Fermi National Accelerator Laboratory
P.O. Box 500 Batavia, Illinois, 60510

Environmental Monitoring Report

For Calendar Year 1974

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1. Introduction

The Fermi National Accelerator Laboratory (Fermilab) facility is a proton synchrotron with a design energy of 200 GeV (billion electron volts); however, the accelerator is now operated routinely at 300 GeV with several weeks at 400 GeV in 1974. The primary purpose of the installation is fundamental research in high energy physics. It is located in the greater Chicago area (Fig. 1), permitting convenient access for users throughout the country. The 27.5 km^2 (10.6 sq. mi.) tract of land comprising the site is in an area which is rapidly changing from farming to residential use. There are many municipalities in the vicinity, resulting in a distinct pattern of high population concentration. Within a 3 km (2 mile) distance from the Laboratory boundaries, Batavia (pop. 9,000*), Warrenville (pop. 3,900*) and West Chicago (pop. 10,100*) can be found.

The two major environmental features near the Laboratory are the Fox River to the west, which flows south through Batavia with an average of 500 million gallons per day, and the west branch of the DuPage River which passes east of the site flowing south with lower flow rate through Warrenville. The rainfall on site during 1974 was 89 cm (35 in.).[1] The land on the site is relatively flat with a high area, elevation 244 m

* 1970 U.S. Census

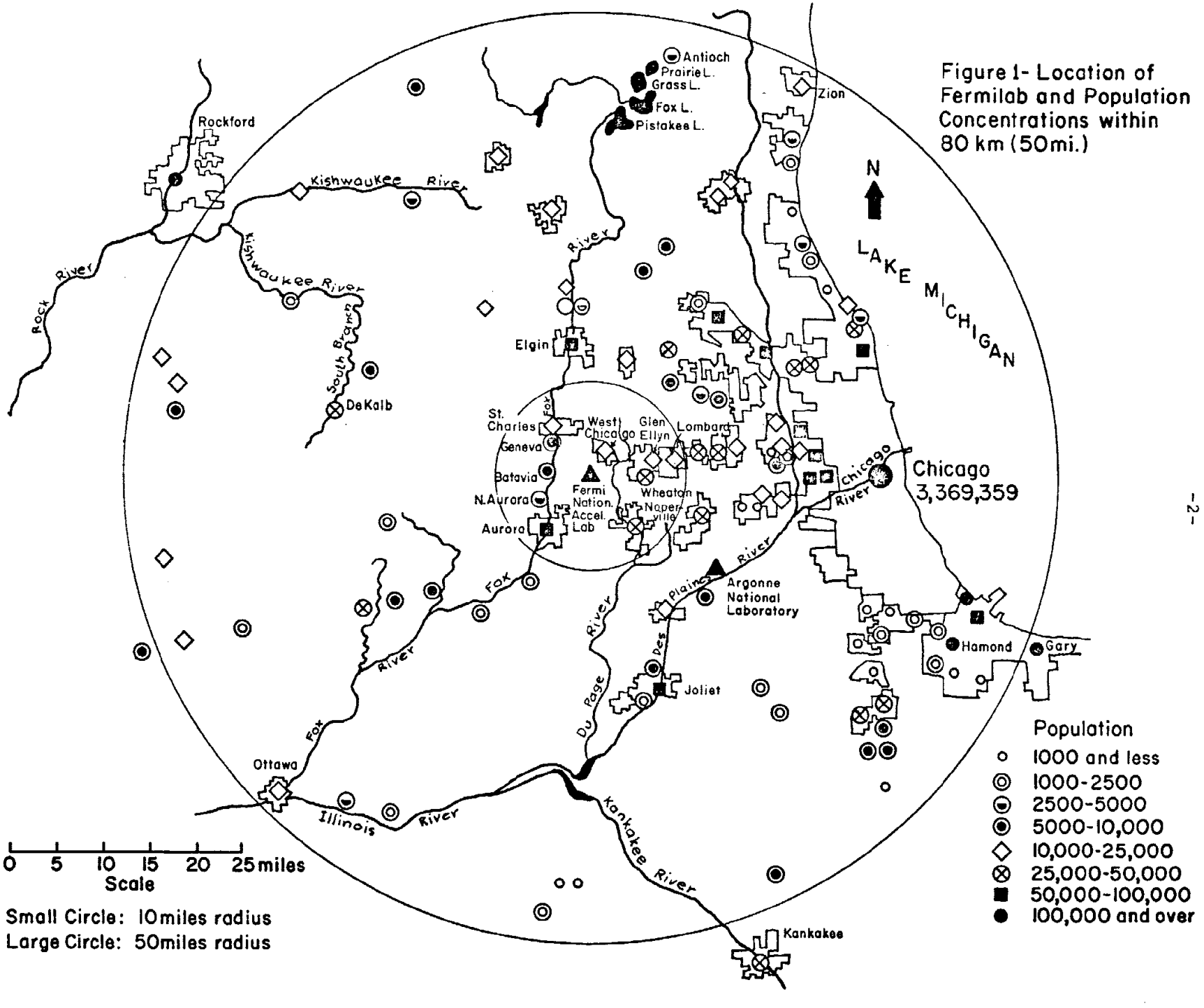

Figure 1- Location of Fermilab and Population Concentrations within 80 km (50 mi.)

