha	Beta	Alpha	Beta
1954	12*	0.1-0.3	6.9-8.1	0.2-1.7	5.0-8.8	0.2-1.9	7.0-9.6	0.3-1.6	5.8-9.7
1955	4	2.1	35	1.4	17	1.5	24	2.8**	27
1958	1	-	-	-	-	2.1	75	-	-
1965	1	-	-	-	-	1.0	12	-	-

*Three samples from each location. The range in the results is given.

**This sample contained 2.4 pCiU/l, 0.2 pCi ^{226}Ra/l, and 0.2 pCi(Th&Pu)/l.

TABLE 3

Nonvolatile Radioactivity in Bottom Sediment Near Plot M

(results in pCi/gram)

Year	No. of Samples*	Location A		Location B		Location C		Location D	
		Alpha	Beta	Alpha	Beta	Alpha	Beta	Alpha	Beta
1954	12	26-33	60-73	25-26	52-68	24-25	61-63	23-29	56-66
1955	4	27	73	29	93	27	65	24	92
1958	1	-	-	-	-	17	54	-	-
1960	1	-	-	-	-	24	49	-	-
1961	1	-	-	-	-	28	53	-	-
1964	4	27	68	27	79	20	60	24	47
1965	4	31	61	26	66	29	66	24	59
1971	5	26	57	26	50	24	45	25-26	50-53
1973	4	27	63	25	59	25	51	26	54
1975	4	27	60	24	44	25	45	24	47

*Total number of samples collected each year. Where more than one sample was collected from a location, the range in the results is given.

TABLE 4

Nonvolatile Radioactivity in Soil Near Plot M
(results in pCi/gram)

Year	No. of Samples*	Alpha	Beta
1954	20	19-31	50-86
1955	5	22-43	63-116
1958	4	22-30	54-77
1960	4	22-33	52-65
1961	5	27-37	53-68
1963	5	22-82	53-138
1964	34	23-139	58-189
1965	8	25-148	62-290
1969	16	17-74	53-153
1971	32	20-46	51-88
1973	10	20-90	51-104
1975	11	24-76	52-151

*Total number of samples collected each year. The range in the results is listed. See text for locations.

TABLE 5

Radionuclides in Soil and Bottom Sediment Near Plot M, 1973 and 1975

(concentrations in pCi/gram)

Sample Number	Location	Year	Nonvolatile Alpha	Nonvolatile Beta	^{228}Th	^{230}Th	^{232}Th	U(fl)**	^{234}U	^{235}U	^{238}U	^{238}Pu	^{239}Pu
	*Surface Soils**												
75S25	25' S & 10' W 0-2" Deep	1975	26	63	0.29	0.49	0.36	1.6	0.62	0.037	0.75	0.0016	0.053
73S35	50' N & 10' W 0-2" Deep	1973	90	104	0.25	0.25	0.18	36	-	-	-	0.009	0.35
75S26	50' N & 10' W 0-2" Deep	1975	76	151	0.14	0.32	0.19	59	33	1.5	35	0.013	0.44
75S27	50' N & 10' W 2-12" Deep	1975	37	81	0.24	0.39	0.27	13	7.3	0.35	8.6	0.0028	0.073
73S36	70' N & 10' W 0-2" Deep	1973	70	102	0.18	0.27	0.15	48	-	-	-	0.007	0.48
75S28	70' N & 10' W 0-2" Deep	1975	24	61	0.28	0.41	0.26	2.9	1.3	0.057	1.3	0.0013	0.056
75S29	70' N & 10' W 2-12" Deep	1975	28	64	0.25	0.31	0.26	1.5	0.78	0.056	0.76	0.0012	0.069
73S38	100' N & 10' W 0-2" Deep	1973	26	60	0.50	0.57	0.40	2.6	-	-	-	0.0015	0.053
75S30	120' N & 10' W 0-2" Deep	1975	25	62	0.29	0.36	0.30	1.6	0.86	0.047	0.94	0.0003	0.011
73S34	50' N & 5' E 0-2" Deep	1973	30	72	0.67	0.68	0.45	3.2	-	-	-	0.014	0.76
73S37	100' N & 5' E 0-2" Deep	1973	24	61	0.56	0.55	0.40	1.5	-	-	-	0.0016	0.057
73S39	125' N & 10' E 0-2" Deep	1973	21	60	0.49	0.43	0.40	1.4	-	-	-	0.0012	0.069
	Soil Cores												
73S30	20' E of NE Corner 5-6' Deep	1973	24	56	-	-	-	-	-	-	-	-	-
75S22	15' E of NE Corner 4.5-6' Deep	1975	28	56	0.43	0.60	0.32	1.4	0.56	0.036	0.82	0.0005	0.0035
73S31	10' N of N Center 5-6' Deep	1973	20	51	-	-	-	-	-	-	-	-	-
75S23	15' N of N Center 4-5' Deep	1975	25	52	0.27	0.34	0.27	1.7	0.61	0.019	0.86	0.0006	0.0047
75S41	17' N of N Center 2.5-3' Deep	1975	29	68	0.34	0.52	0.42	2.1	0.83	0.035	0.96	0.0001	0.0040
73S32	20' N of NW Corner 3-4' Deep	1973	35	66	-	-	-	-	-	-	-	-	-
75S24	15' N of NW Corner 2-3' Deep	1975	36	63	0.54	0.64	0.42	4.3	2.6	0.10	2.8	0.0014	0.068
73S33	20' SE of SE Corner 1-2' Deep	1973	27	104	-	-	-	-	-	-	-	-	-
75S21	15' SE of SE Corner 2-3' Deep	1975	28	105	0.35	0.63	0.44	2.3	0.76	0.033	1.2	0.0020	0.22
	Bottom Sediment												
73BS21	Location A	1973	27	62	0.50	0.66	0.38	1.9	-	-	-	0.0002	0.013
75BS19	Location A	1975	27	60	0.45	0.51	0.29	2.4	0.76	0.033	0.97	0.0007	0.012
73BS22	Location B	1973	25	59	0.47	0.67	0.39	1.3	-	-	-	0.0005	0.011
75BS20	Location B	1975	24	44	0.33	0.44	0.22	1.7	0.64	0.024	0.77	0.0003	0.0055
73BS23	Location C	1973	25	51	0.48	0.57	0.34	1.2	-	-	-	0.0003	0.021
75BS21	Location C	1975	25	45	0.22	0.38	0.24	1.1	0.46	0.013	0.58	0.0006	0.010
73BS24	Location D	1973	26	54	0.50	0.57	0.38	1.4	-	-	-	0.0008	0.039
75BS22	Location D	1975	24	47	0.22	0.37	0.26	1.8	0.71	0.028	0.90	0.0007	0.041

*This first distance and direction is measured from the NW corner of the plot. The second is measured from the center of the swale.

**Results of fluorometric analysis converted to pCi with the assumption that the isotopic composition is that of natural uranium.

speculated that the activity was accidently spread on the surface during operations of burial or storage bin removal. The activity was centered in a small swale which drains the west side of Plot M and may have been washed from the Plot M area to its present location by precipitation runoff. The elevated concentrations appear to be limited to the area 50-200 feet north of the northwest corner and within a few feet of the bed of the swale. Some of the stream bed and soil results, including the effect of fallout on beta activities, are discussed in more detail in reports ANL-5446, ANL-5684, ANL-6047, ANL-6736, and ANL-7104.

The 1971 sampling effort attempted to examine any downward migration of the uranium activity into the soil. A number of samples were collected in two segments, 0-2 in. and 2-6 in., at various locations. A comparison of nonvolatile alpha and beta activities at the two depths showed little difference, which indicates some downward movement of uranium.

Some 1973 and 1975 samples were also analyzed for thorium, uranium, and plutonium as well as total activity, and these data are collected in Table 5. These results demonstrate that the bulk of the above-normal activity levels is uranium of natural isotopic composition. Accompanying this uranium in most cases are smaller amounts of plutonium above the usual fallout levels. The latter range up to about 0.05 pCi/g. Only one sample outside of the area north of the northwest corner of the Plot (the cross-hatched area in Figure 4) - 75S21 - contained an abnormal plutonium concentration, 0.22 pCi/g. The uranium concentration in this sample was normal. The uranium and plutonium concentrations were normal in the other samples, and the thorium concentrations were normal in all samples. The bottom sediment samples did not show any significant differences between locations.

The potential radiation exposure from the uranium and plutonium found in the surface soil can be estimated by assuming the pathway for exposure is by inhalation of suspended soil. Soil resuspension factors measured in our laboratory for vegetation-covered soil are (1 to 5) x 10^{-10} m^{-1}. These factors agree with published values.* Such resuspension factors applied to average

*Bennet, B. G., U.S.A.E.C. Report WASH-1359 (1974), pp. 132-133.

surface soil concentrations in the Plot M area of about 10 pCiU/g and 0.2 pCiPu/g give air concentrations of about 0.4 fCiU/m^3 and 8 x 10^{-3} fCiPu/m^3. Air breathed continuously at these concentrations would result in doses of less than 0.2 mrem/year. For comparison purposes, the natural background dose is about 100 mrem/year and the EPA limit for radionuclides in public water supplies is based on a dose of 4 mrem/year.

Water samples were also taken from several Forest Preserve District wells north of Plot M beginning in 1973. Elevated concentrations of tritiated water were found in some of these wells, particularly the Red Gate Woods well. These were the first water samples from the Site A/Plot M area analyzed for tritiated water (hydrogen-3) and the first indication that radioactive material had migrated. The tritium concentrations ranged from less than the detection limit, 200 pCi/l, up to 1.3 x 10^4 pCi/l. The concentrations varied seasonally, with a maximum in the winter and a minimum in the summer. Analyses of samples from the Red Gate Woods well for other radionuclides gave normal results. All of the measurements made on the well samples are listed and discussed later in this report. Water samples from three small ponds near Site A were collected in 1975 and analyzed for tritium. The concentrations were less than the detection limit.

III. SCOPE OF THE SITE A/PLOT M RADIOLOGICAL SURVEY

Based on the information generated from the environmental program carried out at Site A/Plot M between 1954 and 1975, funding was requested early in 1976 to conduct an extensive radiological survey of the Site A/Plot M area as part of a nationwide ERDA program to resurvey former Manhattan District sites.* The survey was designed to characterize the radiological environment in the area with special emphasis on the immediate vicinity of Plot M. The study was planned to reveal the reasons for the elevated tritiated water content in some of the wells in the Forest Preserve and to establish if other radionuclides buried in Plot M or remaining at Site A have migrated from their original locations. The survey was divided into four principal parts:

---

*Survey and analytical work conducted by L. R. Gibes, B. J. Metta, N. W. Golchert, J. Sedlet, F. S. Iwami, and H. C. Svoboda of the Occupational Health and Safety Division, Argonne National Laboratory, Argonne, Illinois

1. Radiochemical analyses of water from all existing wells in the area.
2. Radiochemical analyses of soil borings at Plot M and Site A, and of surface soil and vegetation samples from the entire Site A area.
3. Drilling several additional wells to measure radioactivity in groundwater near Site A and Plot M, and to provide hydrological information.
4. A study of the geohydrology of the area to determine the rate and direction of groundwater flow in the Forest Preserve.

It was apparent from the results obtained for the picnic wells north of the site that a knowledge of the underground hydrology of the area was essential to explain past and predict future migration of radionuclides from Plot M and/or Site A. For this purpose, the Madison, Wisconsin, office of the Water Resources Division of the USGS was retained as a consultant on the groundwater studies and upon completion of these studies a report will be issued.

A principal purpose of the survey was to obtain information to determine if remedial action would be required to assure that any radioactive materials remaining at Site A/Plot M will not cause a health hazard in the future.

IV. STUDIES AT PLOT M

A. Inventory by Recollection

It would be useful to have a record of the radioactive material placed in Plot M. Since documentation is not available, attempts were made to obtain this information from individuals who might have such knowledge.

Interviews were conducted with twelve people who were at the Laboratory during the time Plot M was used for burial, 1943-49. These individuals included laboratory workers who generated waste that was buried in the Plot and health physicists and others who surveyed waste and actually placed material in the trenches.

Most individuals could provide only very qualitative information. The interviews confirmed that irradiated uranium, fission products, many of the actinide elements, and hydrogen-3, all in various forms, e.g., solutions,

solids, contaminated laboratory equipment, injected laboratory animal carcasses, etc., were buried. The amounts of each element or nuclide could not be ascertained in this way and remain unknown.

The best information came from a few individuals who worked on the project for separating tritium from neutron-irradiated lithium, first as lithium fluoride and later as slugs of lithium-aluminum alloy. The tritium was released as the gas from the irradiated lithium by heating, pumped into a glass bulb, and the bulb sealed off. This work was done in a vacuum system. An estimate was made that about 500 slugs were processed, each containing 50-200 Ci of tritium, and perhaps 1-2% was not recovered and could have been buried with the irradiated slugs and contaminated equipment from the process. The alloy reacts slowly with water. These figures give a maximum tritium burial of 500 x 200 x 0.02, or 2000 Ci. This value is too small to account for all the tritium found in and near the Plot, and most of this work was said to be done from 1948 to 1953. The individual who was appointed custodian of the burial grounds on July 6, 1948, has stated that waste was being buried in bins at that time.

B. Subsurface Soil

The initial effort of the present study was to determine if any radioactive materials buried within Plot M had migrated from their original location. It was presumed that the tritium (as water) in the wells north of the Plot had originated in the Plot. Since the concrete cap was not put on the area until 1956, precipitation was able to infiltrate the buried material for several years, and a considerable vertical and horizontal subsurface examination was necessary.

In the spring of 1976, ten soil borings were dug at various locations around Plot M. The locations were selected in consultation with representatives of the United States Geological Survey, who had been retained as consultants on the entire project. A commercial firm which specializes in this work was hired to bore the holes and obtain the samples. The first eight holes were bored vertically to a depth of 40 feet. Two other holes were bored at a 45° angle from the edge of the burial area, under the side wall and nearby trenches to

obtain samples from under the buried material. These two holes (#9 and #10) were drilled to a total length of 60 feet, which placed the final samples about 40 feet vertically below the surface and 40 feet horizontally from the starting point. From all borings, two-inch Shelby tube samples were taken every two feet down to ten feet and every five feet thereafter. The locations are depicted in Figure 5.

The core samples, after extrusion from the Shelby tubes, were characterized as to composition by visual inspection, wrapped to retain the soil moisture, and delivered to ANL. In preparation for radiochemical analysis, the individual core samples were first dried and the soil moisture collected for tritiated water analysis and to measure the water content of the soil. Tritiated water analyses were performed by liquid scintillation counting in a gel system. The dried soil was pulverized, milled, and mixed. Aliquots of the soil were taken for gamma-ray spectrometric, strontium-90, uranium, and plutonium analyses. Gamma-ray spectrometry utilized a shielded lithium-drifted germanium diode detector calibrated for each gamma-ray emitting nuclide of interest. Samples were leached with mineral acids, including hydrofluoric, for radiochemical analysis. The strontium-90 was determined by a standard radiochemical separation procedure. Uranium was determined fluorophotometrically, and the results calculated in terms of activity with the assumption that the isotopic composition was that of natural uranium, or by chemical separation and alpha spectrometry. Plutonium and thorium were separated on an anion exchange column, electrodeposited, and the isotopic composition determined by alpha spectrometry. Chemical recovery was monitored by the isotope dilution technique. Alpha spectrometry cannot distinguish between plutonium-239 and plutonium-240, and although throughout this report, including the tables, only plutonium-239 is mentioned, it should be understood that the alpha activity due to the plutonium-240 isotope is also included.

Studies at the Oak Ridge National Laboratory waste burial facility and elsewhere have found that the nuclides of interest in this study would migrate through the soil in the following order: H > Sr > (U, Pu, Cs).* The migration

*J. Duguid, Battelle-Columbus Laboratory, Personal Communication, Sept. 1977.

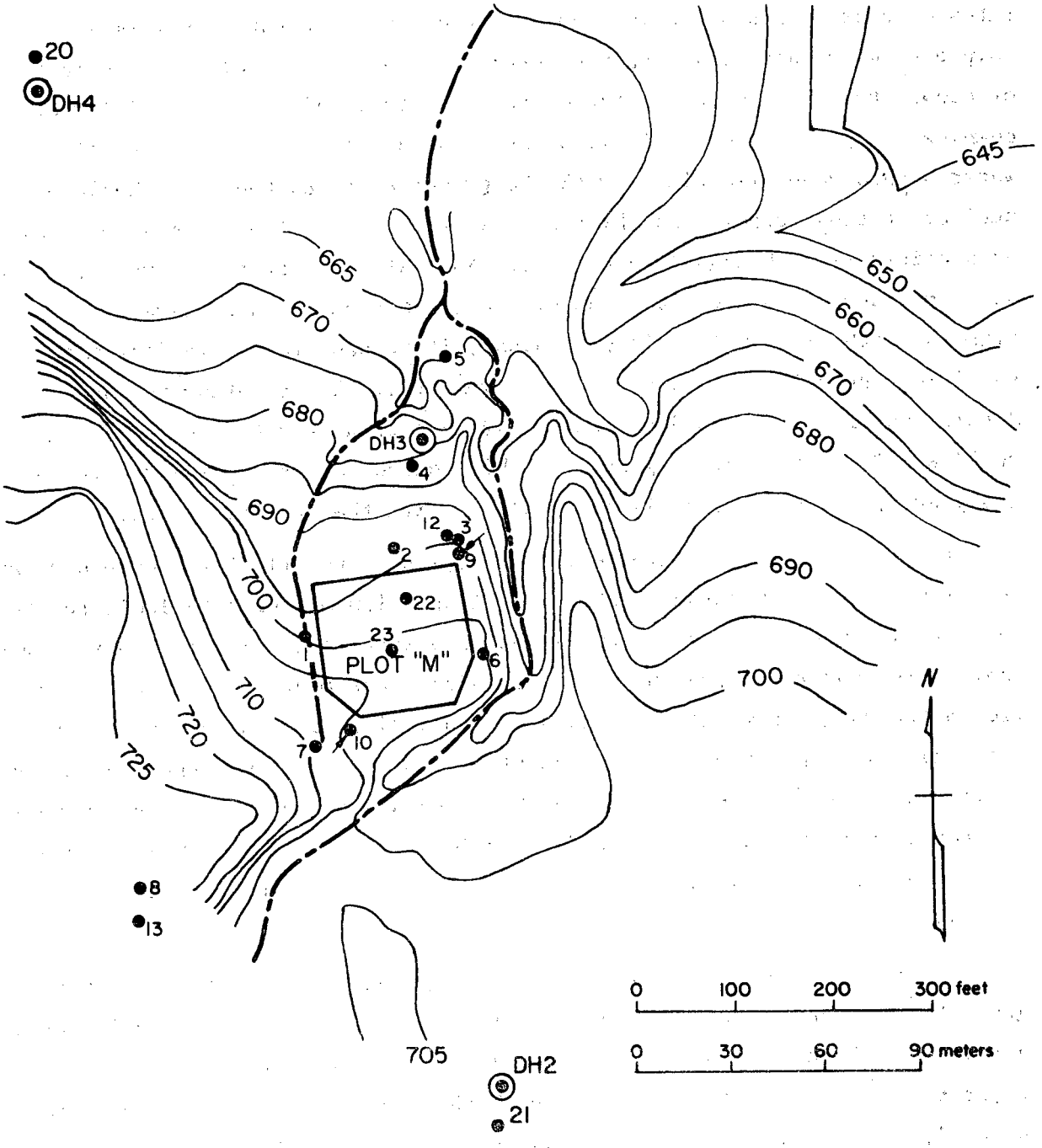


Fig. 5. Location of Soil Borings (•) and Dolomite Bedrock Holes (◉DH) Near Plot M.

rates of plutonium and uranium can vary greatly since they can form soluble complexes with naturally-occurring organic materials. They may move faster or slower than cesium, depending on the soil type and the availability of complexing agents. Cesium is strongly bound by clay soils. The tritiated water should move essentially with the groundwater and the rate should be subject to those conditions which generally affect soil water movement: amount of precipitation, hydraulic head, etc. Following the tritiated water, although at a considerably slower rate, should be the strontium, and therefore, strontium-90 is the key nuclide in this study, if it was present in Plot M in sufficient quantity. If the rate of movement of the strontium-90 can be determined, it can be used to predict if, and at what rate, the slower moving nuclides of interest are migrating within the burial area. The results of analyses for other radionuclides should confirm the strontium data.