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(800 ft.) above sea level (ASL), near the western boundary and low point, elevation 218 m (715 ft.), ASL toward the southeast. The drainage of the ground water and most of the surface water is toward the southeastern corner of the Laboratory, toward the DuPage River. A somewhat smaller amount drains to the southwest, toward the Fox River. The drinking water in many of the surrounding communities comes from deep wells usually drilled 1,200 feet deep into the Cambrian Ordovician aquifer system.[2]

The proton beam extracted from the 2 km (1.2 mi.) diameter main accelerator is taken to three different experimental areas on site. All three of these areas received proton beams for the first time in 1972. Radioactivity is produced as a result of the interaction of the accelerated protons with matter. Operation of the accelerator produces some radiation which penetrates the shielding material as well as some airborne radioactivity. Also, some radioactivation of the soil occurs. Thus, a broad program of environmental monitoring is being maintained.

2. Summary

Almost twice as many protons were accelerated in the second half of Calendar Year (CY-) 1974 as in the first half. The maximum number of protons accelerated at one time reached about 30 per cent of the planned or design intensity and typical operation was at 10 to 20 per cent. Thus, environmental monitoring in CY-1974 was done under operating conditions not grossly different from those expected in the future.

During CY-1974 there were no abnormal natural occurrences which could have resulted from or have had some impact upon the facility or its operation. There was an unusual release of tritium resulting from condensation of moisture in the exhaust line of a vacuum pump. Also, the Laboratory is aware of the possibility that some environmental pollution

may have occurred through the surfacing of water discharged into the underground perforated pipe fields inside the main accelerator (Fig. 2). Total exposure to the general population off-site was 2 man-rem for 1974.

Water discharged into the perforated pipe field inside the main accelerator contains chromates used to inhibit corrosion in the cooling towers. It sometimes contains ^{7}Be and salts from regeneration of water treatment resins (water softeners). While measurements of radioactivity have indicated no problem, insufficient data is available for nonradioactive pollutants. Measurements on their extent and concentration will be made in CY-1975.

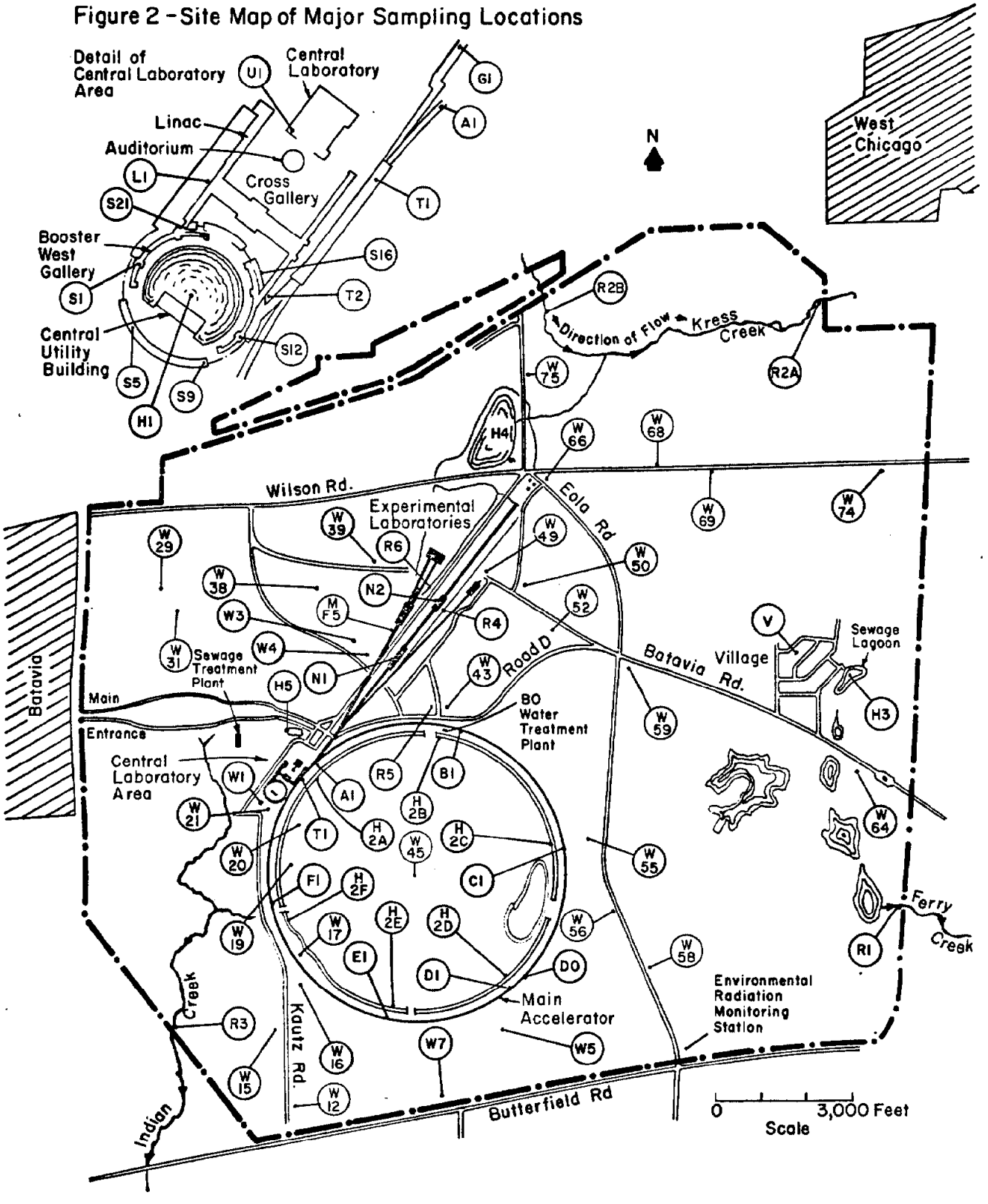
Operation of Muon Laboratory, a facility in one of the three outlying areas receiving a beam of protons, resulted in a small amount of penetrating radiation (muons, in this case) reaching the northern boundary of the site. The maximum dose which could have been delivered at that site boundary for the entire year was 2 mrem or about one per cent of the appropriate standard given in Section 4 for penetrating radiation applied to populations.

Airborne radioactivity was released across the site boundary in small amounts throughout the year from the stack ventilating an enclosure where the beam struck a target. The radioactive gas was primarily ^{11}C and the maximum dose at the site boundary was less than 0.01 mrem for 1974 (Section 3.2). The release was at less than 0.01 per cent of the Concentration Guide (Section 4).

There was also one controlled release of tritium produced in helium gas near another target. The total amount of tritium released was 23 mCi over a period of 24 hours. The maximum concentration at the site boundary was 7×10^{-10} µCi/ml or one per cent of the Concentration Guide, resulting in a negligible off-site exposure.

No radioactivity was detected in the ground water and only one release of tritium in surface water is worthy of note. Condensate from a large pump evacuating the air from the vicinity of a target was drained into a sump pit

Figure 2 - Site Map of Major Sampling Locations



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and subsequently pumped out into a drainage ditch and carried off site via Kress Creek. The total amount of tritium leaving the site from this source is estimated to be 27 mCi at concentrations less than 3 x 10^{-6} μCi/ml or 0.3 per cent of the Concentration Guide for the general population.

3. Monitoring, Data Collection, Analysis and Evaluation

The three types of accelerator-produced radiation meriting monitoring for environmental purposes are discussed below.

3.1. Penetrating Radiation

Operation of the accelerator at current energies and intensities results in production of some penetrating radiation (primarily neutrons and muons) outside the shielding. Although the shielding has been designed to be adequate for foreseeable circumstances, monitoring for purposes of determining actual radiation levels both on and off the site is necessary.

A large network of detectors is used to monitor penetrating radiation. At the end of CY-1974 there were approximately 200 detectors deployed around the site for the main purpose of protecting on-site personnel. The majority of these detectors are connected to a data logger which automatically records the radiation levels and sounds alarms when levels exceed preset values.[3] Approximately 20 detectors are used primarily for environmental radiation monitoring. Most of these are deployed at the ends of the paths traveled by the protons or near the site boundary.

A special radiation monitoring station with detectors of high sensitivity is maintained near the site boundary (Fig. 2).[4] This station detected no accelerator-produced radiation in CY-1974. The station serves the additional function of providing background levels for comparison to levels detected by the Mobile Environmental Radiation Laboratory (MERL). The MERL is a four-wheel-drive vehicle

equipped with detectors of high sensitivity for finding penetrating radiations and measuring levels at different distances for determining levels at the site boundaries. The long distances to the site boundaries and the low levels of radiation there compared to natural background levels make it necessary to measure levels closer to the shielding.

An example of the use of the MERL was for determining the exposure levels at the site boundary and for locating the source of the penetrating radiation discovered behind the Muon Laboratory, a facility in the Neutrino Area (Fig. 3). The MERL was equipped with two 26 cm x 26 cm (8" x 8") scintillation counters, one behind the other, with associated electronics to determine that the penetrating radiation (the individual muons) came through both counters. These counters were used to determine the direction and radiation level of the penetrating radiation. Measurements could be made at the site boundary even though the levels were low enough that around-the-clock operation for a year would result in a dose at the site boundary of less than 10 per cent of the applicable standard of 170 mrem/year. The actual operation during the year resulted in radiation capable of delivering a total dose of 2 mrem over a region about 50 m (150 feet) wide at the site boundary.