The results of the radiochemical analysis of the first ten core samples are given in Table 6 through Table 15. Inspection of the data indicates that no plutonium was detected in any of the core samples, including those from the angle holes under the trenches. The uranium concentrations were normal and are in the range of results obtained for soil elsewhere in the Chicago area. The cesium-137 and strontium-90 concentrations were all less than the detection limit, except those core samples which included surface soil. These samples had concencentrations attributable to fallout from previous atmospheric nuclear tests. No other gamma-ray emitting fission or activation products were detected.

The tritiated water concentrations are given in terms of activity per gram of soil, for direct comparison to the other measurements, and in activity per volume of water. These data show elevated concentrations of tritiated water throughout the Plot M area. The highest concentration in the vertical holes is at 40 feet of Core #2. This is the closest core to the Plot in the northerly direction, which is the expected direction of water flow. There exists a general pattern in the distribution of tritium with depth in Cores #1 through #6, although the magnitude of the concentrations is different. In general, the tritiated water concentration increases to a maximum from 10 to 30 feet below the surface, then decreases. Several of the cores show

TABLE 6

Plot M - Core #1 (3/30/76)

Sample Number	Depth (feet)	Water Content	^{3}H nCi/l	^{3}H pCi/g	^{90}Sr pCi/g	^{137}Cs pCi/g	U pCi/g	^{238}Pu fCi/g	^{239}Pu fCi/g
76S7	0-2	21.3%	2.1	0.45	0.18	0.18	3.0	-	-
76S8	2-4	19.4%	3.5	0.68	-	-	-	-	-
76S9	4-6	17.0%	3.2	0.54	-	-	-	-	-
76S10	6-8	15.6%	3.3	0.51	< 0.1	< 0.1	2.2	< 0.1	< 0.1
76S11	10-10.5	13.1%	21.9	2.9	-	-	-	-	-
76S12	12-13	11.6%	145	16.8	-	< 0.1	-	-	-
76S13	15-16.5	12.0%	225	27.0	< 0.1	< 0.1	2.3	< 0.1	< 0.1
76S14	20-22	12.3%	8.34×10^{3}	1.03×10^{3}	-	< 0.1	2.0	-	-
76S15	25-27	10.8%	2.44×10^{4}	2.64×10^{3}	< 0.1	< 0.1	1.4	< 0.1	< 0.1
76S16	30-32	11.7%	1.14×10^{4}	1.33×10^{3}	-	< 0.1	2.2	< 0.1	< 0.1
76S17	35-37	9.7%	3.64×10^{3}	353	< 0.1	< 0.1	1.6	< 0.1	< 0.1
76S18	40-41.5	13.9%	1.80×10^{4}	2.50×10^{3}	-	< 0.1	-	-	-

TABLE 7

Plot M - Core #2 (4/6/76)

Sample Number	Depth (feet)	Water Content	^{3}H nCi/l	^{3}H pCi/g	^{90}Sr pCi/g	^{137}Cs pCi/g	U pCi/g	^{238}Pu fCi/g	^{239}Pu fCi/g
76S41	0-2	21.4%	3.5	0.75	< 0.1	0.10	2.6	-	-
76S42	2-4	17.4%	5.5	0.96	-	-	-	-	-
76S43	4-6	14.7%	5.2	0.77	-	-	-	-	-
76S44	6-7	12.9%	6.9	0.90	-	-	-	-	-
76S45	10.5-12.5	12.1%	3.9	0.47	< 0.1	< 0.1	1.8	< 0.1	< 0.1
76S46	15-17	11.2%	23.1	2.6	< 0.1	< 0.1	1.8	< 0.1	< 0.1
76S47	20-22	11.9%	3.50×10^{3}	417	-	< 0.1	1.8	-	-
76S48	25-27	10.0%	5.69×10^{3}	569	< 0.1	< 0.1	1.8	< 0.1	< 0.1
76S49	30-32	12.3%	1.29×10^{4}	1.59×10^{3}	-	< 0.1	2.4	-	-
76S50	35-37	11.7%	4.63×10^{4}	5.42×10^{3}	< 0.1	< 0.1	2.5	< 0.1	< 0.1
76S51	40-40.5	9.3%	6.16×10^{4}	5.73×10^{3}	-	-	-	-	-

TABLE 8

Plot M - Core #3 (4/6/76)

Sample Number	Depth (feet)	Water Content	^{3}H nCi/l	^{3}H pCi/g	^{90}Sr pCi/g	^{137}Cs pCi/g	U pCi/g	^{238}Pu fCi/g	^{239}Pu fCi/g
76S63	0-2	20.2%	11.1	2.2	0.12	0.22	2.6	-	-
76S64	2-4	16.4%	28.5	4.7	-	-	-	-	-
76S65	4-6	13.5%	7.5	1.0	-	-	-	-	-
76S66	6-8	10.4%	28.9	3.0	-	-	-	-	-
76S67	10-10.5	10.7%	539	57.7	< 0.1	< 0.1	1.5	< 0.1	< 0.1
76S68	15-16.5	13.4%	3.38×10^{3}	452	-	< 0.1	2.0	-	-
76S69	20-22	11.4%	1.02×10^{4}	1.16×10^{3}	< 0.1	< 0.1	1.7	< 0.1	< 0.1
76S70	25-26.5	8.5%	1.28×10^{4}	1.09×10^{3}	-	< 0.1	3.2	-	-
76S71	30-32	13.5%	2.24×10^{4}	3.02×10^{3}	< 0.1	< 0.1	1.8	< 0.1	< 0.1
76S72	35-37	11.5%	3.96×10^{3}	456	-	< 0.1	2.0	-	-
76S73	40-42	13.2%	1.26×10^{4}	1.66×10^{3}	< 0.1	< 0.1	2.0	< 0.1	< 0.1

TABLE 9

Plot M - Core #4 (4/7/76)

Sample Number	Depth (feet)	Water Content	^{3}H nCi/l	^{3}H pCi/g	^{90}Sr pCi/g	^{137}Cs pCi/g	U pCi/g	^{238}Pu fCi/g	^{239}Pu fCi/g
76S52	0-2	21.5%	40.0	8.6	< 0.1	< 0.1	2.5	-	-
76S53	2.5-4.5	14.3%	51.3	7.3	-	-	-	-	-
76S54	5-6	12.7%	114	14.5	-	-	-	-	-
76S55	7.5-9.5	11.9%	205	24.4	-	-	-	-	-
76S56	10-12	13.1%	2.80×10^{3}	367	< 0.1	< 0.1	2.2	< 0.1	< 0.1
76S57	16.5-17.5	12.5%	1.09×10^{4}	1.36×10^{3}	-	< 0.1	1.9	-	-
76S58	20-22	9.8%	2.59×10^{4}	2.54×10^{3}	< 0.1	< 0.1	1.7	< 0.1	< 0.1
76S59	25-27	11.0%	1.98×10^{3}	218	-	< 0.1	1.8	-	-
76S60	30-32	11.8%	713	84.1	< 0.1	< 0.1	1.8	< 0.1	< 0.1
76S61	35-37	11.1%	3.27×10^{3}	363	-	< 0.1	1.8	-	-
76S62	40-42	10.8%	3.20×10^{4}	3.46×10^{3}	< 0.1	< 0.1	1.5	< 0.1	< 0.1

TABLE 10

Plot M - Core #5 (4/8/76)

Sample Number	Depth (feet)	Water Content	^{3}H nCi/l	^{3}H pCi/g	^{90}Sr pCi/g	^{137}Cs pCi/g	U pCi/g	^{238}Pu fCi/g	^{239}Pu fCi/g
76S85	0-2	20.7%	1.4	0.29	< 0.1	0.49	2.0	-	-
76S86	2-4	12.6%	3.5	0.44	-	-	-	-	-
76S87	4-5	10.6%	49.3	5.2	-	-	-	-	-
76S88	6-8	11.6%	532	61.7	-	-	-	-	-
76S89	10-12	11.6%	1.35×10^{3}	156	< 0.1	< 0.1	1.6	< 0.1	< 0.1
76S90	15-17	10.2%	208	21.2	-	< 0.1	1.5	-	-
76S91	20-21	9.2%	110	10.1	< 0.1	< 0.1	1.6	< 0.1	< 0.1
76S92	25-27	10.6%	349	37.0	-	< 0.1	1.9	-	-
76S93	30-32	11.7%	44.2	5.2	< 0.1	< 0.1	1.6	< 0.1	< 0.1
76S94	35-37	11.8%	3.1	0.37	-	< 0.1	2.2	-	-
76S95	40-42	11.9%	6.0	0.71	< 0.1	< 0.1	1.8	< 0.1	< 0.1

TABLE 11

Plot M - Core #6 (4/5/76)

Sample Number	Depth (feet)	Water Content	^{3}H nCi/l	^{3}H pCi/g	^{90}Sr pCi/g	^{137}Cs pCi/g	U pCi/g	^{238}Pu fCi/g	^{239}Pu fCi/g
76S30	0-2	16.9%	1.4	0.23	0.14	< 0.1	2.4	-	-
76S31	2.5-4.5	18.3%	0.78	0.14	-	-	-	-	-
76S32	5-7	13.9%	2.8	0.39	-	-	-	-	-
76S33	7.5-9.5	10.6%	26.0	2.8	-	-	-	-	-
76S34	10-12	12.0%	242	28.9	0.1	< 0.1	1.9	< 0.1	< 0.1
76S35	15-17	12.1%	1.10×10^3	133	-	< 0.1	-	-	-
76S36	20-21.5	11.0%	2.31×10^3	254	< 0.1	< 0.1	2.0	< 0.1	< 0.1
76S37	25-26	10.9%	1.58×10^3	172	-	< 0.1	2.2	< 0.1	< 0.1
76S38	30-30.5	8.8%	1.09×10^3	95.6	< 0.1	< 0.1	1.9	< 0.1	< 0.1
76S39	35-36.5	10.9%	70.1	7.6	-	< 0.1	1.8	< 0.1	< 0.1
76S40	40-41.5	10.7%	36.4	3.9	< 0.1	< 0.1	1.6	< 0.1	< 0.1

TABLE 12

Plot M - Core #7 (4/1/76)

Sample Number	Depth (feet)	Water Content	^{3}H nCi/l	^{3}H pCi/g	^{90}Sr pCi/g	^{137}Cs pCi/g	U pCi/g	^{238}Pu fCi/g	^{239}Pu fCi/g
76S19	0-2	16.1%	3.1	0.50	< 0.1	0.34	2.5	-	-
76S20	2.5-4.5	19.3%	0.63	0.12	-	-	-	-	-
76S21	5-7	14.9%	0.39	0.06	-	-	-	-	-
76S22	7.5-9.5	13.2%	1.1	0.15	-	< 0.1	-	-	-
76S23	10-12	12.9%	1.9	0.24	< 0.1	< 0.1	2.0	< 0.1	< 0.1
76S24	15-17	13.0%	4.1	0.53	-	< 0.1	-	-	-
76S25	20-22	11.6%	6.5	0.75	< 0.1	< 0.1	2.2	< 0.1	< 0.1
76S26	25-27	9.8%	1.3	0.13	-	< 0.1	1.8	-	-
76S27	30-32	12.2%	1.5	0.18	< 0.1	< 0.1	2.2	< 0.1	< 0.1
76S28	35-36.5	8.4%	2.7	0.22	-	< 0.1	1.9	-	-
76S29	40-41.5	13.9%	0.99	0.14	< 0.1	< 0.1	2.3	< 0.1	< 0.1

TABLE 13

Plot M - Core #8 (4/8/76)

Sample Number	Depth (feet)	Water Content	^{3}H nCi/l	^{3}H pCi/g	^{90}Sr pCi/g	^{137}Cs pCi/g	U pCi/g	^{238}Pu fCi/g	^{239}Pu fCi/g
76S74	0-2	20.2%	0.75	0.15	< 0.1	< 0.1	2.9	-	-
76S75	2-4	17.9%	1.1	0.19	-	-	-	-	-
76S76	4-5	14.1%	3.2	0.45	-	-	-	-	-
76S77	6-7	13.9%	0.83	0.12	-	-	-	-	-
76S78	10-11	11.3%	2.7	0.31	< 0.1	< 0.1	3.3	< 0.1	< 0.1
76S79	15-17	12.3%	2.0	0.25	-	< 0.1	1.8	-	-
76S80	20-22	12.5%	11.1	1.4	< 0.1	< 0.1	2.4	< 0.1	< 0.1
76S81	25-27	11.6%	1.5	0.17	-	< 0.1	2.3	-	-
76S82	30-32	11.4%	0.90	0.10	< 0.1	< 0.1	2.2	< 0.1	< 0.1
76S83	35-35.5	10.4%	11.5	1.2	-	< 0.1	2.2	-	-
76S84	40-42	13.8%	2.8	0.39	< 0.1	< 0.1	2.1	< 0.1	< 0.1

TABLE 14

Plot M - Core #9 (4/23/76 & 4/28/76) - Slant Core in NE Corner

Sample Number	Depth* (feet)	Water Content	^{3}H nCi/l	^{3}H pCi/g	^{90}Sr pCi/g	^{137}Cs pCi/g	U pCi/g	^{238}Pu fCi/g	^{239}Pu fCi/g
76S111	2-4	16.9%	29.0	4.9	-	-	-	-	-
76S112	5-7	15.9%	433	68.8	-	-	-	-	-
76S113	7.5-9.5	13.5%	33.9	4.6	-	-	-	-	-
76S114	10-12	11.1%	22.9	2.5	< 0.1	< 0.1	2.6	< 0.1	< 0.1
76S115	15-17	11.7%	365	42.7	-	-	-	-	-
76S116	20-22	10.4%	9.75×10^{4}	1.01×10^{4}	< 0.1	< 0.1	1.9	< 0.1	< 0.1
76S117	25-27	12.4%	2.06×10^{5}	2.55×10^{4}	-	-	-	-	-
76S118	30-32	13.3%	1.13×10^{5}	1.50×10^{4}	< 0.1	< 0.1	2.4	< 0.1	< 0.1
76S119	35-36	9.9%	1.73×10^{5}	1.71×10^{4}	-	-	-	-	-
76S120	40-42	12.0%	4.88×10^{5}	5.86×10^{4}	< 0.1	< 0.1	2.4	< 0.1	< 0.1
76S121	45-46	11.0%	1.31×10^{5}	1.44×10^{4}	-	-	-	-	-
76S122	50-52	11.4%	2.08×10^{5}	2.37×10^{4}	< 0.1	< 0.1	2.4	< 0.1	< 0.1
76S123	55-56	13.9%	1.05×10^{5}	1.46×10^{4}	-	-	-	-	-
76S124	60-61	13.4%	1.19×10^{5}	1.59×10^{4}	< 0.1	< 0.1	2.2	< 0.1	< 0.1

*Distance from surface starting point.

TABLE 15

Plot M - Core #10 (4/26/76) - Slant Core From South

Sample Number	Depth * (feet)	Water Content	^{3}H nCi/l	^{3}H pCi/g	^{90}Sr pCi/g	^{137}Cs pCi/g	U pCi/g	^{238}Pu fCi/g	^{239}Pu fCi/g
76S96	1-3	12.3%	24.7	3.0	-	-	-	-	-
76S97	3-5	17.0%	89.5	15.2	-	-	-	-	-
76S98	5-7	19.0%	21.4	4.1	-	-	-	-	-
76S99	7.5-9.5	15.7%	26.0	4.1	-	-	-	-	-
76S100	10-11	12.9%	99.1	12.8	< 0.1	< 0.1	2.3	< 0.1	< 0.1
76S101	15-16.5	13.1%	52.6	6.9	-	-	-	-	-
76S102	20-22	12.9%	74.9	9.7	< 0.1	< 0.1	2.2	< 0.1	< 0.1
76S103	25-27	12.3%	47.8	5.9	-	-	-	-	-
76S104	30-32	11.8%	958	113	< 0.1	< 0.1	2.3	< 0.1	< 0.1
76S105	35-37	10.1%	1.33×10^{4}	1.34×10^{3}	-	-	-	-	-
76S106	40-42	9.7%	9.54×10^{4}	9.25×10^{3}	< 0.1	< 0.1	2.3	< 0.1	< 0.1
76S107	45-47	11.1%	3.91×10^{5}	4.34×10^{4}	-	-	-	-	-
76S108	50-51	9.2%	5.38×10^{5}	4.95×10^{4}	< 0.1	< 0.1	2.0	< 0.1	< 0.1
76S109	55-56	8.3%	3.78×10^{5}	3.14×10^{4}	-	-	-	-	-
76S110	60.5-61.5	12.4%	4.16×10^{5}	5.16×10^{4}	< 0.1	< 0.1	2.7	< 0.1	< 0.1

*Distance from surface staring point.

subsequent increases in the deepest samples. The depth measurements for each core hole have not been normalized to each other in the tables. The Geohydrology report will provide this information and profiles of the subsurface tritium distribution based on the core measurements. For example, Figure 5 indicates a 25-foot difference in surface elevation between Core #2 and Core #5. None of the borings was deep enough to show the extent to which tritium has penetrated the soil. The two slant holes, Core #9 and Core #10, had the expected tritiated water distribution. The concentrations were relatively low until samples were obtained from below the buried material, at which point the concentrations increased sharply. The levels were about an order of magnitude higher than the concentrations in the vertical holes around Plot M. This finding and the higher concentrations in soil, down-gradient from the Plot, e.g., Core #2 compared with Core #7, confirm that the tritium found in the wells north of the Plot originated in the buried material.