Doses at the site boundaries from all other accelerator-produced penetration radiation were less than ten per cent of that mentioned above. Hence, the operation of the Muon Laboratory gave by far the largest contribution to the dose at the site boundary. It should be pointed out, however, that the source of the penetrating radiation was traced to locations where the sub-nuclear particles interacted with components in the transport system guiding the beam toward the Muon Laboratory. Hence, it was not directly associated with the particular experiment being done in the Muon Laboratory.

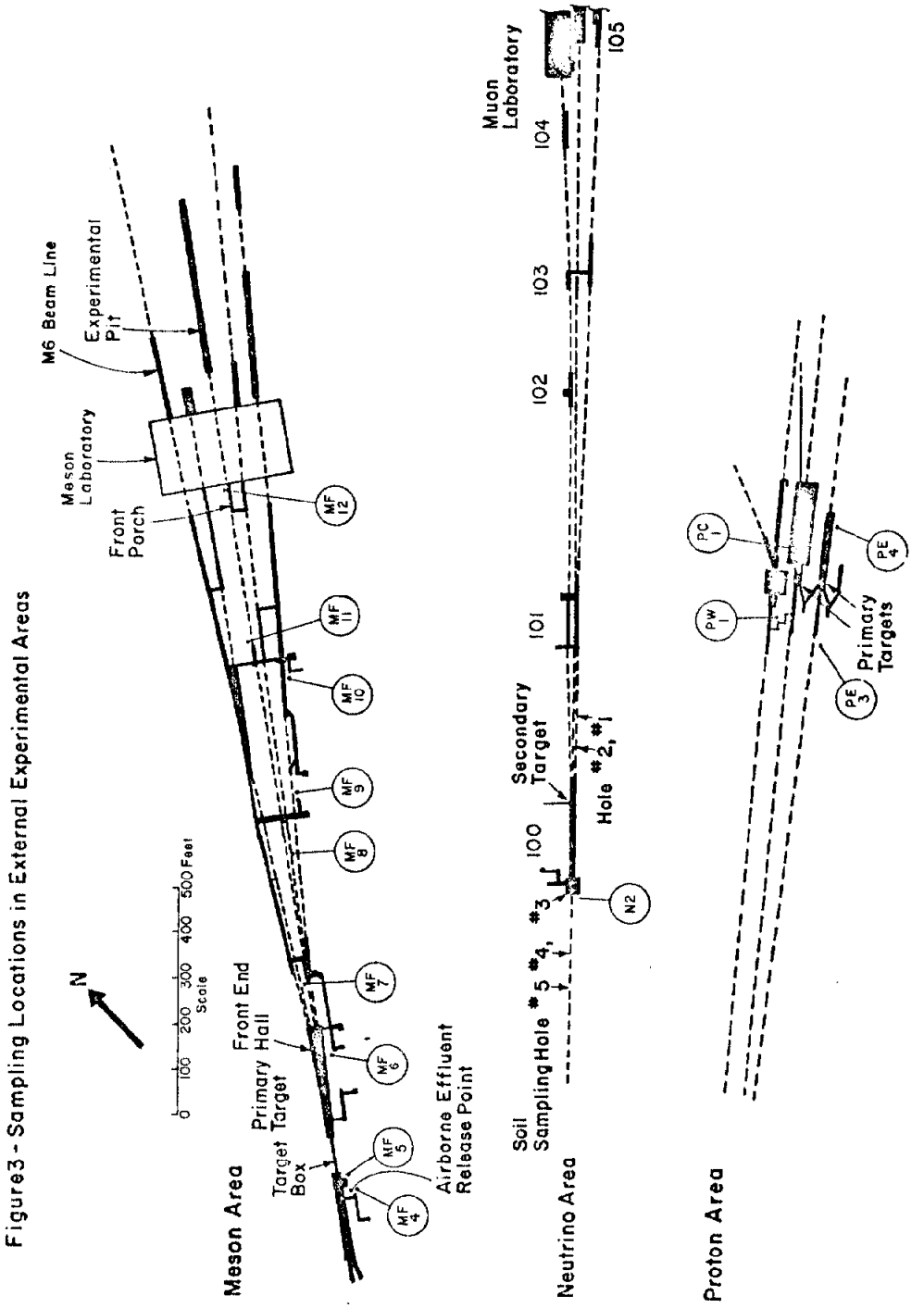

Figure3 - Sampling Locations in External Experimental Areas

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3.2. Airborne Radioactivity

Radioactivation of air in measurable concentrations will occur wherever the proton beam or the spray of secondary particles resulting from its interactions with matter passes through the air. Along most proton beam lines (paths of the protons from the accelerator) the protons travel inside evacuated pipes. Thus, radioactivation of air is now usually caused by secondary particles. Monitoring of such activation is carried out for purposes of personnel exposure control. Under no circumstances is the off-site concentration of airborne radioactivity expected to approach the limits set forth in the Energy Research and Development Administration Manual, Chapter 0524 (ERDAM 0524).