Core #7, up-gradient from Plot M, and Core #8, which was intended as a control, show significantly lower concentrations of tritiated water compared with the other cores. It is difficult to explain the levels of tritiated water found in what was to be a control core, although the highest results (> 1.0 pCi/g) could have been due to cross-contamination in the analytical laboratory. After these results were obtained, the laboratory operations were modified to preclude this possibility.

In order to verify that the tritiated water concentrations were accurately determined, two additional holes were bored. One hole, Core #12, was drilled next to Core #3, and the other, Core #13, was drilled next to Core #8, and tritiated water measured in the resulting samples. A comparison of tritium concentrations in Cores #3 and #12 is in Table 16 and a comparison of Cores #8 and #13 is in Table 17. The agreement between Cores #3 and #12 is excellent, both in magnitude and distribution. This provides confidence that the measurements were accurate. Comparison of the results of Cores #8 and #13 indicates that small amounts of subsurface tritiated water are actually present substantially up-gradient from Plot M.

In the fall of 1976, two additional holes were drilled in the Plot M area to obtain further information on the underground tritium distribution. Core #20

TABLE 16

Plot M - Comparison of Tritiated Water Concentrations
Cores #12 and #3

Core #12 (5/26/76) Sample Number	Depth (feet)	^3H nCi/l	Core #3 (4/6/76) Sample Number	Depth (feet)	^3H nCi/l
76S136	0-2	44.3	76S63	0-2	11.1
76S137	2-4	21.6	76S64	2-4	28.5
76S138	4-6	7.8	76S65	4-6	7.5
76S139	6-6.5	31.8	76S66	6-8	28.9
76S140	10-11.5	351	76S67	10-10.5	539
76S141	15-16.5	2.05×10^3	76S68	15-16.5	3.38×10^3
76S142	20-22	1.42×10^4	76S69	20-22	1.02×10^4
76S143	25-27	1.68×10^4	76S70	25-26.5	1.28×10^4
76S144	30-32	2.50×10^4	76S71	30-32	2.24×10^4
76S145	35-37	1.96×10^4	76S72	35-37	3.96×10^3
76S146	40-42	6.29×10^3	76S73	40-42	1.26×10^4

TABLE 17

Plot M - Comparison of Tritiated Water Concentrations
Cores #13 and #8

Core #13 (5/26/76)			Core #8 (4/8/76)		
Sample Number	Depth (feet)	^3H nCi/l	Sample Number	Depth (feet)	^3H nCi/l
76S147	0-2	1.7	76S74	0-2	0.75
76S148	2-4	3.8	76S75	2-4	1.1
76S149	4-5.5	1.4	76S76	4-5	3.2
76S150	6-7.5	5.5	76S77	6-7	0.83
76S151	10-12	2.1	76S78	10-11	2.7
76S152	15-17	0.74	76S79	15-17	2.0
76S153	20-22	0.93	76S80	20-22	11.1
76S154	25-27	4.7	76S81	25-27	1.5
76S155	30-32	0.64	76S82	30-32	0.90
76S156	35-36	3.6	76S83	35-35.5	11.5
76S157	40-41.5	0.44	76S84	40-42	2.8

was midway between Plot M and the Red Gate Woods well (Figure 2). Core #21 was south of Plot M, across the intermittent stream between Plot M and Site A (Figure 5). All samples were analyzed for tritiated water. Two samples from each core were analyzed for strontium-90, uranium, plutonium, and gamma-ray emitters. The results are in Table 18 and Table 19. All the strontium-90, plutonium, and gamma-ray spectrometric analyses were less than the detection limit and the uranium results were normal. The tritium concentrations were relatively low between Plot M and Site A, but were higher in Core #20, between Red Gate Woods and Plot M.

To aid in understanding the subsurface tritium data around Plot M, it is useful to compare these data to the results for two cores dug at locations sufficiently removed from the Palos Forest Preserve so that any tritium detected could not be attributed to Site A/Plot M operations. These two control cores were Core #18 in Argonne Park, about 4 mi west of Site A/Plot M, and Core #19 on 104th Ave. near Route 83, about 2.5 mi southeast of Site A/Plot M (Figure 1). The results are in Table 20 and Table 21. Although the tritiated water concentrations in some samples from Cores #18 and #19 were less than the detection limit, positive values were obtained at the five to ten foot depth and again at the 30 foot depth. Such concentrations and distributions can reasonably be expected as a result of fallout from atmospheric nuclear tests. On this basis, Core #21 would be considered normal, whereas Core #20 contains some tritium from the Plot M waste material. This conclusion is based on the depth distribution, not on absolute concentration. Comparison of the tritiated water concentrations for Cores #8 and #13 (Table 17) to the control cores indicates that tritium in these cores is elevated, and the source is probably from Plot M or other operations at Site A.

In the spring of 1977, two cores were dug through and beneath Plot M to measure the radioactivity distribution with depth directly under the buried material. One hole was dug in the north half of the burial area where waste had been in metal containers, which were later removed, and the second was dug in the area where waste was placed in trenches. The first 10 feet of the hole was cased off with pipe to prevent possible contamination of soil samples collected at greater depths with the buried waste material. After all the samples

TABLE 18

Core #20 (10/1/76) - Between Red Gate Woods and Plot M

Sample Number	Depth (feet)	Water Content	^{3}H nCi/l	^{3}H pCi/g	^{90}Sr pCi/g	^{234}U pCi/g	^{235}U pCi/g	^{238}U pCi/g	^{238}Pu fCi/g	^{239}Pu fCi/g	γ* pCi/g
76S278	0-1.5		0.26	-	-	-	-	-	-	-	-
76S279	5-6.5		< 0.2	-	-	-	-	-	-	-	-
76S280	10-11.5		0.37	-	-	-	-	-	-	-	-
76S281	15-16.5		0.57	-	-	-	-	-	-	-	-
76S282	20-21.5		0.50	-	-	-	-	-	-	-	-
76S283	27-28.5	14.3%	0.64	0.09	< 0.1	0.77	0.032	0.89	< 0.1	< 0.1	< 0.1
76S284	30-31.5		0.53	-	-	-	-	-	-	-	-
76S285	35-36.5		0.64	-	-	-	-	-	-	-	-
76S286	40-41.5		0.28	-	-	-	-	-	-	-	-
76S287	45-45.8		< 0.2	-	-	-	-	-	-	-	-
76S288	50-51.5		0.36	-	-	-	-	-	-	-	-
76S289	55-55.5	14.6%	0.38	0.06	< 0.1	0.83	0.038	0.89	< 0.1	< 0.1	< 0.1
76S290	60-61.5		< 0.2	-	-	-	-	-	-	-	-

*Each gamma-ray emitting fission or activation product.

TABLE 19

Core #21 (10/1/76) - Between Plot M and Site A

Sample Number	Depth (feet)	Water Content	^{3}H nCi/l	^{3}H pCi/g	^{90}Sr pCi/g	^{234}U pCi/g	^{235}U pCi/g	^{238}U pCi/g	^{238}Pu fCi/g	^{239}Pu fCi/g	γ* pCi/g
76S291	0-1.5		0.21	-	-	-	-	-	-	-	-
76S292	5-6.5		0.24	-	-	-	-	-	-	-	-
76S293	10-11.5		0.53	-	-	-	-	-	-	-	-
76S294	15-16.5		0.58	-	-	-	-	-	-	-	-
76S295	20-21.5		0.38	-	-	-	-	-	-	-	-
76S296	25-26.5	10.2%	< 0.2	< 0.03	< 0.1	0.71	0.022	0.77	< 0.1	< 0.1	< 0.1
76S297	30-31.5		< 0.2	-	-	-	-	-	-	-	-
76S298	35-36.5		< 0.2	-	-	-	-	-	-	-	-
76S299	40-41.5		< 0.2	-	-	-	-	-	-	-	-
76S300	45-46.5		< 0.2	-	-	-	-	-	-	-	-
76S301	50-51.5		< 0.2	-	-	-	-	-	-	-	-
76S302	55-56.5		< 0.2	-	-	-	-	-	-	-	-
76S303	60-61.5		0.34	-	-	-	-	-	-	-	-
76S304	65-66.5		< 0.2	-	-	-	-	-	-	-	-
76S305	70-71.5		< 0.2	-	-	-	-	-	-	-	-
76S306	75-76.5	13.8%	0.46	0.06	< 0.1	0.35	0.015	0.44	< 0.1	< 0.1	< 0.1

*Each gamma-ray emitting fission or activation product.

TABLE 20

Core #18 (9/27/76) - Argonne Park

Sample Number	Depth (feet)	Water Content	^{3}H nCi/g	^{3}H pCi/g	^{90}Sr pCi/g	^{234}U pCi/g	^{235}U pCi/g	^{238}U pCi/g	^{238}Pu fCi/g	^{239}Pu fCi/g	γ* pCi/g
76S251	0-1.5	11.1%	< 0.2	< 0.03	-	-	-	-	-	-	< 0.1
76S252	5-6.5	16.0%	0.30	0.05	-	-	-	-	-	-	< 0.1
76S253	10.5-12	13.0%	0.52	0.07	< 0.1	0.45	0.02	0.53	< 0.1	< 0.1	< 0.1
76S254	15-16.5	11.3%	< 0.2	< 0.03	-	-	-	-	-	-	< 0.1
76S255	20-21.5	13.6%	< 0.2	< 0.03	-	-	-	-	-	-	< 0.1
76S256	25-26.5	11.0%	< 0.2	< 0.03	-	-	-	-	-	-	< 0.1
76S257	30-31	12.4%	0.30	0.04	-	-	-	-	-	-	< 0.1
76S258	31-31.5	12.2%	0.23	0.03	-	-	-	-	-	-	< 0.1
76S259	35-36.5		0.27	-	-	-	-	-	-	-	-
76S260	40-41.5		< 0.2	-	-	-	-	-	-	-	-
76S261	45-46.5	11.8%	< 0.2	< 0.03	< 0.1	0.50	0.02	0.59	< 0.1	< 0.1	< 0.1
76S262	50-51.5		< 0.2	-	-	-	-	-	-	-	-
76S263	55-56.5		< 0.2	-	-	-	-	-	-	-	-
76S264	60-61.5		< 0.2	-	-	-	-	-	-	-	-

*Each gamma-ray emitting fission or activation product.

TABLE 21

Core #19 (9/29/76) - 104th Ave., South of Route 83

Sample Number	Depth (feet)	Water Content	^{3}H nCi/l	^{3}H pCi/g	^{90}Sr pCi/g	^{234}U pCi/g	^{235}U pCi/g	^{238}U pCi/g	^{238}Pu fCi/g	^{239}Pu fCi/g	γ* pCi/g
76S265	0-1.5		< 0.2	-	-	-	-	-	-	-	-
76S266	5-6.5		0.20	-	-	-	-	-	-	-	-
76S267	10-11.5		0.32	-	-	-	-	-	-	-	-
76S268	15-16.5	15.8%	< 0.2	< 0.03	< 0.1	0.62	0.02	0.56	< 0.1	< 0.1	< 0.1
76S269	20-21.5		< 0.2	-	-	-	-	-	-	-	-
76S270	25-26.5		0.31	-	-	-	-	-	-	-	-
76S271	30-31.5	11.3%	0.61	0.07	< 0.1	0.54	0.02	0.55	< 0.1	< 0.1	< 0.1
76S272	35-36.5		0.26	-	-	-	-	-	-	-	-
76S273	40-41.5		< 0.2	-	-	-	-	-	-	-	-
76S274	45-46.5		< 0.2	-	-	-	-	-	-	-	-
76S275	50-51.5		< 0.2	-	-	-	-	-	-	-	-
76S276	55-56.5		< 0.2	-	-	-	-	-	-	-	-
76S277	60-61.5		< 0.2	-	-	-	-	-	-	-	-

*Each gamma-ray emitting fission or activation product.

had been collected, the holes were completely filled with grout to prevent access to the buried material and to prevent surface water from entering the hole. During the entire operation of drilling and sampling the two holes, radiation safety coverage was provided by a mobile health physics laboratory. Services included constant air monitoring, measurements with portable tritium detection equipment, and radioactivity surveys of all samples produced by the operations and of all the equipment. No above-normal activity of any type was detected in the field monitoring.

There is approximately 2.5 feet of soil overburden on top of the one foot thick concrete cover, therefore, the top of the buried material is about 3.5 feet below the present surface. Assuming the trenches to be six feet deep, the first samples below the trench area are about ten feet below the present surface. Samples less than 10 feet below the surface are from the trench itself and may contain buried material.

The same radiochemical analyses were performed on these samples as on previous cores. The results are presented in Table 22 and Table 23. Examination of the tritiated water concentrations indicates that tritium has migrated deep into the underlying subsoil, as illustrated by Figure 6. The highest tritium concentration is 65 feet below the surface in Core #22. One method of estimating the migration rate of the tritiated water is as follows. The dolomite is about 130 feet below the surface at Plot M, and if it is assumed the tritium was placed into the burial area about 1947 and has moved downward in the form of a pulse at a constant rate for the past 30 years, the rate would be about 2 ft/year. This would imply that the peak tritium concentration would reach the dolomite aquifer in another 30 years. By this time, radioactive decay would have reduced this peak concentration to 19% of its present value, or about 2.6 nCi/g.

One sample (77S25) obtained in drilling through the trench area in Core #23 contained a piece of graphite. Gamma-ray spectrometric analysis of this sample indicated that the graphite had been in a nuclear reactor since it contained cesium-137 and europium-152. The sample immediately above the graphite, 77S24, contained cesium-137. The concentrations of these nuclides were low.

TABLE 22

Plot M - Core #22 (4/18/77) - Through Concrete Cap,
50' W and 25' S of NE Corner

Sample Number	Depth (feet)	Water Content	^{3}H nCi/l	^{3}H pCi/g	^{90}Sr pCi/g	^{234}U pCi/g	^{235}U pCi/g	^{238}U pCi/g	^{238}Pu fCi/g	^{239}Pu fCi/g	γ* pCi/g
77S1	3.5-5	17.9%	27.2	4.87	< 0.1	0.51	0.02	0.68	< 0.1	1.1	< 0.1
77S2	6-7.5	19.8%	30.4	6.01	< 0.1	0.64	0.02	0.90	< 0.1	2.1	< 0.1
77S3	7.5-9	15.7%	52.4	8.22	< 0.1	0.56	0.02	0.77	< 0.1	1.0	< 0.1
77S4	10-11.5	13.4%	64.0	8.57	< 0.1	0.72	0.03	0.94	< 0.1	< 0.1	< 0.1
77S5	11.5-13	13.4%	63.9	8.56	< 0.1	0.80	0.03	1.03	< 0.1	0.70	< 0.1
77S6	13-14.5	12.1%	179	21.7	< 0.1	0.59	0.03	0.77	< 0.1	< 0.1	< 0.1
77S7	14.5-16	12.3%	218	26.8	-	-	-	-	-	-	< 0.1
77S8	16-17.5	12.4%	299	37.1	-	-	-	-	-	-	< 0.1
77S9	17.5-19	12.3%	539	66.3	-	-	-	-	-	-	< 0.1
77S10	19-20.5	11.7%	1.72×10^{3}	202	< 0.1	0.54	0.02	0.68	< 0.1	1.7	< 0.1
77S11	25-26.5	11.6%	4.06×10^{3}	471	-	-	-	-	-	-	< 0.1
77S12	30-31.5	10.7%	9.54×10^{3}	1.02×10^{3}	-	-	-	-	-	-	< 0.1
77S13	35-36.5	12.5%	1.45×10^{4}	1.81×10^{3}	-	-	-	-	-	-	< 0.1
77S14	40-41.5	11.2%	3.23×10^{4}	3.62×10^{3}	-	-	-	-	-	-	< 0.1
77S15	45-46.5	11.0%	4.52×10^{4}	4.97×10^{3}	< 0.1	0.60	0.09	0.83	< 0.1	< 0.1	< 0.1
77S16	50-51.5	11.9%	4.76×10^{4}	5.67×10^{3}	-	-	-	-	-	-	< 0.1
77S17	55-56.5	12.6%	4.00×10^{4}	5.04×10^{3}	-	-	-	-	-	-	< 0.1
77S18	60-61.5	12.2%	5.56×10^{4}	6.79×10^{3}	-	-	-	-	-	-	< 0.1
77S19	65-66.5	12.8%	1.07×10^{5}	1.36×10^{4}	< 0.1	0.49	0.02	0.61	< 0.1	< 0.1	< 0.1
77S20	70-71.5	11.0%	5.18×10^{4}	5.70×10^{3}	-	-	-	-	-	-	< 0.1
77S21	75-76.5	15.2%	6.09×10^{4}	9.26×10^{3}	-	-	-	-	-	-	< 0.1
77S22	80-81.5	10.7%	6.35×10^{4}	6.80×10^{3}	-	-	-	-	-	-	< 0.1

*Each gamma-ray emitting fission or activation product.