Monitoring of airborne radioactivity was carried out by detecting the beta particles emitted in the radioactive decay.[4] Radioactive gas, primarily ^{11}C, was monitored continuously during all periods of release from the stack in the Neutrino Area during 1974. From measurements made at the stack and calculations based on a Gaussian plume diffusion model[5], the expected dose at the site boundary for 1974 was less than 0.01 mrem. The calculation was felt to be more accurate than any direct measurement of the very low concentrations at the site boundaries.

The Concentration Guide for exposure of the general population to ^{11}C was calculated from the Guide for radiation workers[6] by converting from 5 to 0.17 rem per year and from 40 to 168 hours per week. The result is 0.48×10^{-6} μCi/ml. The exposure at the site boundary from stack releases in the Neutrino Area is less than .006 per cent of the applicable Guide.

On December 3, 1974, helium gas containing tritium at a concentration of approximately 8×10^{-4} μCi/ml was released to the atmosphere in the Meson Area on a day when the wind speed was high (approximately 7 m/sec or 16 mph) and blowing toward the southwest. Mixing was good and the

rate of release was controlled so the concentration never exceeded 8 x 10^{-5} μCi/ml at 0.6 m (2 ft.) from the outlet and averaged less than 5 x 10^{-6} μCi/ml. The maximum concentration at the site boundary calculated using the Gaussian plume diffusion model was 1.8 x 10^{-10} μCi/ml or 0.3 per cent of the Concentration Guide given in ERDAM 0524. The total release was 23 mCi.

3.3. Waterborne Radioactivity

During accelerator operations, some radioactivation of the soil will occur.[7,8] Leaching of these radionuclides into the ground water provides a possible mechanism for transport of Fermilab-produced radionuclides into surface run-off waters and aquifer. Hence, a broad program of ground water monitoring for radioactivity is maintained.

Monthly water samples are taken at various locations on and off the site and analyzed for the presence of those radionuclides which have been experimentally determined to be produced in and to be leachable from Fermilab soils in measurable quantities.

The water sampling locations were chosen to sample two ground water systems:

1. Surface and near-surface waters. These samples were taken from sumps which collect water in the vicinity of accelerator components and from streams, rivers and industrial holding ponds. Samples were taken periodically* from the three on-site streams at locations where their waters left the site (Fig. 2). Samples were also obtained from the DuPage River and the Fox River into which these streams flow (Fig. 1).

2. Silurian aquifer. These samples were taken from farm wells which tap the 21 m (70 ft.) silurian dolomite aquifer which is a prime water supply for many private residences in the area. One deep well (436 m or 1432 ft.) sample is also collected quarterly.

Water samples were also taken monthly from the

*Monthly from Kress Creek and quarterly from Ferry and Indian Creeks.

recirculating systems which cool radioactive components. During 1974 one small capacity (227 ℓ or 60 gal) system reached a tritium concentration greater than the applicable Guide for radiation workers, was emptied, and the ^{3}H will be disposed of by off-site burial as radioactive waste.

3.3.1. Water Sample Collection and Analytical Procedures

Water samples collected from wells not in regular use are pumped for a sufficient length of time to insure that the water standing in the pipe has been pumped out before a sample is taken. The water in the pipe could conceivably have been there since the last time a sample was taken. Water samples from sumps, creeks and other surface waters are collected by dipping a bottle well below the surface or using a peristaltic pump. Several of the sumps inside normally locked enclosures are sampled by remotely operated peristaltic pumps or the sump pumps themselves.

Before shipment off-site to an independent testing laboratory for analysis, the samples collected were treated with concentrated hydrochloric acid to prevent the precipitation of radionuclides, particularly ^{7}Be. The monthly shipment included a sample containing known amounts of several of the accelerator-produced radionuclides to check the accuracy of the assays. Samples were analyzed by U.S. Testing Company in Richland, Washington during Fiscal Year (FY-) 1974. The contract for FY-1975 was awarded to Eberline Instrument Company, Midwest Facility, West Chicago, Illinois.

The agreement of the reported concentration with the known concentrations of radionuclides for these control samples provided verification that the analyses were meeting the specifications agreed upon in the contract. These specifications, given in Section 4, provide warning of the presence of radionuclides at concentrations far below the applicable concentration guides.

Water samples are subjected to one of the following tests:

Type 1. Test for ^{3}H, ^{7}Be, ^{22}Na, ^{45}Ca, ^{54}Mn and ^{60}Co. Analysis Type 1 is performed on almost all samples.

Type 2. Type 1 plus a test for ^{226}Ra and ^{232}Th. Routine sampling of the one deep well on the Fermilab site for radium and thorium is being carried out to observe any long term changes in the concentrations which might signal a change in the pattern of water flow.

Type 3. Type 1 plus chemical separation of ^{45}Ca. If the concentrations of certain radionuclides ever become large, the detection of a low concentration of ^{45}Ca in the presence of a high concentration of these radionuclides will be difficult. In those cases a chemical separation will be required before analysis.

Type 4. Tritium only. Because tritium has only a very low energy beta particle emission (19 keV end point), it is normally detected by intimate mixing with liquid scintillator. Analyses are usually used in conjunction with studies of closed water cooling systems.