TABLE 23

Plot M - Core #23 (4/27/77) - Through Concrete Cap, 65' W and 75' S of NE Corner

Sample Number	Depth (feet)	Water Content	^{3}H nCi/l	^{3}H pCi/g	^{90}Sr pCi/g	^{234}U pCi/g	^{235}U pCi/g	^{238}U pCi/g	^{238}Pu fCi/g	^{239}Pu fCi/g	γ* pCi/g
77S23	3.5-5	19.3%	118	22.8	0.46	1.61	0.04	1.86	< 0.1	145	< 0.1
77S24	5-6.5	17.4%	111	19.3	1.47	1.61	0.06	1.80	0.25	80	0.46 (^{137}Cs)
77S25	6.5-8	18.0%	156	28.1	2.43	8.33	0.39	7.95	2.22	1.08×10^{3}	1.0 (^{137}Cs) 1.7 (^{152}Eu)
77S26	8-9.5	14.7%	246	36.1	2.90	0.70	0.03	0.88	0.39	119	< 0.1
77S27	9.5-11	15.0%	275	41.2	0.45	0.72	0.04	0.90	< 0.1	30.5	< 0.1
77S28	11-12.5	12.2%	293	35.8	0.20	0.73	0.04	0.88	< 0.1	8.6	< 0.1
77S29	12.5-14	12.8%	308	39.4	0.38	0.82	0.04	1.01	< 0.1	71.1	< 0.1
77S30	14-15.5	6.0%	339	20.3	0.13	0.80	0.03	0.92	< 0.1	6.4	< 0.1
77S31	15.5-17	12.1%	435	52.6	-	-	-	-	-	-	< 0.1
77S32	17-18.5	11.7%	695	81.3	-	-	-	-	-	-	< 0.1
77S33	18.5-20	12.0%	1.14×10^{3}	137	-	-	-	-	-	-	< 0.1
77S34	25-26.5	12.6%	1.53×10^{3}	193	-	-	-	-	-	-	< 0.1
77S35	30-31.5	10.3%	3.95×10^{3}	407	-	-	-	-	-	-	< 0.1
77S36	35-36.5	8.6%	2.34×10^{4}	2.01×10^{3}	-	-	-	-	-	-	< 0.1
77S37	40-41.5	10.7%	3.37×10^{4}	3.60×10^{3}	< 0.1	0.39	0.02	0.41	< 0.1	< 0.1	< 0.1
77S38	45-46.5	11.7%	7.95×10^{3}	930	-	-	-	-	-	-	< 0.1
77S39	50-51.5	6.2%	1.54×10^{4}	952	-	-	-	-	-	-	< 0.1
77S40	55-56.5	12.6%	1.51×10^{4}	1.90×10^{3}	-	-	-	-	-	-	< 0.1
77S41	60-61.5	11.2%	2.05×10^{3}	230	-	-	-	-	-	-	< 0.1
77S42	65-66.5	10.6%	28.3	3.0	< 0.1	0.68	0.04	0.82	< 0.1	< 0.1	< 0.1
77S43	70-71.5	13.0%	112	14.6	-	-	-	-	-	-	< 0.1
77S44	75-76.5	11.0%	148	16.2	-	-	-	-	-	-	< 0.1
77S45	80-81.5	7.5%	63.3	4.8	-	-	-	-	-	-	< 0.1
77S46	85-86.5	11.8%	76.6	9.0	-	-	-	-	-	-	< 0.1
77S47	90-91.5	12.9%	93.1	12.0	-	-	-	-	-	-	< 0.1
77S48	95-96.5	13.7%	249	34.1	-	-	-	-	-	-	< 0.1
77S49	100-101.5	18.0%	46.6	8.4	< 0.1	0.60	0.03	0.72	< 0.1	< 0.1	< 0.1

*Each gamma-ray emitting fission or activation product.

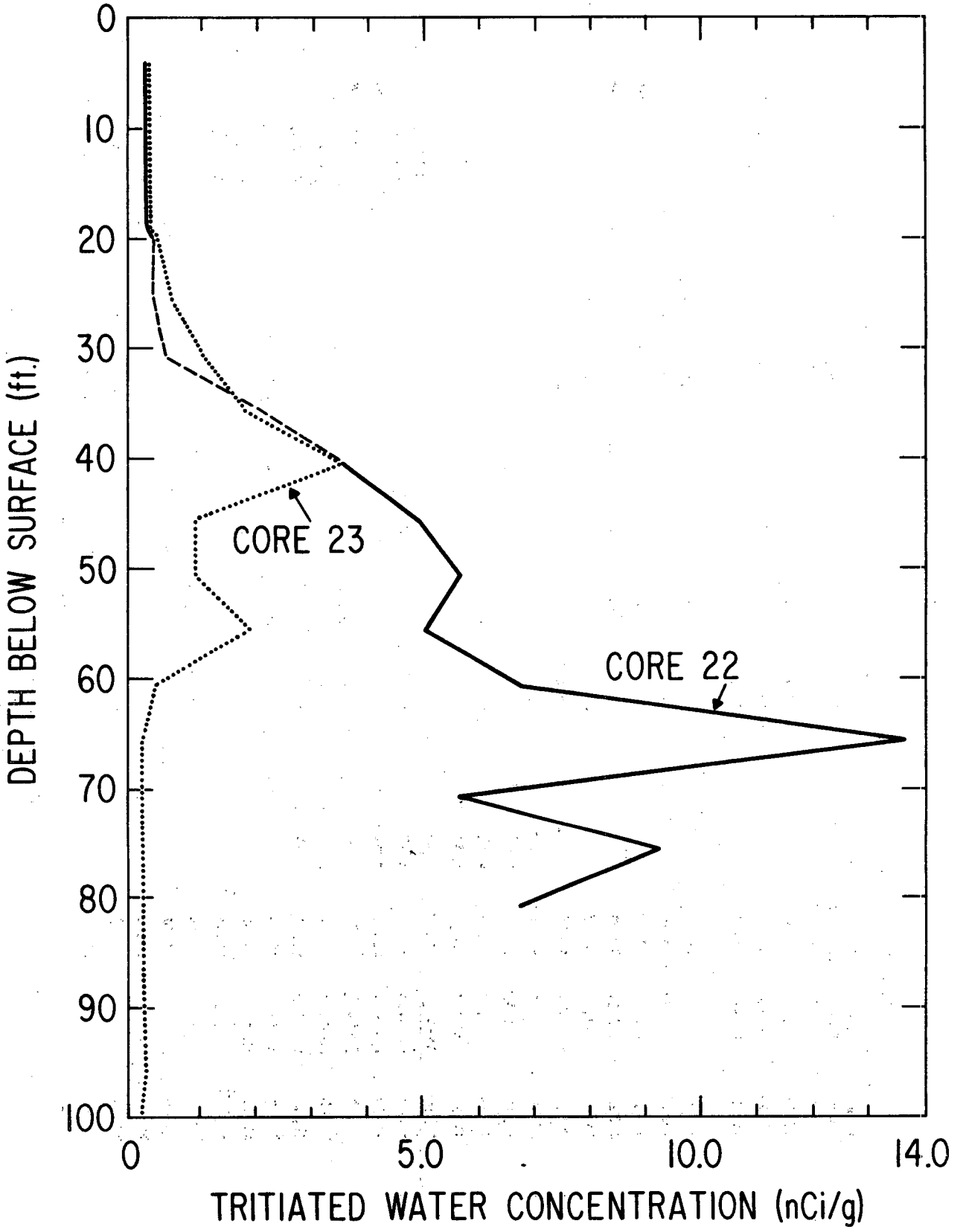


Fig. 6. Tritiated Water Concentrations as a Function of Depth Beneath Plot M.

No other evidence of buried material, i.e., metal, glass, etc., was observed in any of the samples.

Gamma-ray analyses were performed on all the soil samples in Cores #22 and #23. Except for the radionuclides discussed above, no gamma-ray activity was detected. Some of the samples obtained from the first 10 feet in the area believed to be the original burial grounds contained elevated concentrations of uranium, plutonium, and strontium-90. These samples were centered around the area containing the irradiated graphite. Detectable levels of plutonium and strontium-90 were also observed in a few samples taken below the trench area. The highest plutonium result found below the trench area, in sample 77S29, is about twice the fallout level of surface soil.

It is known that some of the waste material was in liquid form, and probably acidic, when disposed of into the trenches. These solutions could soak into the ground below the trench floor and move downward a short distance before becoming bound to the soil. Therefore, the presence of material below the trenches may not be due to the slow leaching effect of precipitation over the years, but to the initial relatively rapid movement while the radionuclides were ionic in character.

The two most probable sources for the tritium buried in the Plot are neutron irradiation of deuterium in the heavy water in the CP-3 reactor and neutron irradiation of lithium. It is possible to distinguish between these two sources by measuring the deuterium/hydrogen (D/H) ratio in tritiated water from the Plot. If the source were heavy water, the D/H ratio would be greater than occurs naturally, while lithium irradiation would produce tritiated water with a naturally-occurring D/H ratio. Two surface water samples collected in the spring of 1976 had sufficiently high tritium concentrations so that elevated D/H ratios would have been measurable if the source were heavy water. These samples were analyzed by mass spectrometry for their D/H ratios by Klaus Ernst, Lawrence Livermore Laboratory. The ratios were indistinguishable from natural water, which indicates that the tritium was produced from lithium irradiation rather than deuterium irradiation.

An estimate of the total tritium content of the Plot M area can be made by integrating the tritium concentrations in the cores over the volume covered

by the cores. The average tritium content of the soil volume, about 300 ft x 200 ft x 80 ft deep, is approximately 10^4 pCi/g, and the tritium, as water, in this soil is approximately 3000 Ci. This estimate is considered reliable to about a factor of 10.

C. Surface Water Studies

The surface drainage around Plot M is principally by an intermittent stream that travels south to north along the east side of the Plot. A small stream drains the west side of the Plot and joins the main stream north and downhill of the Plot as shown in Figure 4. The stream continues north until it empties into the Illinois & Michigan Canal about 800 yards north of Plot M. It is only after heavy precipitation, normally in the spring, that the flow reaches the Canal. Under lighter rains, the water usually infiltrates into the coarse gravel bed in the vicinity of Red Gate Woods, and during much of the year the entire stream bed is dry.

As a result of an early spring, water was flowing in the intermittent stream in February of 1976, when this study was begun. Water samples were collected from the stream at various points around and downstream of Plot M and analyzed for tritiated water. Similar sampling was conducted in March and April, 1976, and again in the spring of 1977. Water was collected from the stream in the spring of 1954, as discussed previously. Since these samples had been retained, they were now analyzed for tritiated water and corrected for decay to 1954. The sampling locations are shown in Figure 7, and the tritiated water concentrations are shown in Table 24. All the samples were taken from the stream itself except the sample collected at map location #6 in Figure 7. This was a low-volume seep at the base of the Plot M hill whose water flowed into the intermittent stream bed northeast of the burial area.

The general trend of the tritiated water concentration is to increase as water moves from upstream to below the Plot M area and then to decrease downstream from Plot M as a result of dilution by other surface water. Except for the seep, the concentrations increase at location #9, which is at the confluence of the streams that drain the Plot. Comparison of samples collected in 1976 and 1977 show the same general trend, but the concentrations differ in magnitude.

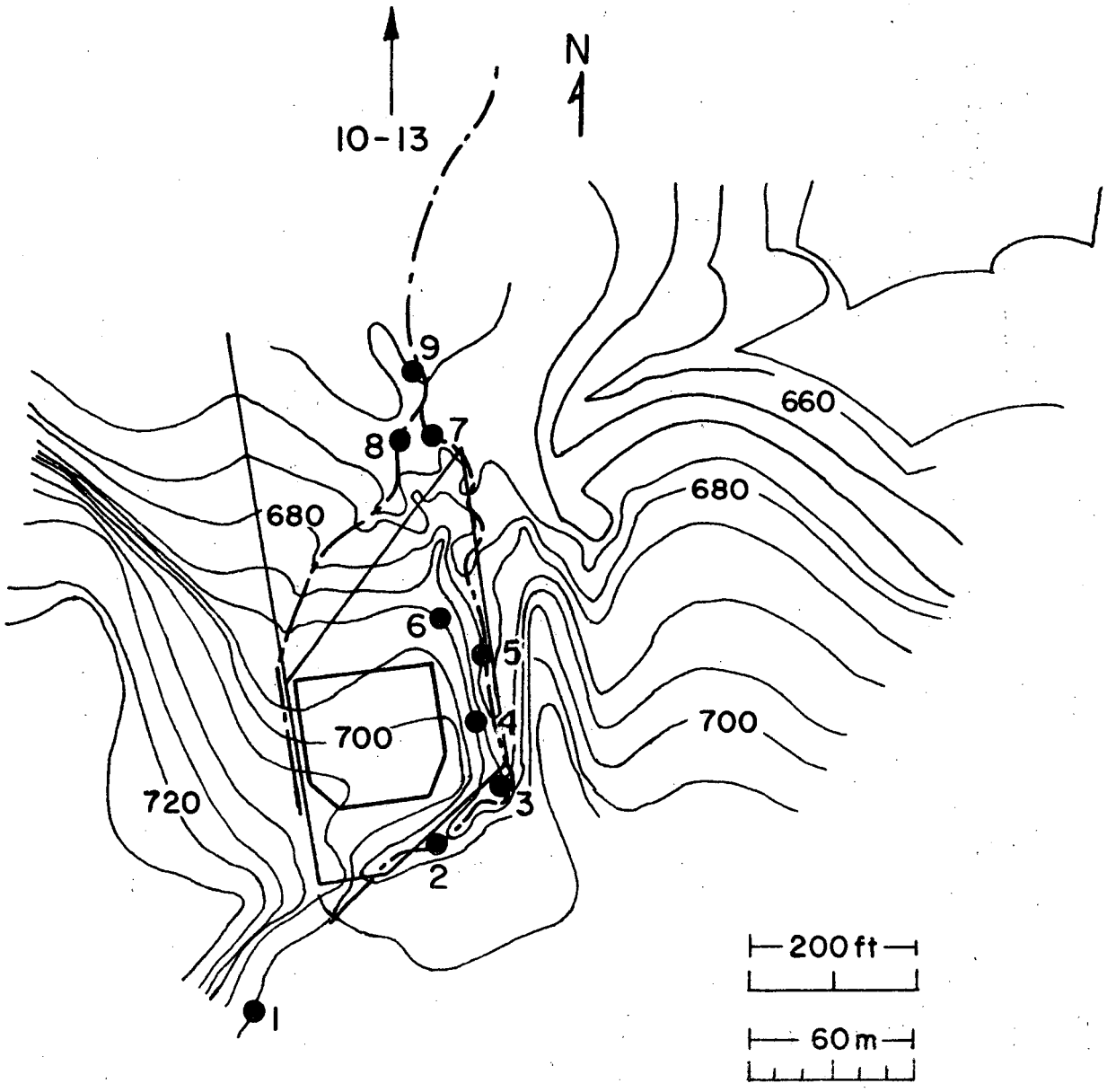


Fig. 7. Surface Water Sampling Locations Near Plot M.

TABLE 24

Tritiated Water in Streams Draining Plot M

(concentrations in nCi/1)

Location*	No.*	3/19,4/6 & 4/14/54	2/25 & 2/26/76	3/5 & 3/15/76	4/29/76	3/2,3/8 & 3/19/77	3/29/77	4/20,4/27 & 5/4/77	5/5/77
Upstream (S) Location A	1	1.8/2.3/2.6	< 0.2	-	-	-	< 0.2	-	0.49
Adjacent (SE) Location B	2	13/16/429	-	0.24	-	-	-	-	1.5
Adjacent (E)	3	-	8	-	-	-	-	-	-
Adjacent (E)	4	-	-	13	-	-	-	-	-
Adjacent (E) Location C	5	48/79/490	31	-	-	-	29	-	14
Adjacent (NE) (Seep)	6	-	1930	970	1240	-	84	-	-
Downstream (250 ft N)	7	-	75/149	-	-	-	-	-	-
Downstream (In Swale - 250 ft N)	8	-	110	-	-	-	-	-	-
Downstream (325 ft N) Location D	9	880/902/2910	75/95	79	128	30/36/47	24	46/39/48	17
Downstream (650 ft N)	10	-	67	-	-	-	-	-	-
Downstream (975 ft N)	11	-	38	-	-	-	-	-	-
Downstream (2000 ft N)	12	-	12	-	-	-	-	-	-
Downstream (3000 ft N at I & M Canal)	13	-	-	5.1	-	-	-	-	-

*Refer to Figure 7 for location numbers.

The samples collected in 1977 at location #9 contained about a factor of two less tritium than in 1976; tritium from the seep at location #6 is about an order of magnitude lower in 1977.

The downstream concentrations in the 1954 samples were about a factor of ten higher than at present. The upstream water samples in 1954 were abnormally high at that location due to fallout. These samples had the same tritiated water concentration as precipitation samples collected at the same time.

It is possible that in 1954 the bulk of the tritiated water in Plot M was within or just below the burial area, and horizontal leaching out of the Plot into the stream was greater than now because the Plot was not covered with concrete in 1954. However, it is reasonable to expect concentrations to decrease with time as the tritiated water source is depleted by both horizontal and vertical migration and radioactive decay. Since substantial amounts of tritium still remain below the surface of the Plot, its current presence in the stream is to be expected.

Other surface water samples in the area were also analyzed for tritiated water. Water from the Sanitary and Ship Canal and the Des Plaines River in the vicinity of the Palos Forest Preserve, and Illinois & Michigan Canal water downstream from the point where the intermittent stream enters, were analyzed for tritium and the concentrations were less than the detection limit of 0.2 nCi/l. Water was collected from two small ponds in the Red Gate Woods located just south of the Red Gate Woods well. No tritiated water was detected in either of these ponds.

In addition to tritiated water, radiochemical analyses were performed on some surface water samples for strontium-90, uranium, plutonium-239, and other transuranic nuclides (TU). The results are collected in Table 25. If the strontium-90 concentration at Location A (Figure 4) is the fallout background for the precipitation, which constitutes most of the water, it is possible that the seep water contains a small contribution from Plot M. Plutonium is measurable in the seep water at very low concentrations, and like the strontium-90, may have been leached from the Plot. The volume of water from the seep is very small, and this water becomes highly diluted in the stream so that at location D

TABLE 25

Specific Radiochemical Analyses of Water Samples at Plot M

(concentrations in pCi/1)

Sample Number	Date Collected	Location	^{90}Sr	U (natural)	^{239}Pu	Other TU*
76W53	2/26/76	Location A	1.2	-	-	-
76W56	2/26/76	Seep	3.0	2.1	-	-
76W58	2/26/76	Location D	1.6	0.74	< 0.0005	< 0.001
76W88	3/5/76	Swale - W of NW Corner	-	0.07	-	-
76W89	3/5/76	Swale - 50' N of NW Corner	-	3.0	-	-
76W90	3/5/76	Seep	-	2.2	0.0087	-
77W181	5/5/77	Seep	3.1	1.4	0.0031	< 0.001

*Transuranic elements.

all radionuclide concentrations were normal. The uranium concentrations are in their normal range at all locations.