3.3.2. Results of Analyses

The Fermilab water sampling locations for radioisotopic analysis sampling locations are shown in Figs. 2, 3, and 4*. The results for off-site and well water measurements made in CY-1974 are shown in Table 1. The appropriate concentration guides are given in Section 4. Note that no accelerator-produced radioactivity has been detected in these waters within the uncertainty of the measurements for CY-1974. The results for on-site tritium

*Holding ponds are denoted by the letter H, ditches and creeks by R, wells by V and W and sumps by the other letters.

Table 1

RESULTS OF OFF-SITE WATER SAMPLE ANALYSES

Collection Point	Number of Samples Collected*	Accelerator Produced Radioisotope	Minimum Detectable Concentration (μCi/ml)	Maximum Concentration Detected (μCi/ml)	Percentage Of Relevant Standard
Ferry Creek	4				
Indian Creek	4				
		^{3}H	3×10^{-6}	$<3\times10^{-6}$	< 0.3
Kress Creek	11	^{7}Be	5×10^{-7}	$<5\times10^{-7}$	< 0.075
		^{22}Na	3×10^{-7}	$<3\times10^{-7}$	< 3
DuPage River (West Branch)	2	^{45}Ca	3×10^{-7}	$<3\times10^{-7}$	<10
		^{54}Mn	5×10^{-8}	$<5\times10^{-8}$	< 0.15
Fox River	2	^{60}Co	1×10^{-7}	$<1\times10^{-7}$	< 1
Wells 4,5,17,20, 21,38,39,43,45, 49,50,52,55,59, 66,74,75	>1 each				
Wells 7,12,19,29, 31,56,58,64,69	1 each				

* Results apply to each sample, i.e., no accelerator produced activity was found.

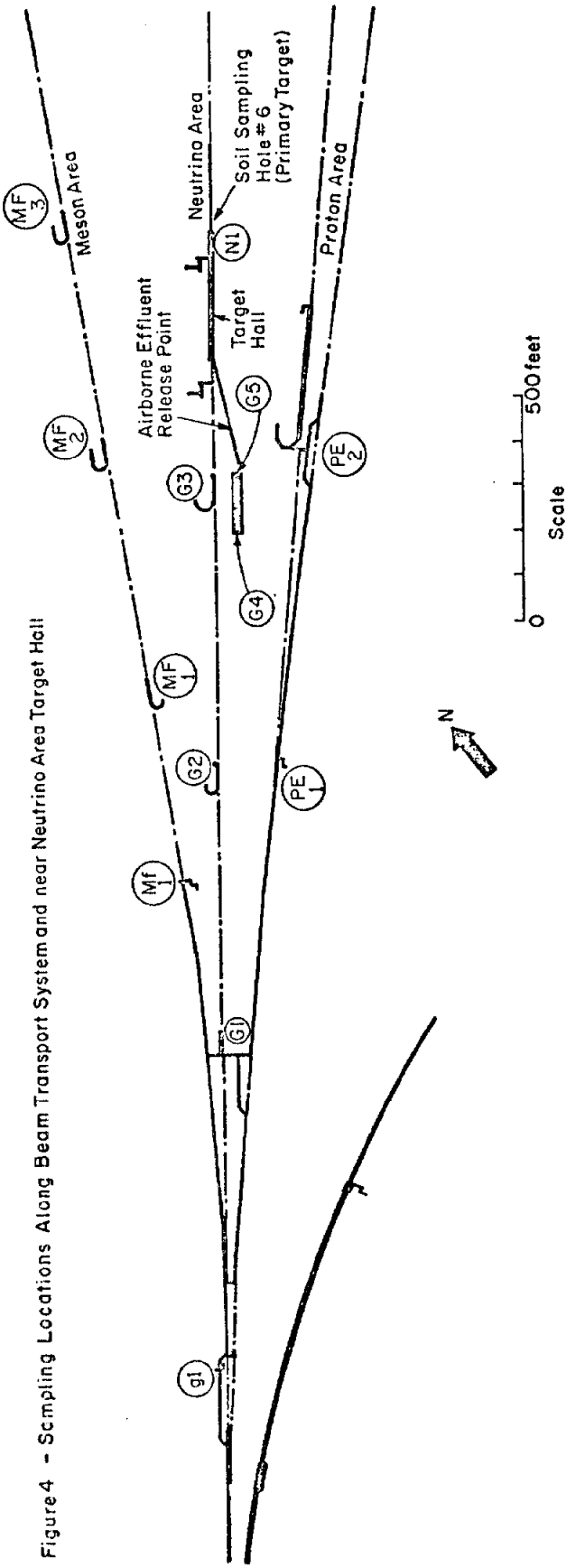

Figure 4 - Sampling Locations Along Beam Transport System and near Neutrino Area Target Hall

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measurements yielding detectable levels in surface waters are given in Table 2. All other sampling points were essentially at background levels. Also, no detectable levels of the other accelerator-produced radioisotopes were found with the exception of ^{45}Ca in the MF5 pump. Levels there have reached the Concentration Guide of 3 pCi/ml. Since the half-life of ^{45}Ca is 165 days and the concentration in waters leaving the site is much reduced by dilution and by its affinity for soil, no problem is anticipated.