D. *In-Situ* Gamma-ray Measurements

At the time the initial set of ten core samples was drilled around Plot M, well-points were installed, and the holes were cased with 2.5 in. PVC pipe. This was done to allow the future measurement of water levels, collection of water, and for gamma-ray spectrometry. The gamma-ray spectrometry was carried out by W. Scott Keys, Borehole Geophysics Section, Water Resources Division, USGS. A 2 in. diameter NaI(Tl) detector was lowered into the cased bore holes, the data collected by a multichannel analyzer and stored on magnetic tape.

Three days were spent at Plot M in April, 1976, making gamma-ray spectrometric measurements in the vertical holes. The results showed only the presence of natural gamma-ray emitting nuclides at normal concentrations. Neutron logging of the cores was also done to provide information on the soil water content for the geohydrological study.

A gamma-ray survey of the surface soil in the Plot M area was conducted by the ANL Radiological Resurvey Team. Using a sodium iodide detector from the mobile laboratory, surface measurements were made at and around Plot M. No radioactivity attributable to buried waste materials could be detected.

An aerial survey for gamma-ray activity over the entire Site A/Plot M area was conducted by the Aerial Measurements System (AMS) group from EG&G, Inc. in May of 1976. The survey consisted of a low-level helicopter flyover of the area with an array of sodium iodide detectors. Gross gamma-ray distributions were plotted on an aerial photograph of the site and isopleths of the various radiation levels plotted. The distribution and levels appeared normal by comparison to radiation spectra from other areas. The only indication of any above-normal concentrations was a few isolated areas of cesium-137. The highest cesium-137 area could be correlated to cesium-137 measured by gamma-ray spectrometry in surface soil samples collected at Site A (see Section V). These levels were about three times fallout concentrations of cesium-137. No other activity attributable to operations at Site A/Plot M could be detected. A separate report on this survey will be issued by EG&G, Inc.

The external penetrating radiation dose in the Plot M area was measured with calcium fluoride thermoluminescent dosimeters (TLD). The response of the chips was calibrated with an NBS standard radium-226 source, and the results calculated in terms of air dose. A set of TLD's was placed at various locations around Plot M in the spring of 1976 for about one month and again in the spring of 1977 for about two months. The results are collected in Table 26. All the results fall within the range of dose rates measured at five off-site locations used to determine the radiation background in this area for the Environmental Monitoring TLD Program, as described in ANL-77-13. These results confirm the previous measurements that there is no surface exposure from buried waste material.

V. STUDIES AT SITE A

This section deals with the two major studies, subsurface and surface, conducted at the 19-acre experimental area, Site A. Figure 3 is a drawing of the laboratory and auxiliary buildings within the fenced-in Site A area. The CP-3 reactor was housed in Lab "B" and the CP-2 reactor was located in Lab "A".

A. Subsurface Soil

For the subsurface study, four vertical holes were drilled to depths of 60 feet in the vicinity of the buried CP-3 reactor containment shell to determine if any radionuclides that remained with the reactor shell have migrated into the surrounding area. The holes were drilled 50 feet from the center of the buried reactor shell in each of the four compass points. The locations of the core holes, #14 through #17, are shown in Figure 8.

A total of 16 samples was generated from each boring. All the samples were analyzed for tritiated water and gamma-ray emitting nuclides. Selected samples were analyzed for nonvolatile alpha and beta activity, strontium-90, uranium, and plutonium. The results are presented in Tables 27 to 30.

The nonvolatile alpha, beta, and the uranium results are in the normal range of these activities in soil throughout the Chicago area. The isotopic

TABLE 26

TLD Measurements at Plot M

Sample Number	Location	Dose Rate (mrem/year)
76TLD64	Near Bore #8	104
76TLD65	S of Plot M	110
76TLD66	SE of Plot M	111
76TLD67	Near Bore #6	103
76TLD68	E of Plot M	123
76TLD69	Near Bore #3	110
76TLD70	Near Bore #2	109
76TLD71	NW Corner of Plot M	104
76TLD72	Near Bore #1	113
76TLD73	SW Corner of Plot M	104
77TLD62	Near Bore #8	93
77TLD64	NE of Bore #3	98

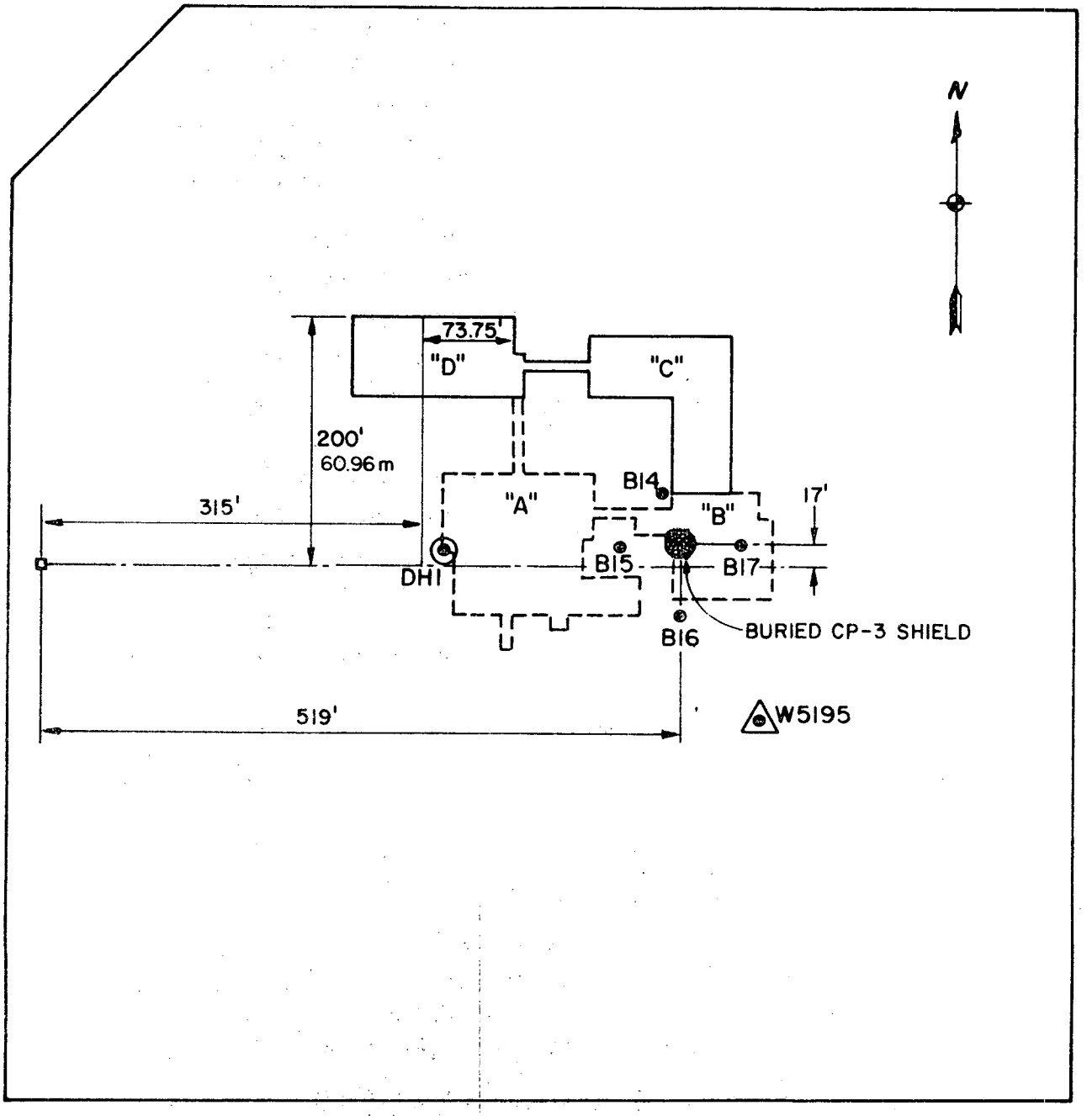


Fig. 8. Locations of Soil Borings, Dolomite Holes, and Wells Near the Buried CP-3 Reactor.

TABLE 27

Site A - Core #14 (8/18/76)

Sample Number	Depth (feet)	Water Content	Gross α pCi/g	Gross β pCi/g	^{3}H nCi/l	^{3}H pCi/g	^{90}Sr pCi/g	^{234}U pCi/g	^{235}U pCi/g	^{238}U pCi/g	^{238}Pu fCi/g	^{239}Pu fCi/g	γ* pCi/g
76S187	0-1.5	~15%	-	-	0.76	0.11	-	-	-	-	-	-	< 0.1
76S188	2-3.5	15.0%	-	-	< 0.2	< 0.03	-	-	-	-	-	-	< 0.1
76S189	4-5.5	15.3%	-	-	0.41	0.06	-	-	-	-	-	-	< 0.1
76S190	6-7.5	13.9%	-	-	0.72	0.10	-	-	-	-	-	-	< 0.1
76S191	8-9.5	15.0%	-	-	0.66	0.10	-	0.59	0.09	0.93	< 0.1	< 0.1	< 0.1
76S192	10-11.5	14.0%	25	56	2.27	0.32	-	-	-	-	-	-	< 0.1
76S193	15-16.5	12.7%	-	-	17.7	2.25	< 0.1	-	-	-	-	-	< 0.1
76S194	20-21.5	12.5%	-	-	6.59	0.82	-	0.90	0.04	1.13	< 0.1	< 0.1	< 0.1
76S195	25-26.5	11.3%	15	38	13.2	1.49	-	-	-	-	-	-	< 0.1
76S196	30-31.5	12.7%	-	-	1.66	0.21	< 0.1	-	-	-	-	-	< 0.1
76S197	35-36.5	12.2%	-	-	< 0.2	< 0.03	-	0.60	0.03	0.79	< 0.1	< 0.1	< 0.1
76S198	40-41.5	12.2%	18	45	< 0.2	< 0.03	-	-	-	-	-	-	< 0.1
76S199	45-46.5	12.2%	-	-	< 0.2	< 0.03	< 0.1	-	-	-	-	-	< 0.1
76S200	50-51.5	12.7%	-	-	< 0.2	< 0.03	-	0.68	0.03	0.80	< 0.1	< 0.1	< 0.1
76S201	55-56.5	12.1%	18	42	< 0.2	< 0.03	-	-	-	-	-	-	< 0.1
76S202	60-61.5	12.9%	-	-	3.76	0.49	< 0.1	-	-	-	-	-	< 0.1

*Each gamma-ray emitting fission or activation product.

TABLE 28

Site A - Core #15 (8/19/76)

Sample Number	Depth (feet)	Water Content	Gross α pCi/g	Gross β pCi/g	^{3}H nCi/l	^{3}H pCi/g	^{90}Sr pCi/g	^{234}U pCi/g	^{235}U pCi/g	^{238}U pCi/g	^{238}Pu fCi/g	^{239}Pu fCi/g	γ* pCi/g
76S203	0.5-2	9.8%	-	-	28.4	2.78	-	-	-	-	-	-	< 0.1
76S204	2-3.5	10.0%	-	-	51.6	5.16	-	-	-	-	-	-	< 0.1
76S205	4-5.5	11.0%	-	-	248	27.2	-	-	-	-	-	-	< 0.1
76S206	6-7.5	13.9%	-	-	345	47.9	-	-	-	-	-	-	< 0.1
76S207	8-9.5	15.0%	-	-	317	47.5	-	1.02	0.05	1.36	< 0.1	< 0.1	< 0.1
76S208	10-11.5	13.9%	23	39	444	61.7	-	-	-	-	-	-	< 0.1
76S209	15-16.5	13.1%	-	-	429	56.2	< 0.1	-	-	-	-	-	< 0.1
76S210	20-21.5	12.9%	-	-	233	30.0	-	1.00	0.04	1.28	< 0.1	< 0.1	< 0.1
76S211	25-26.5	11.0%	18	40	198	21.8	-	-	-	-	-	-	< 0.1
76S212	30-31.5	12.7%	-	-	124	15.7	< 0.1	-	-	-	-	-	< 0.1
76S213	35-36.5	11.3%	-	-	18.4	2.08	-	0.69	0.03	0.88	< 0.1	< 0.1	< 0.1
76S214	40-41.5	11.1%	16	35	15.7	1.74	-	-	-	-	-	-	< 0.1
76S215	45-46.5	12.1%	-	-	22.0	2.66	< 0.1	-	-	-	-	-	< 0.1
76S216	50-51.5	12.4%	-	-	18.8	2.33	-	0.59	0.02	0.79	< 0.1	< 0.1	< 0.1
76S217	55-56.5	12.7%	16	44	33.6	4.27	-	-	-	-	-	-	< 0.1
76S218	60-61.5	12.7%	-	-	99.2	12.6	< 0.1	-	-	-	-	-	< 0.1

*Each gamma-ray emitting fission or activation product.

TABLE 29

Site A - Core #16 (8/20/76)

Sample Number	Depth (feet)	Water Content	Gross α pCi/g	Gross β pCi/g	^{3}H nCi/l	^{3}H pCi/g	^{90}Sr pCi/g	^{234}U pCi/g	^{235}U pCi/g	^{238}U pCi/g	^{238}Pu fCi/g	^{239}Pu fCi/g	γ* pCi/g
76S219	0-1.5	3.4%	-	-	84.9	2.89	-	-	-	-	-	-	< 0.1
76S220	2-3.5	14.9%	-	-	0.52	0.08	-	-	-	-	-	-	< 0.1
76S221	4-5.5	16.7%	-	-	0.61	0.10	-	-	-	-	-	-	< 0.1
76S222	6-7.5	19.8%	-	-	2.64	0.52	-	-	-	-	-	-	< 0.1
76S223	8-9.5	15.6%	-	-	8.74	1.36	-	0.79	0.04	1.09	< 0.1	< 0.1	< 0.1
76S224	10-11.5	14.8%	29	61	15.9	2.35	-	-	-	-	-	-	< 0.1
76S225	15-16.5	15.7%	-	-	92.7	14.6	< 0.1	-	-	-	-	-	< 0.1
76S226	20-21.5	13.3%	-	-	75.0	9.98	-	1.21	0.05	1.44	< 0.1	< 0.1	< 0.1
76S227	25-26.5	13.2%	20	47	45.0	5.94	-	-	-	-	-	-	< 0.1
76S228	30-31.5	12.3%	-	-	35.1	4.32	< 0.1	-	-	-	-	-	< 0.1
76S229	35-36.5	12.0%	-	-	10.7	1.29	-	1.02	0.06	1.29	< 0.1	< 0.1	< 0.1
76S230	40-41.5	11.2%	19	42	2.06	0.23	-	-	-	-	-	-	< 0.1
76S231	45-46.5	11.5%	-	-	0.20	0.02	< 0.1	-	-	-	-	-	< 0.1
76S232	50-51.5	11.9%	-	-	< 0.2	< 0.03	-	0.58	0.03	0.79	< 0.1	< 0.1	< 0.1
76S233	55-56.5	12.3%	17	42	< 0.2	< 0.03	-	-	-	-	-	-	< 0.1
76S234	60-61.5	11.8%	-	-	4.39	0.52	< 0.1	-	-	-	-	-	< 0.1

*Each gamma-ray emitting fission or activation product.

TABLE 30

Site A - Core #17 (8/20/76)

Sample Number	Depth (feet)	Water Content	Gross α pCi/g	Gross β pCi/g	^{3}H nCi/l	^{3}H pCi/g	^{90}Sr pCi/g	^{234}U pCi/g	^{235}U pCi/g	^{238}U pCi/g	^{238}Pu fCi/g	^{239}Pu fCi/g	γ* pCi/g
76S235	0-1.5	10.3%	-	-	0.86	0.09	-	-	-	-	-	-	< 0.1 except ^{137}Cs = 0.1
76S236	2-3.5	10.7%	-	-	2.09	0.22	-	-	-	-	-	-	< 0.1 except ^{137}Cs = 0.1
76S237	4-5.5	15.2%	-	-	0.68	0.10	-	-	-	-	-	-	< 0.1
76S238	6-7.5	15.1%	-	-	1.06	0.16	-	-	-	-	-	-	< 0.1
76S239	8-9.5	15.6%	-	-	1.48	0.23	-	0.71	0.03	1.02	< 0.1	< 0.1	< 0.1
76S240	10-11.5	15.4%	23	59	1.96	0.30	-	-	-	-	-	-	< 0.1
76S241	15-16.5	13.5%	-	-	2.26	0.31	< 0.1	-	-	-	-	-	< 0.1
76S242	20-21.5	13.3%	-	-	1.75	0.23	-	-	-	-	< 0.1	< 0.1	< 0.1
76S243	25-26.5	13.3%	17	40	0.22	0.03	-	-	-	-	-	-	< 0.1
76S244	30-31.5	13.1%	-	-	0.23	0.03	< 0.1	-	-	-	-	-	< 0.1
76S245	35-36.5	11.9%	-	-	0.22	0.03	-	0.64	0.03	0.84	< 0.1	< 0.1	< 0.1
76S246	40-41.5	11.7%	17	42	< 0.2	< 0.03	-	-	-	-	-	-	< 0.1
76S247	45-46.5	11.8%	-	-	< 0.2	< 0.03	< 0.1	-	-	-	-	-	< 0.1
76S248	50-51.5	12.0%	-	-	< 0.2	< 0.03	-	0.64	0.02	0.83	< 0.1	< 0.1	< 0.1
76S249	55-56.5	15.4%	18	45	26.1	4.03	-	-	-	-	-	-	< 0.1
76S250	60-61.5	13.1%	-	-	9.09	1.19	< 0.1	-	-	-	-	-	< 0.1

*Each gamma-ray emitting fission or activation product.

composition of the uranium nuclides is also normal. No strontium-90 or plutonium nuclides were found in any of the core samples and the concentration of all gamma-ray emitting fission or activation products was less than the detection limit except for cesium-137 in the first two samples of Core #17. These cesium-137 concentrations are in the range found for fallout from atmospheric tests.

Tritiated water, at concentrations above the detection limit, was found in most of the samples in all four cores. Tritium at concentrations greater than about 0.5 nCi/l must be considered abnormal, based on the results for Cores #18 and #19 (Tables 20 and 21), and are attributed to heavy water used in the CP-3 reactors.

Although the magnitude of the tritiated water concentration is different in each core, with the highest being west and the lowest east of the buried reactor containment shell, the distributions are very similar. Each core shows an increase in tritiated water concentration with depth to a maximum at about 15 feet below the ground surface followed by a decrease in concentration to a minimum at about 40 to 50 feet, and then an increase at the greatest depths.