A high tritium level (7.3×10^{-2} μCi/ml) was detected in the MF4 sump (Fig. 4) on a routine measurement in March, 1974 and was traced to condensate from a large vacuum pump which was being used to evacuate the 1.2 m x 1.2 m x 23 m (4 ft. x 4 ft. x 74 ft.) target box enclosing the Meson Area primary target. The condensate is now being collected instead of being allowed to drain into the sump pits and the target box is filled with helium instead of being evacuated. It was also discovered that the float levels in the MF4 sump were set too high, and water had been backing up in the underdrains and was not being pumped out of the MF4 sump. Thus, it was possible to keep the radioactivity in the MF4 sump from leaving the site.

At the same time the condensate was draining into the MF4 sump it was also draining into the MF5 sump. The MF5 sump pump was discharging about 150 ℓ (40 gal.) of water per hour from the underdrain below the target box. Thus, the estimated 38 ℓ (10 gal.) of condensate in each sump at 3 μCi/ml* accumulated over two months would have

*A sample of the condensate remaining in the exhaust line was analyzed by Eberline Instrument Corporation and they reported a tritium concentration of 0.7 μCi/ml. The sample contained no other radioisotopes in more than trace amounts. They also analyzed a second sample collected during accelerator operation between June and September and found a concentration of 5 μCi/ml. The approximate average of the two concentrations (3 μCi/ml) was used in the collection.

Table 2

RESULTS OF ON-SITE WATER SAMPLE ANALYSES

Collection Point	Number of Samples Collected	Tritium Concentration C (μCi/ml)* C max	C min	C mean	2σ**	Percentage of Relevant Standard
N1 Sump	12	1.2×10^{-5}	$<3\times10^{-6}$	5×10^{-6}	1×10^{-6}	0.5
N2 Sump	11	2.2×10^{-3}	$<3\times10^{-6}$	3.0×10^{-4}	4.5×10^{-5}	30.
MF4 Sump†	5	1.7×10^{-5}	$<3\times10^{-6}$	9×10^{-6}	1.4×10^{-6}	0.9
MF5 Sump	12	3.7×10^{-5}	$<3\times10^{-6}$	1.3×10^{-5}	2×10^{-6}	1.3
T1 Sump	8	4×10^{-6}	$<3\times10^{-6}$	3×10^{-6}	1×10^{-6}	0.3
D0 Sump	6	4×10^{-6}	$<3\times10^{-6}$	3×10^{-6}	1×10^{-6}	0.3
PE4 Sump	3	7×10^{-6}	$<3\times10^{-6}$	4×10^{-6}	1×10^{-6}	0.4
PW1 Sump	3	8×10^{-6}	$<3\times10^{-6}$	5×10^{-6}	1×10^{-6}	0.5
PC1 Sump	1	9×10^{-6}	---	9×10^{-6}	1.4×10^{-6}	0.9

* C max is the highest concentration detected in any sample from that location and C min is the lowest. C mean is the average for all samples from one location.

** The two standard deviation value given is the uncertainty expected in making a single measurement of a sample containing the concentration C mean. It was determined from the results for test samples sent to the independent testing laboratories.

† For those months when water from the sump was being pumped out into the ditch.

resulted in an average concentration of 5×10^{-4} μCi/ml in the sump and a total release of 100 mCi of tritium. This concentration would be reduced significantly (estimate, 50 times) by additional dilution before the water left the site. The measurements of tritium concentration in the monthly water samples from the MF5 sump for the two months (April and May, 1974) when the concentration was high in the MF4 sump were 0.8×10^{-5} and 1.8×10^{-5} μCi/ml, respectively. No activity was detected at the site boundary where the water left via Kress Creek (Table 1). Using the estimated average concentration of 5×10^{-4} μCi/ml and a dilution of 50 times, one would expect the off-site release to be at an average concentration of 1×10^{-5} μCi/ml or one per cent of the applicable Concentration Guide for the general population during the two month release period. The MF5 sump also collects water from the underdrain below the target. The presence of tritium concentrations similar to those observed in April and May later in the year when the condensate no longer drained into the sump indicates that tritium in small concentrations may be coming from the underdrain.

Concentrations of tritium in the closed loop cooling systems are increasing. The ^{7}Be produced at the same time is removed by the resin used to maintain the high purity and low conductivity of the water. Release of these radionuclides is being carefully monitored and controlled. One system was drained in 1974 when its tritium concentration exceeded the Concentration Guide for ingestion by radiation workers. The total off-site release of tritiated water in CY-1974 was 8.2 mCi, an average concentration of less than 3 pCi/ml*, or less than 0.3 per cent of the concentration guide for continuous consumption by the general population.