B. Surface Soil

The second major study at Site A was a sampling of the surface soil over the entire experimental area. Samples were taken at 25-foot intervals in the center of the Site near the reactor, 50-foot intervals outside of this area, and at 100-foot intervals at the Site perimeter. This procedure produced 104 samples. Each soil sample consisted of two 4 in. diameter 6 in. deep cores. The sampling locations, designated by the sample number, are shown in Figure 9. All the samples were analyzed for nonvolatile alpha and beta activity and by gamma-ray spectrometry. The soil moisture from 12 samples was analyzed for tritiated water. The results are listed in Table 31 and shown in Figure 10.

The surface composition of the Site varied greatly, from gravel and building rubble to black humus soil. This is probably the main reason for the observed range in concentrations of the nonvolatile alpha and beta activities,

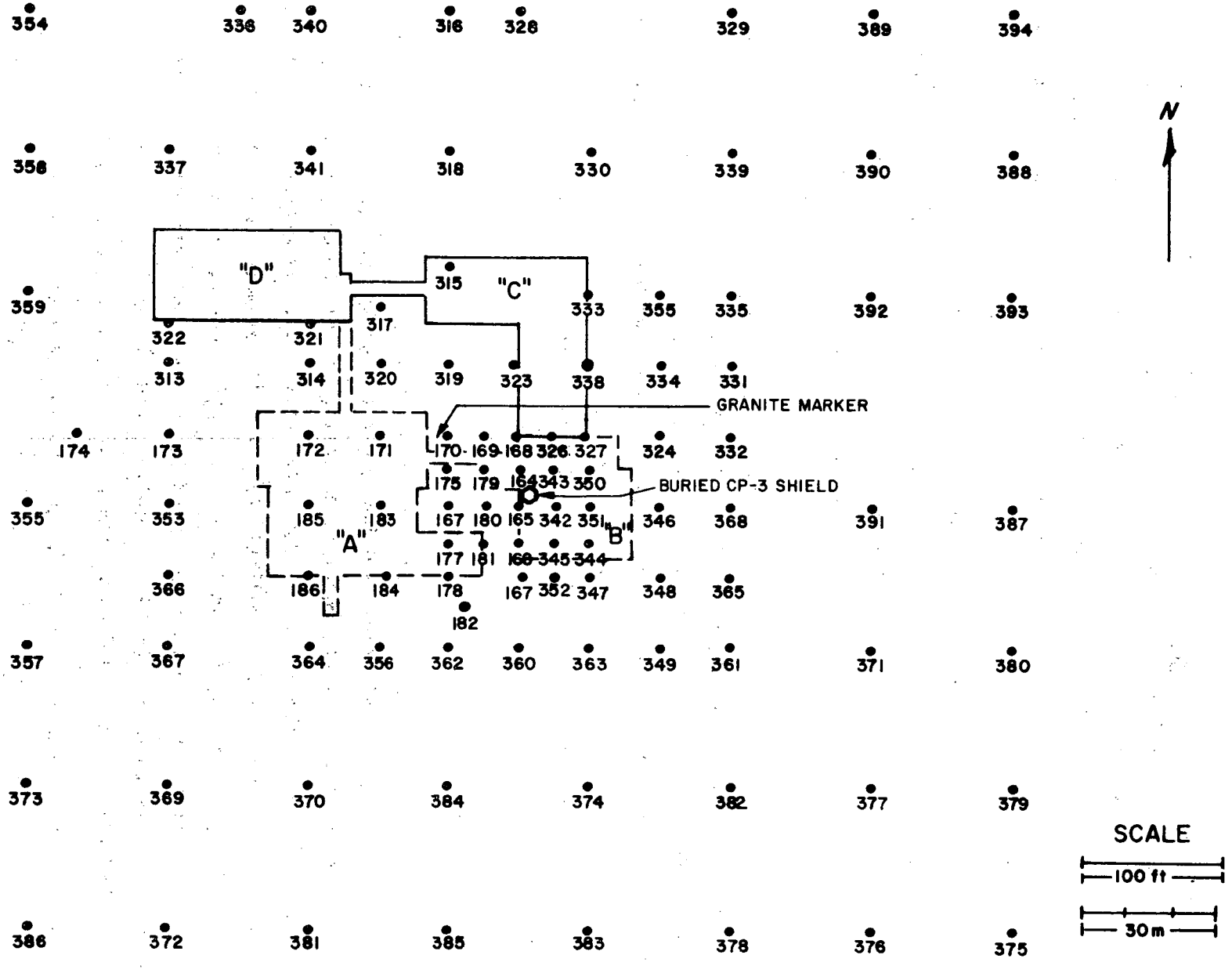


Fig. 9. Locations of Surface Soil Samples Collected at Site A.

TABLE 31

Surface Soil - Site A

Sample Number	Date Collected	Total α pCi/g	Total β pCi/g	^{3}H nCi/l	^{60}Co pCi/g	^{125}Sb pCi/g	^{137}Cs pCi/g	^{155}Eu pCi/g
76S164	7/23/76	23	49	-	< 0.05	< 0.05	0.5	< 0.05
76S165	7/23/76	24	50	-	< 0.05	< 0.05	0.2	< 0.05
76S166	7/23/76	19	46	-	< 0.05	< 0.05	< 0.05	< 0.05
76S167	7/23/76	11	22	-	< 0.05	< 0.05	0.4	< 0.05
76S168	7/23/76	21	47	-	< 0.05	< 0.05	0.4	< 0.05
76S169	7/23/76	22	50	-	< 0.05	< 0.05	0.3	< 0.05
76S170	7/23/76	20	52	-	< 0.05	< 0.05	0.4	< 0.05
76S171	7/23/76	20	50	-	< 0.05	< 0.05	0.2	< 0.05
76S172	7/27/76	20	46	-	< 0.05	< 0.05	0.5	< 0.05
76S173	7/27/76	20	50	-	< 0.05	< 0.05	1.2	< 0.05
76S174	7/27/76	23	57	-	< 0.05	< 0.05	1.1	< 0.05
76S175	7/27/76	20	50	-	< 0.05	< 0.05	< 0.05	< 0.05
76S176	7/27/76	22	47	-	< 0.05	< 0.05	0.1	< 0.05
76S177	7/27/76	23	46	-	< 0.05	< 0.05	0.6	< 0.05
76S178	7/27/76	20	48	-	< 0.05	< 0.05	0.7	< 0.05
76S179	7/29/76	23	52	-	< 0.05	< 0.05	0.6	< 0.05
76S180	7/29/76	22	50	-	< 0.05	< 0.05	< 0.05	< 0.05
76S181	7/29/76	24	55	-	< 0.05	< 0.05	1.0	< 0.05
76S182	7/29/76	19	47	-	< 0.05	< 0.05	0.9	< 0.05
76S183	7/29/76	23	48	-	< 0.05	< 0.05	0.1	< 0.05
76S184	7/29/76	21	44	-	< 0.05	< 0.05	0.8	< 0.05
76S185	7/29/76	21	44	-	< 0.05	< 0.05	0.1	< 0.05
76S186	7/29/76	20	48	-	< 0.05	< 0.05	0.4	< 0.05

TABLE 31 (contd)

Sample Number	Date Collected	Total α pCi/g	Total β pCi/g	^{3}H nCi/l	^{60}Co pCi/g	^{125}Sb pCi/g	^{137}Cs pCi/g	^{155}Eu pCi/g
76S313	10/21/76	17	47	-	< 0.05	< 0.05	0.84	< 0.05
76S314	10/21/76	26	56	-	< 0.05	< 0.05	0.38	< 0.05
76S315	10/21/76	29	66	-	< 0.05	< 0.05	0.10	< 0.05
76S316	10/21/76	22	36	-	< 0.05	< 0.05	3.51	< 0.05
76S317	10/21/76	22	47	-	< 0.05	< 0.05	0.75	< 0.05
76S318	10/21/76	23	42	< 0.2	0.05	0.35	5.55	0.36
76S319	10/21/76	18	27	-	< 0.05	< 0.05	0.56	< 0.05
76S320	10/21/76	21	38	0.48	< 0.05	< 0.05	0.72	< 0.05
76S321	10/21/76	16	53	-	< 0.05	< 0.05	1.02	< 0.05
76S322	10/21/76	20	49	0.78	< 0.05	< 0.05	0.78	< 0.05
76S323	10/21/76	25	48	-	0.06	< 0.05	0.93	< 0.05
76S324	10/22/76	32	57	-	< 0.05	< 0.05	0.19	< 0.05
76S325	10/22/76	34	60	-	< 0.05	< 0.05	0.44	< 0.05
76S326	10/22/76	24	64	-	< 0.05	< 0.05	0.51	< 0.05
76S327	10/22/76	26	54	-	< 0.05	< 0.05	0.31	< 0.05
76S328	10/22/76	30	65	-	< 0.05	< 0.05	1.29	< 0.05
76S329	10/22/76	26	38	-	< 0.05	< 0.05	1.03	< 0.05
76S330	10/22/76	29	55	-	< 0.05	< 0.05	0.83	< 0.05
76S331	10/22/76	26	60	-	< 0.05	< 0.05	0.54	< 0.05
76S332	10/22/76	31	65	-	< 0.05	< 0.05	0.35	< 0.05
76S333	10/22/76	27	62	-	< 0.05	< 0.05	0.51	< 0.05
76S334	10/22/76	23	54	-	< 0.05	< 0.05	0.43	< 0.05
76S335	10/22/76	29	62	< 0.2	< 0.05	< 0.05	0.29	< 0.05

TABLE 31 (contd)

Sample Number	Date Collected	Total α pCi/g	Total β pCi/g	^{3}H nCi/l	^{60}Co pCi/g	^{125}Sb pCi/g	^{137}Cs pCi/g	^{155}Eu pCi/g
76S336	10/22/76	25	60	-	< 0.05	< 0.05	0.46	< 0.05
76S337	10/22/76	26	56	-	< 0.05	< 0.05	0.53	< 0.05
76S338	10/22/76	24	67	< 0.2	< 0.05	< 0.05	0.48	< 0.05
76S339	10/22/76	27	60	-	< 0.05	< 0.05	1.01	< 0.05
76S340	10/22/76	28	61	-	< 0.05	< 0.05	0.45	< 0.05
76S341	10/22/76	32	69	-	< 0.05	< 0.05	0.34	< 0.05
76S342	10/26/76	19	56	-	< 0.05	< 0.05	0.12	< 0.05
76S343	10/26/76	21	53	-	< 0.05	< 0.05	0.72	< 0.05
76S344	10/26/76	18	33	-	0.18	< 0.05	0.78	< 0.05
76S345	10/26/76	21	49	-	< 0.05	< 0.05	0.25	< 0.05
76S346	10/26/76	21	53	-	< 0.05	< 0.05	0.26	< 0.05
76S347	10/26/76	22	53	0.79	< 0.05	< 0.05	0.13	< 0.05
76S348	10/26/76	21	52	-	< 0.05	< 0.05	1.01	< 0.05
76S349	10/26/76	22	52	-	< 0.05	< 0.05	0.06	< 0.05
76S350	10/26/76	21	48	-	< 0.05	< 0.05	0.25	< 0.05
76S351	10/26/76	21	50	-	< 0.05	< 0.05	0.20	< 0.05
76S352	10/26/76	16	36	-	< 0.05	< 0.05	0.54	< 0.05
76S353	10/27/76	18	50	-	< 0.05	< 0.05	0.96	< 0.05
76S354	10/27/76	11	23	-	< 0.05	< 0.05	1.34	< 0.05
76S355	10/27/76	22	38	-	< 0.05	< 0.05	1.35	< 0.05
76S356	10/27/76	29	67	3.02	< 0.05	< 0.05	0.50	< 0.05
76S357	10/27/76	13	24	-	< 0.05	< 0.05	0.22	< 0.05
76S358	10/27/76	25	53	-	< 0.05	< 0.05	0.19	< 0.05

TABLE 31 (contd)

Sample Number	Date Collected	Total α pCi/g	Total β pCi/g	^{3}H nCi/l	^{60}Co pCi/g	^{125}Sb pCi/g	^{137}Cs pCi/g	^{155}Eu pCi/g
76S359	10/27/76	27	65	-	< 0.05	< 0.05	0.16	< 0.05
76S360	10/27/76	26	68	-	< 0.05	< 0.05	0.61	< 0.05
76S361	10/27/76	27	63	-	< 0.05	< 0.05	0.53	< 0.05
76S362	10/27/76	15	38	-	< 0.05	< 0.05	0.87	< 0.05
76S363	10/27/76	29	64	-	< 0.05	< 0.05	1.66	< 0.05
76S364	10/27/76	13	25	-	< 0.05	< 0.05	1.33	< 0.05
76S365	10/27/76	25	60	-	< 0.05	< 0.05	0.43	< 0.05
76S366	10/27/76	13	28	-	< 0.05	< 0.05	1.74	< 0.05
76S367	10/27/76	22	47	0.49	< 0.05	< 0.05	0.62	< 0.05
76S368	10/27/76	22	53	-	< 0.05	< 0.05	0.08	< 0.05
76S369	10/28/76	20	52	-	< 0.05	< 0.05	0.74	< 0.05
76S370	10/28/76	7	19	-	< 0.05	< 0.05	0.55	< 0.05
76S371	10/28/76	24	62	-	< 0.05	< 0.05	0.35	< 0.05
76S372	10/28/76	26	61	-	< 0.05	< 0.05	0.14	< 0.05
76S373	10/28/76	23	59	-	< 0.05	< 0.05	< 0.05	< 0.05
76S374	10/28/76	18	38	-	< 0.05	< 0.05	0.91	< 0.05
76S375	10/28/76	24	59	-	< 0.05	< 0.05	0.60	< 0.05
76S376	10/28/76	24	55	-	< 0.05	< 0.05	0.56	< 0.05
76S377	10/28/76	24	61	-	< 0.05	< 0.05	0.73	< 0.05
76S378	10/28/76	22	54	-	< 0.05	< 0.05	0.69	< 0.05
76S379	10/28/76	22	52	-	< 0.05	< 0.05	0.70	< 0.05
76S380	10/28/76	30	62	-	< 0.05	< 0.05	0.39	< 0.05
76S381	10/28/76	17	34	-	< 0.05	< 0.05	1.30	< 0.05
76S382	10/28/76	39	67	9.66	< 0.05	< 0.05	0.70	< 0.05

TABLE 31 (contd)

Sample Number	Date Collected	Total α pCi/g	Total β pCi/g	^{3}H nCi/l	^{60}Co pCi/g	^{125}Sb pCi/g	^{137}Cs pCi/g	^{155}Eu pCi/g
76S383	10/28/76	22	55	-	< 0.05	< 0.05	0.61	< 0.05
76S384	10/28/76	35	73	2.42	< 0.05	< 0.05	0.51	< 0.05
76S385	10/28/76	24	57	-	< 0.05	< 0.05	0.49	< 0.05
76S386	10/28/76	25	58	-	< 0.05	< 0.05	0.65	< 0.05
76S387	10/29/76	24	55	0.24	< 0.05	< 0.05	0.61	< 0.05
76S388	10/29/76	26	73	-	< 0.05	< 0.05	0.61	< 0.05
76S389	10/29/76	28	58	-	< 0.05	< 0.05	0.63	< 0.05
76S390	10/29/76	26	63	-	< 0.05	< 0.05	0.72	< 0.05
76S391	10/29/76	22	44	0.57	< 0.05	< 0.05	0.39	< 0.05
76S392	10/29/76	23	56	-	< 0.05	< 0.05	0.36	< 0.05
76S393	10/29/76	24	63	-	< 0.05	< 0.05	1.73	< 0.05
76S394	10/29/76	32	61	-	< 0.05	< 0.05	0.67	< 0.05

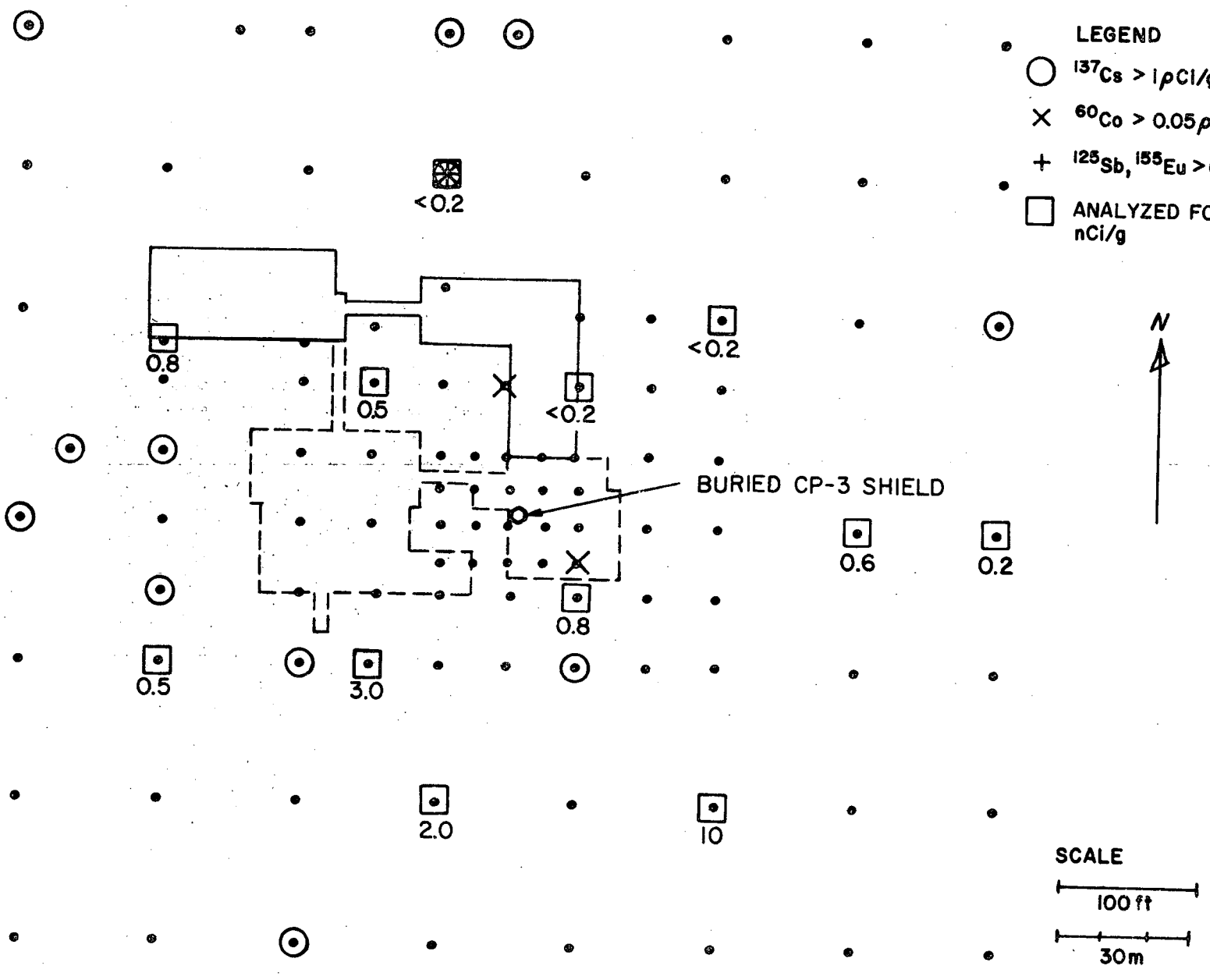


Fig. 10. Radionuclides Detected in Surface Soil at Site A.

although all the results were in the normal range for surface soil in the Chicago area. Gamma-ray spectrometry indicated that about 90% of the samples contained normal amounts of gamma-ray emitters. Cesium-137 concentrations from fallout average about 0.5 pCi/g and may range up to 1 pCi/g. Concentrations above this value are probably due to operations at the Site. One sample, 76S318, contained antimony-125 above its detection limit. This sample also had the highest cesium-137 concentration of all the 104 samples collected. Three samples had cobalt-60 in detectable concentrations. The two samples with the highest cesium-137 concentrations, 76S316 and 76S318, were also analyzed for strontium-90. Sample 76S316 contained 0.78 pCi/g and 76S318 contained 1.12 pCi/g of strontium-90. Present fallout concentrations of strontium-90 are about 0.1-0.2 pCi/g. The results show that small amounts of radionuclides from Site A operations remain at random locations.

Of the 12 samples whose soil moisture was analyzed for tritiated water, nine samples had concentrations greater than the detection limit of 0.2 nCi/l. No definite pattern could be established based on the few samples analyzed, although the three highest samples were on the south side of the Site. The surface samples from Cores #14-17 also contained abnormal amounts of tritium. It is difficult to understand why tritiated water at the measured concentrations should still be present at or near the surface after 20 years. In addition, most of the samples were collected in the fall of 1976, which was one of the driest seasons in recent years. For comparison purposes, the tritium concentration of surface soil samples collected elsewhere in the Chicago area has been less than 0.2 nCi/l.

VI. WELL WATER STUDIES

The first evidence of any subsurface migration of material from the Plot M area was the detection of tritiated water in the Red Gate Woods picnic well in November of 1973. Regular periodic sampling was instituted, and continues to the present time, in this and the four additional wells closest to Red Gate Woods (Figure 2). The Red Gate Woods well, #5167, is about 400 yards north of

Plot M and 1,000 yards north of Site A. The well opposite the entrance to Red Gate Woods, #5159, is about 700 yards north of Plot M and in line with the Red Gate Woods well. Well #5158 is about 300 yards northeast of well #5159 and 850 yards north of Plot M. The fourth well at 95th and Archer, #5157, is 1,500 yards north-northeast of Plot M. A fifth well, #5215, which was used to provide water to the guard post on the entrance road to Site A when it was in use, was reactivated by the Cook County Forest Preserve District for this study. This well is about 400 yards west-northwest of Plot M, and though there appears to be a component of subsurface water flow from the Plot in this direction, the magnitude is insufficient to affect the tritium content appreciably. All of these wells are hand pumped.

The data are collected in Table 32 and are graphed for three of the wells in Figures 11, 12, and 13. Tritiated water concentrations in the Red Gate Woods well showed a seasonal fluctuation, and were highest in the winter and lowest in the summer, although in the summer of 1977 the usual summer decrease was not as pronounced as in the previous three years. The reasons for this change are not yet clear, but are being investigated. The well opposite the entrance to Red Gate Woods, and down-gradient from the Red Gate Woods well, showed the same seasonal pattern but about four months out of phase, as illustrated in Figure 14. This cyclic pattern was not as apparent in any other wells.

Although all five wells are available to the public, the Red Gate Woods well receives the greatest use because of its location, and since it has the highest tritium content, the greatest interest is in this well. The maximum tritium concentrations in the Red Gate Woods well are in the winter when the picnic area is used the least. During each summer (except 1977), the tritium concentration was at or near the detection limit of 0.2 nCi/1. The highest concentration in any single sample was 14 nCi/1 and the annual average is about 7 nCi/1. The cyclic nature of the data implies a pulse of tritium entering the aquifer at regular intervals. The core studies discussed earlier show that the source of the tritium is Plot M. The spring rains recharging the groundwater and aquifer provide the vehicle for movement of the tritiated water through the glacial till and into the dolomite. This movement will be discussed in greater detail in the USGS study to be published later.

TABLE 32

Tritium in Wells Near Site A/Plot M

(concentrations in nCi/l)

Date Collected	5167 Red Gate Woods	5159 Opposite Entrance to Red Gate Woods	5158 300 yds East of Entrance to Red Gate Woods	5157 95th & Archer	5215 Guard Well
11/13/73	11.9	1.3	-	-	-
12/27/73	11.2	5.2	0.24	0.34	-
5/23/74	4.7	8.5	0.68	0.33	-
7/29/74	0.49	-	-	-	-
10/9/74	8.8	0.65	0.43	0.25	-
11/6/74	11.3	0.92	0.27	< 0.2	-
12/4/74	10.1	0.54	0.27	< 0.2	-
1/8/75	10.0	< 0.2	0.21	0.24	-
2/5/75	8.8	3.2	< 0.2	< 0.2	-
3/5/75	11.4	0.72	< 0.2	0.26	-
4/2/75	7.8	3.5	< 0.2	< 0.2	-
5/7/75	2.8	4.5	0.27	< 0.2	-
6/4/75	0.23	2.8	0.45	< 0.2	-
7/2/75	0.21	1.9	0.24	< 0.2	-
8/6/75	1.8	0.83	0.48	< 0.2	-
9/3/75	4.7	0.54	0.37	< 0.2	-
10/1/75	11.5	0.58	0.26	< 0.2	-
11/5/75	14.1	0.40	< 0.2	< 0.2	-
12/3/75	12.7	< 0.2	< 0.2	< 0.2	-
12/16/75	13.2	-	-	-	-

TABLE 32 (contd)

Date Collected	5167 Red Gate Woods	5159 Opposite Entrance to Red Gate Woods	5158 300 yds East of Entrance to Red Gate Woods	5157 95th & Archer	5215 Guard Well
1/14/76	10.5	2.9	< 0.2	< 0.2	-
2/4/76	11.3	1.4	< 0.2	< 0.2	-
2/19/76	12.4	0.55	-	-	-
2/26/76	9.4	1.3	< 0.2	0.26	-
3/3/76	7.9	1.5	< 0.2	< 0.2	-
3/15/76	4.7	3.8	0.22	0.27	-
4/7/76	3.0	4.4	< 0.2	< 0.2	-
5/5/76	0.23	4.1	0.24	0.20	-
6/1/76	< 0.2	2.6	< 0.2	< 0.2	< 0.2
7/7/76	2.3	1.5	0.25	< 0.2	< 0.2
7/14/76	1.2	1.3	-	-	-
7/21/76	4.1	1.2	-	-	-
7/28/76	3.3	1.2	-	-	-
8/4/76	2.0	1.2	< 0.2	0.20	< 0.2
8/10/76	0.65	1.1	-	-	-
8/18/76	0.41	1.0	-	-	-
8/24/76	1.1	1.5	-	-	-
9/1/76	0.70	1.5	< 0.2	< 0.2	-
9/8/76	1.2	1.0	-	-	-
9/15/76	3.7	2.4	-	-	0.30
9/24/76	0.86	0.97	-	-	-
9/29/76	6.9	0.98	-	-	-
10/6/76	8.3	2.4	-	-	< 0.2

TABLE 32 (contd)

Date Collected	5167 Red Gate Woods	5159 Opposite Entrance to Red Gate Woods	5158 300 yds East of Entrance to Red Gate Woods	5157 95th & Archer	5215 Guard Well
10/20/76	11.5	3.0	-	-	-
10/27/76	-	2.8	-	-	-
11/3/76	9.7	2.6	< 0.2	< 0.2	< 0.2
11/10/76	9.4	3.2	-	-	-
11/17/76	10.0	2.7	-	-	-
11/24/76	9.7	2.3	-	-	-
12/1/76	9.2	1.9	0.26	< 0.2	< 0.2
12/8/76	9.4	2.8	-	-	-
12/15/76	9.9	3.7	-	-	-
12/22/76	10.1	2.7	-	-	-
12/29/76	9.6	2.2	-	-	-
1/5/77	8.3	2.2	0.24	0.28	0.22
1/12/77	8.6	2.2	-	-	-
1/19/77	8.5	1.6	-	-	-
1/26/77	7.9	1.7	-	-	-
2/2/77	8.3	1.3	-	0.20	< 0.2
2/9/77	8.6	1.4	-	-	-
2/16/77	8.2	1.7	-	-	-
2/23/77	8.1	2.2	-	-	-
3/2/77	8.1	1.9	< 0.2	< 0.2	< 0.2
3/8/77	8.2	1.6	-	-	-
3/16/77	8.4	2.3	-	-	-

TABLE 32 (contd)

Date Collected	5167 Red Gate Woods	5159 Opposite Entrance to Red Gate Woods	5158 300 yds East of Entrance to Red Gate Woods	5157 95th & Archer	5215 Guard Well
3/23/77	8.0	2.4	-	-	-
3/30/77	8.1	4.0	-	-	-
4/6/77	7.6	4.1	0.35	0.29	< 0.2
4/14/77	7.8	5.0	-	-	-
4/20/77	7.6	5.9	-	-	-
4/27/77	7.7	5.4	-	-	-
5/4/77	8.2	4.0	< 0.2	0.27	< 0.2
5/11/77	8.8	3.0	-	-	-
5/18/77	8.5	1.8	-	-	-
5/25/77	8.7	1.6	-	-	-
6/1/77	8.7	1.3	< 0.2	0.28	< 0.2
6/8/77	9.3	1.2	-	-	-
6/15/77	9.4	1.2	-	-	-
6/22/77	9.1	0.88	-	-	-
6/29/77	9.4	0.66	-	-	-
7/6/77	8.8	0.91	< 0.2	< 0.2	< 0.2
7/13/77	8.8	1.1	-	-	-
7/20/77	8.8	0.81	-	-	-
7/27/77	9.1	0.74	-	-	-
8/3/77	8.8	0.63	< 0.2	< 0.2	< 0.2
8/10/77	9.3	0.38	-	-	-
8/17/77	9.9	1.2	-	-	-
8/24/77	8.4	1.4	-	-	-

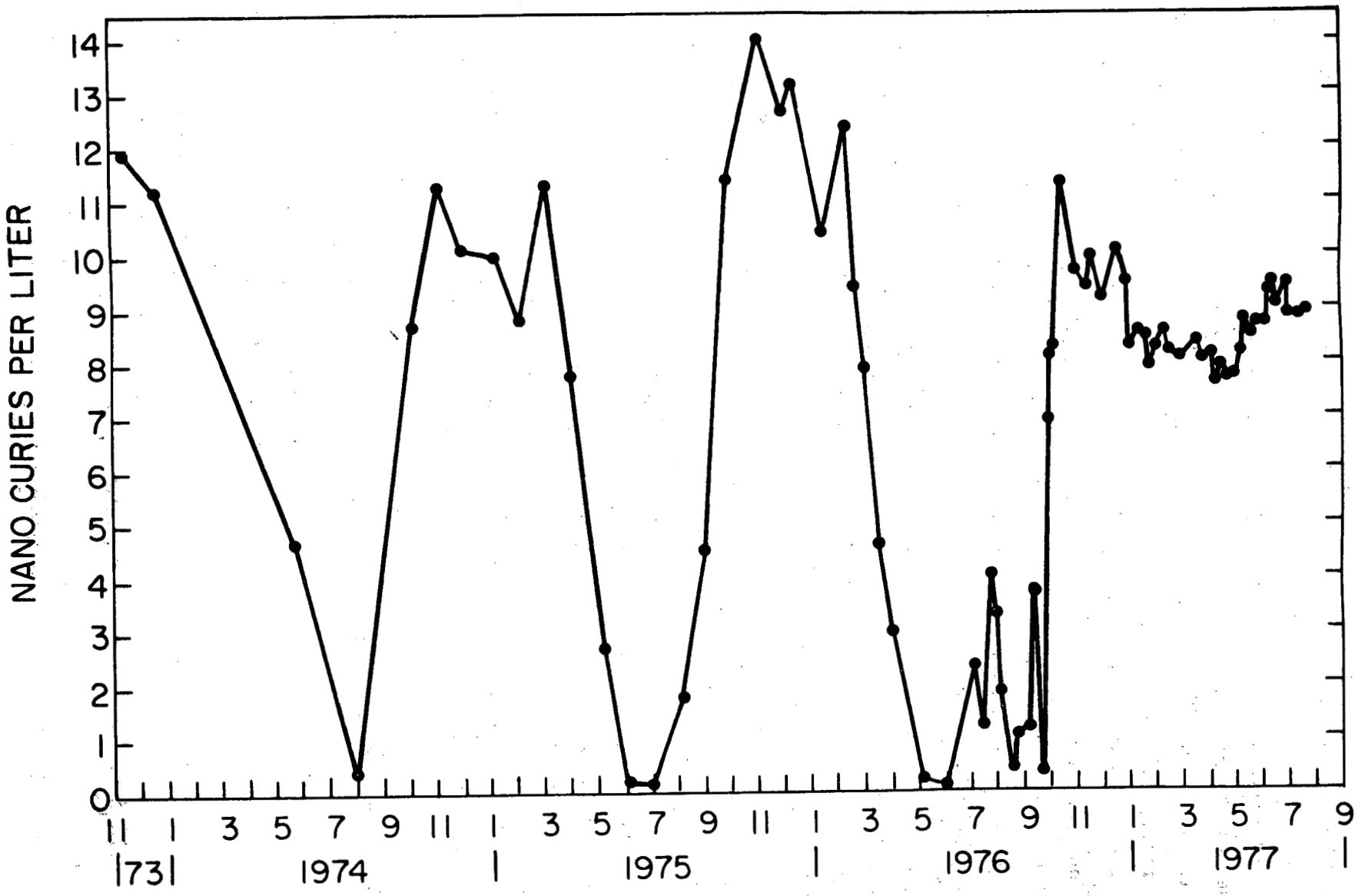


Fig. 11. Tritium Content of Water From Red Gate Woods Well (5167).

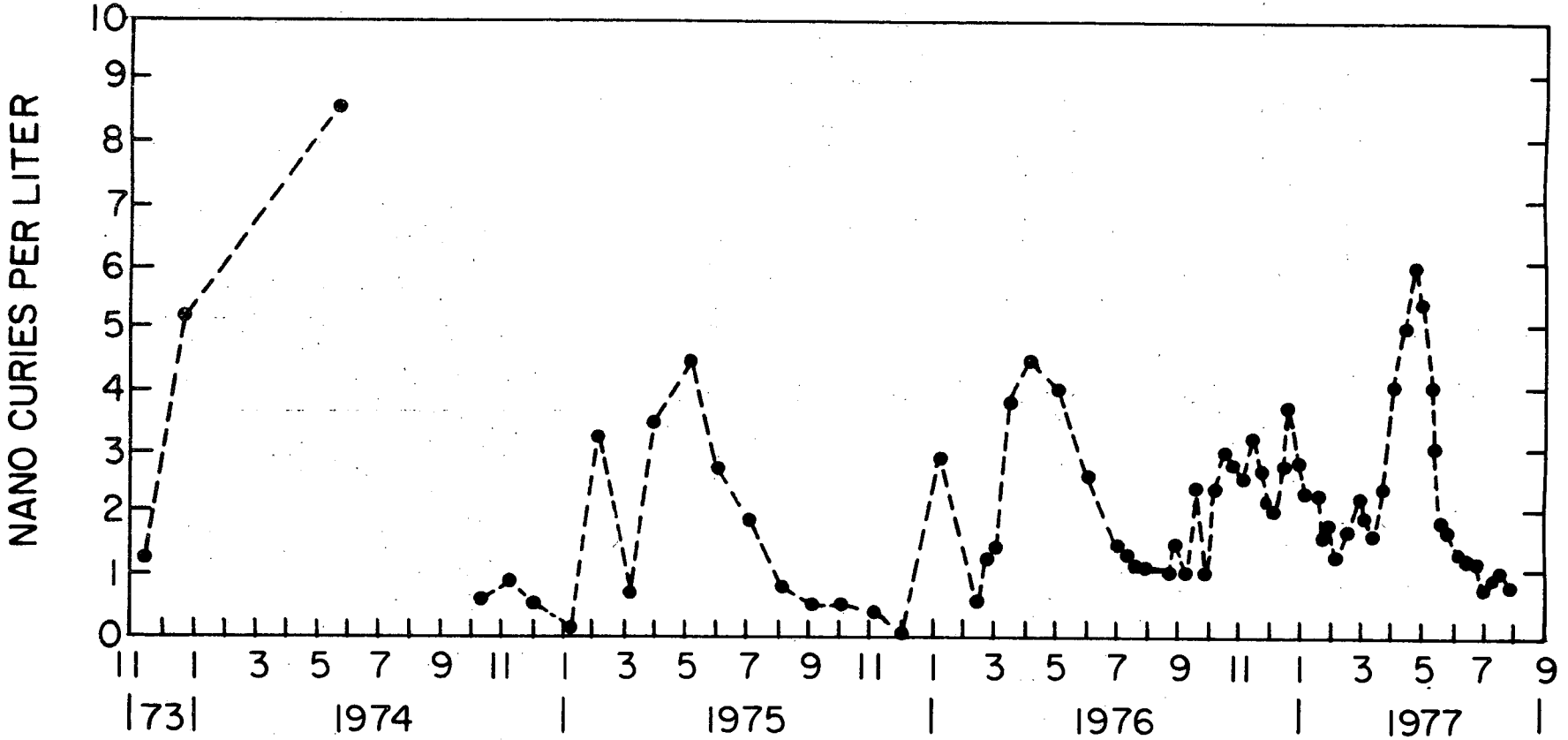


Fig. 12. Tritium Content of Water From Well 5159.

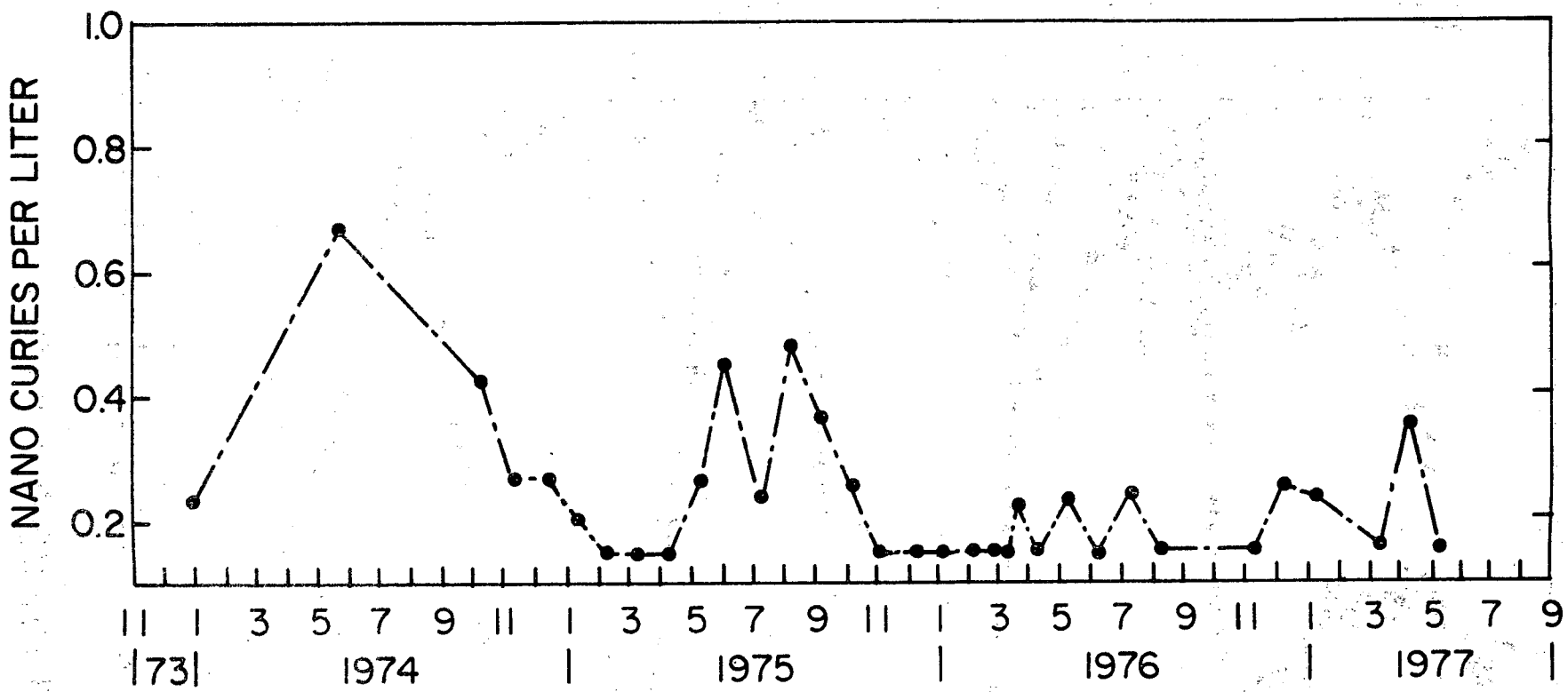


Fig. 13. Tritium Content of Water From Well 5158.

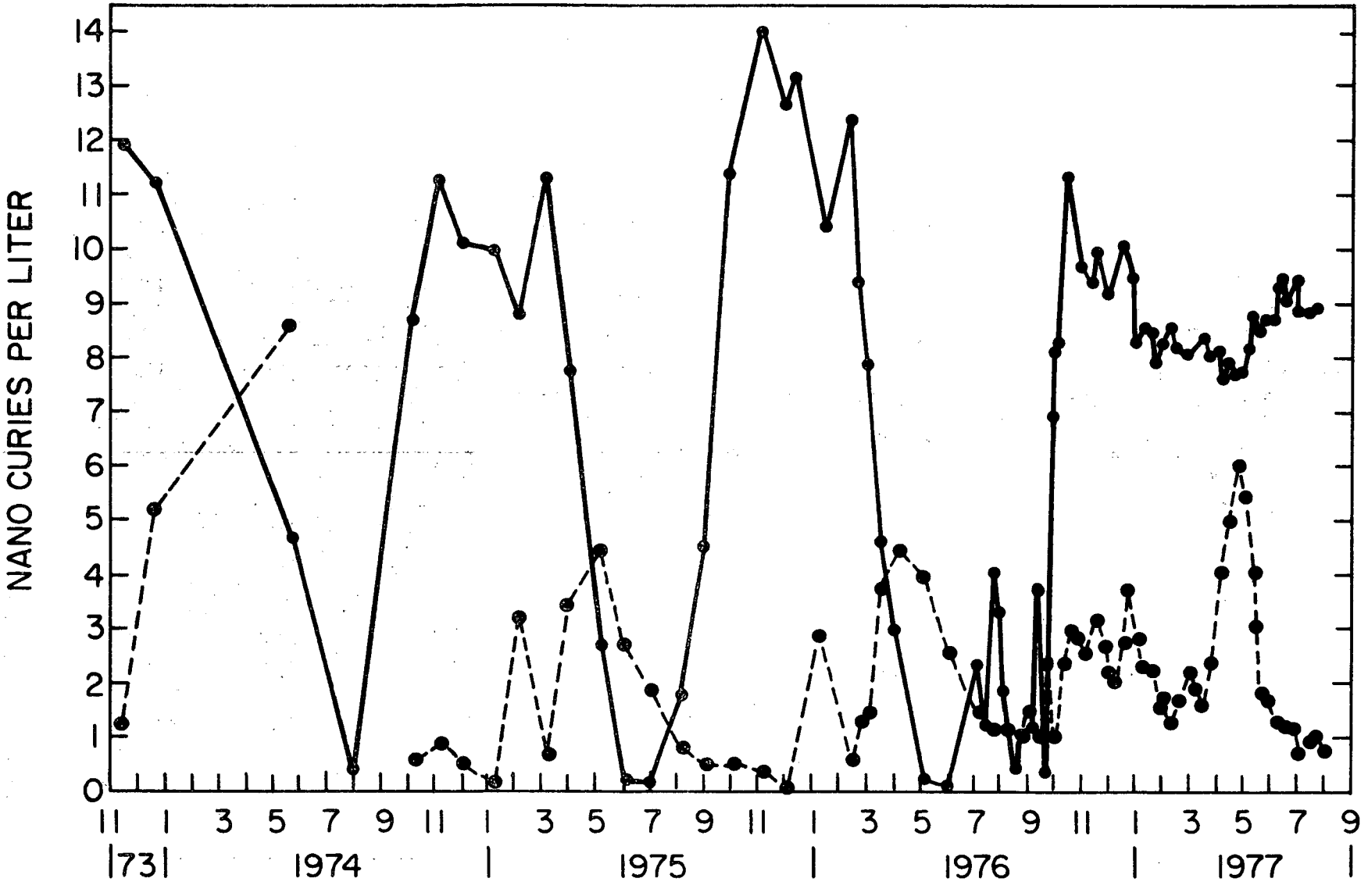


Fig. 14. Comparison of Tritium Content of Water From Red Gate Woods Well (5167) and Well 5159.

The radiological hazard due to drinking water from these wells can be evaluated by comparing their tritium content with appropriate standards. The most restrictive standard in effect is the EPA limit for public drinking water supplies,* 20 nCi/l, which is assumed to produce a dose of 4 mrem/year to an individual whose entire water consumption, considered to be 2 liters per day, contains tritium at this concentration. The total dose from one liter of water at the average concentration in the well at Red Gate Woods of 7 nCi/l would be 0.002 mrem. If an individual consumed one liter of water each day at this concentration, the resulting dose would be 0.7 mrem/year. No individual is known to use this water as his only source of drinking water. Consequently, any reasonably postulated dose from the picnic wells is small compared to the most restrictive standard.

In addition, this concentration-dose relationship was based on a quality factor of 1.7 for the tritium beta particle and a biological half-life for water of 12 days. The ICRP has since reduced the quality factor to 1.0 and the half-life to 10 days, so the dose of 0.7 mrem/yr should actually be reduced by a factor of about two to conform to the most recent ICRP recommendations.

The average concentration of 7 nCi/l that was used in the dose calculation has not changed significantly as a result of the change in the summer of 1977. The integrated tritium content of the Red Gate Woods well averaged from August through July for the past three years is as follows:

1974/75	6.7 nCi/l
1975/76	6.6 nCi/l
1976/77	6.9 nCi/l

Analysis of Red Gate Woods water samples for other radionuclides expected to be buried in Plot M (Table 33) show tritium to be the only non-natural radionuclide present. The uranium concentrations are within the normal range for wells in the area.

In addition to the five wells listed in Table 32, a number of other Forest Preserve wells were also sampled. These were located east and south of Site A/Plot M. The tritiated water concentrations in these wells were all less than the detection limit of 0.2 nCi/l. The locations and results are in Table 34.

*40CFR141 (Federal Register, Vol. 41, No. 133, July 9, 1976, p. 28404).

TABLE 33

Specific Radiochemical Analyses of
Red Gate Woods Well Water Samples

(concentrations in pCi/l)

Sample Number	Date Collected	^{90}Sr	U(natural)	^{239}Pu	Other TU*
74W131	7/29/74	-	0.54	< 0.0005	-
75W252	12/16/75	< 0.5	0.58	< 0.0005	< 0.001
76W160	6/1/76	< 0.5	0.72	< 0.0005	< 0.001
77W185	5/11/77	< 0.5	1.01	< 0.0005	< 0.001

*Transuranic elements.

TABLE 34

Tritium Content of Wells in Palos Forest Preserve

Location	Well No.	Date	nCi/l
Rainbarrel Slough	5188	3/3/76	< 0.2
Home-Bull Frog Lake Entrance	5190	3/3/76	< 0.2
Bull Frog Lake Entrance	5162	3/3/76	< 0.2
Bull Frog Lake	5031	3/3/76	< 0.2
Picnic Shelter B	5193	3/3/76	< 0.2
Picnic Shelter B	5154	3/3/76	< 0.2
Wolf Road Woods	5232	3/3/76	< 0.2
Wolf Road Woods	2286	3/3/76	< 0.2
Saganashkee Slough - East	5021	3/3/76	< 0.2
Saganashkee Slough - West	5148	3/3/76	< 0.2
St. James Church	5218	3/2/76	< 0.2

Samples collected from several private residences in the area of Archer Ave. and 107th St. west and south of Site A/Plot M were also all less than the detection limit.

In the fall of 1976, four deep holes, labeled DH 1 to DH 4, were drilled down into the dolomite aquifer at the locations shown in Figure 2. DH 1 is at Site A. DH 2 is between Site A and Plot M next to Core #21. DH 3 is just north of Plot M near Core #4. DH 4 is between Plot M and Red Gate Woods well near Core #20. Samples were collected on a monthly basis and analyzed for tritiated water. The results are in Table 35. Sampling has been carried out for too short a time to identify any seasonal variation in the concentration of the tritiated water. It is surprising that the magnitude of the concentrations in DH 3 and DH 4, which are below Plot M, is considerably less than the corresponding concentrations in the Red Gate Woods well. As expected, DH 3, close to and down-gradient from the Plot, contains tritium at a concentration attributable to Plot M.

DH 4 was drilled completely through the dolomite layer to the underlying shale. In July, 1977, water samples for tritium analyses were collected from four different levels spanning the entire aquifer to determine the tritiated water distribution in the aquifer. The results were inconclusive since the tritium concentration in all the samples was less than the detection limit. Since there has been little opportunity for mixing, considerable water may have to be pumped out of this hole to bring in water that has the same tritium concentration as the surrounding dolomite.

When the initial set of holes was bored around Plot M, piezometers were installed for water level measurements. In addition to the measurement of water levels in these holes, aliquots were periodically removed and analyzed for tritiated water. The results are in Table 36. The relative concentrations of the tritium in the bore hole water are similar to the tritiated water obtained from the soil borings. It should be noted that later in the year the zone of saturation dropped below the bottom of some of the borings and no water was available for analysis.

TABLE 35

Tritium in Water From Dolomite Holes at Site A/Plot M
(concentrations in nCi/l)

Date Collected	DH #1	DH #2	DH #3	DH #4
10/20/76	< 0.2	< 0.2	2.1	< 0.2
11/17/76	0.46	0.35	4.0	< 0.2
12/16/76	0.36	0.30	4.4	0.40
1/19/77	0.26	< 0.2	4.2	< 0.2
2/15/77	< 0.2	< 0.2	4.2	0.25
3/17/77	0.40	< 0.2	4.0	0.26
4/14/77	0.42	0.31	3.8	0.21
4/27/77	0.31	0.24	3.9	< 0.2
5/11/77	0.48	< 0.2	4.2	0.23
5/17/77	0.44	< 0.2	3.7	0.38
6/1/77	< 0.2	< 0.2	3.7	< 0.2
6/15/77	0.22	< 0.2	3.7	< 0.2
6/29/77	< 0.2	< 0.2	3.8	< 0.2
7/13/77	< 0.2	< 0.2	3.5	< 0.2

TABLE 36

Tritiated Water Concentrations in Plot M Bore Holes

(concentrations in nCi/l)

Date Collected	Core Number 1	2	3	4	5	6	7	8	9	10
5/19/76	1290	2.20×10^4	983	6620	269	404	5.9	0.49	-	-
6/16/76	1560	1.64×10^4	3000	6890	187	691	4.6	0.64	448	629
7/21/76	1420	1.76×10^4	3020	6240	145	639	3.5	0.53	2990	937
8/18/76	1495	1.65×10^4	3320	6350	171	575	6.3	0.43	1.13×10^4	1522
9/15/76	1410	1.56×10^4	3082	6018	161	491	3.7	1.2	1.30×10^5	3.02×10^4
10/21/76	1445	1.51×10^4	3084	5739	163	452	-	1.3	1.59×10^5	-
11/17/76	1444	1.56×10^4	3080	5540	153	342	-	0.52	1.39×10^5	4.40×10^4
12/16/76	-	1.84×10^4	2934	5321	151	269	-	0.58	-	-
1/19/77	-	-	-	-	127	-	-	-	-	-
2/15/77	0.28	1.88×10^4	2884	4513	107	-	-	0.22	-	-
3/17/77	303	1.98×10^4	2919	4471	91	-	-	-	-	-
4/14/77	-	8812	2651	3786	118	-	-	-	-	-
4/20/77	-	5838	2492	3538	70	-	-	0.24	-	-
4/27/77	-	4175	2640	3318	74	-	-	0.34	9339	-
5/4/77	-	4165	2589	3295	87	-	-	0.57	-	-
5/11/77	-	4274	2721	3325	120	510	-	0.31	-	-
5/17/77	-	4495	2717	3309	101	696	-	0.25	-	-
5/25/77	-	4520	2543	3518	94	935	-	0.32	-	-
6/1/77	-	4491	2759	3481	95	1015	-	0.29	-	-
6/15/77	-	6546	2702	3516	87	1147	-	0.22	-	-
6/29/77	-	4692	2877	3463	83	1078	-	0.38	-	-
7/13/77	-	4778	2872	3368	64	963	-	0.33	-	-
8/17/77	677	8079	2832	3284	65	733	-	-	-	-

In general, the concentrations do not exhibit any cyclic pattern with time. The decrease in concentration in the spring of 1977 may be due to dilution from precipitation as a result of recharge. The large decrease in Core #1 is probably due to a leak in the pipe which allowed surface water into the bore hole. Since the primary purpose of these bore holes was to measure water levels, only a small quantity of water was removed for each tritium analysis. A better procedure would have been to remove the water from the bore hole each time and sample the water that refilled the hole. This method would have produced a sample containing the same tritium concentration as the surrounding soil water, but would have invalidated the water level data.

VII. SUMMARY

The principal finding of this study on the radiological status of the Site A/Plot M area is the presence of tritium (as water) in the Plot M area and in the three wells to the north. No abnormal amounts of radioactivity were found in any other Forest Preserve District wells or in any private wells. The only radionuclide in the Site A core samples attributable to operations at the Site is tritium. The concentrations were substantially less than in the Plot M area.

The Site A area has small spots of surface contamination which are only slightly above fallout levels. Elevated concentrations of uranium and plutonium were found on the surface of the bed of a swale 50 to 200 feet north and downhill of Plot M. Although the concentrations varied considerably from place to place, average values over this area were about 10 pCi/g for uranium (1-3 pCi/g is normal) and 0.2 pCi/g for plutonium (about 0.05 pCi/g is a common concentration for fallout plutonium).

The only important pathway for exposure to the public from the radionuclides buried in Plot M is from the tritiated water moving from the Plot to the dolomite aquifer and consumed by individuals using the picnic wells. The possible dose to people from this pathway is estimated at 0.7 mrem/yr as compared to the EPA drinking water standard of 4 mrem/yr.

The cyclic nature of the tritiated water concentrations in the Forest Preserve District wells, primarily the Red Gate Woods well, is attributed to the movement of tritiated water from the Plot M area to the dolomite aquifer and then to the wells, principally by the spring rains when they recharge the groundwater supply. The time required for this transit is not firmly established, but is presently estimated to be about 20 months. The time of travel will be discussed in the forthcoming report of the USGS study, which was conducted simultaneously with the radiological survey.

Elevated tritium concentrations were found in the soil around and beneath Plot M. The concentrations decrease with increasing distance from the Plot. Since the water flow is in the northerly direction from the Plot, the concentration decreases more slowly with distance in this direction than in other directions. Tritium has been found in the subsoil as deep as samples have been collected, so it must be assumed that the ground beneath and immediately around the Plot contains tritium down to the dolomite aquifer, which is about 130 feet below the surface of the Plot. The total tritium content in this area is estimated to be of the order of 3000 Ci. The dolomite aquifer beneath the soil north of the Plot must also be assumed to contain tritium from the Plot, based on the well water results. However, in the three waterways that drain the Plot, the Illinois & Michigan Canal, Des Plaines River, and Chicago Sanitary & Ship Canal, tritium from the Plot was not detected.

Small amounts of other radionuclides - uranium, plutonium, and strontium-90 - have been found in bore holes beneath the concrete cap covering the Plot, but not in the subsoil outside of the Plot. The concentrations found to date are too low to result in any measurable radiation exposure to the public even if they should be leached from the site at some future time.