The resins containing ^{7}Be are regenerated on site and the discharge containing ^{7}Be is released into the soil six feet below the surface inside the main accelerator.

*Detection limit - see specifications in Section 4.

The short half-life (53 days) of the ^{7}Be and its very strong chemical affinity with the soil insure that its release will place no burden on the environment.

Some ^{7}Be reached the surface from the perforated pipe fields in CY-1974. The concentrations in the silt at these points was less than 50 pCi/g. Neglecting the strong chemical affinity of ^{7}Be for soil or other materials, this concentration would be less than ten per cent of the concentration guide for consumption by the general population (Section 4) if each gram were water instead of soil, i.e., a concentration of 5×10^{-5} μCi/ml. Thus, the surfacing of ^{7}Be is not creating a radiation hazard.

For the purpose of determining the concentration of accelerator-produced radionuclides in the soil, a number of soil borings were made in the Neutrino Area (Figs. 3, 4) in CY-1974. In every case except two the sampling was made in areas protected by an impervious membrane to create a "bathtub" for collecting any radioactive water. In the case of the soil or sand and gravel not protected by a bathtub, the cores were obtained 0.6 m (2 ft.) from the center of the pipe through which the beam passed. The first hole was 2.7 m (9 ft.) from the wall of the building or enclosure for a secondary target and the second was only 0.6 m (2 ft.) from the wall. The results are given in Table 3. Note that the highest concentration of the long-lived ^{22}Na in the first boring is about 10 per cent of that of the second. Tests made of the fraction (less than ten per cent) leachable from sand and gravel into a volume of water weighing ten times that of sand and gravel indicate that the concentrations leached from these samples would be less than the Concentration Guides for the general population without further dilution. There is an underdrain around the base of the building which should collect any radioactive water leached from the soil in the second hole. That fact notwithstanding, the downward percolation of ground water toward the aquifer

Table 3

RESULTS OF SOIL BORINGS NEAR NEUTRINO AREA ENCLOSURE 100

Location	Sampling Region Distance to Ground Water* (m)	(ft.)	^{22}Na Concentration (pCi/g dry weight**)
2.7 m or 9 ft. from north wall	16.0 to 15.5	52.5 to 51.0	7
	15.1 to 14.6	49.5 to 48.0	37
	14.6 to 14.0	48.0 to 46.0	51
0.6 m or 2 ft. from north wall	15.8 to 15.4	52.0 to 50.5	20
	15.4 to 14.9	50.5 to 49.0	110
	14.9 to 14.5	49.0 to 47.5	133
	14.5 to 14.0	47.5 to 46.0	438
	14.0 to 13.6	46.0 to 44.5	139

* Ground water level is 212.8 m or 698 ft. above mean sea level[1], and the center of the pipe through which the protons travel is 14.3 m or 47 ft. above the ground water at these locations.

** The dry weight was determined after heating in an oven for three hours at 200°C.

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is calculated to be very slow--less than 1 m (3 ft.) per year--through the type of soil, mostly clay, which lies below normal ground level** from a depth of about 3 m (10 ft.) to the limestone at about 21 m (70 ft.).[9] Also, there would be a lot of dilution in the aquifer if any radioactivity reached it.

The half-life for ^{22}Na is 2.6 years. Thus, unless there is a shorter path through the clay to the aquifer, the ^{22}Na activity should be greatly reduced before the leached sodium reaches the aquifer. On the other hand, an appreciable fraction of the leached tritium, ^{3}H, an accelerator-produced radionuclide with a half-life of about 12 years, could still remain. The Concentration Guide (Section 4) for ^{3}H is 100 times that for ^{22}Na, but its long half-life makes careful monitoring necessary.

Tritium determinations for the soil samples were made by Eberline Instrument Corporation. A 20g sample was mixed with 20 ml of water for one hour and allowed to stand for one hour. Then an aliquot was decanted, distilled and assayed for tritium. The maximum concentration observed for samples 2.7 m or 9 ft. from the north wall of Enclosure 100 was 6.0×10^{-5} μCi/ml. For samples 0.6 m or 2 ft. from the wall the maximum was 1.1×10^{-4} μCi/m. These results are about ten per cent of the Concentration Guides for consumption by the general population.

The maximum ^{3}H and ^{22}Na activities found in the two holes agreed well with expectations based on soil sample irradiations, on measurements made inside the building using foil activation techniques, and on calculations made of the activation with distance from the building. The same was true for a hole drilled 1.5 m (5 ft.) from the primary target which received the majority of the protons accelerated in CY-1974. In that case the aquifer is protected by an impervious membrane with a drain above it and three underdrains

**The Meson Area and Neutrino Area have high berms or mounds of dirt for additional shielding over the beam lines and enclosures for targets and magnets. The Proton Area has its facilities below the existing ground level.

1.5 m (5 ft.) below it. The maximum ^{22}Na concentration was found in the sand and gravel just outside the 1.8 m (6 ft.) diameter pipe. The concentration there was 22,000 pCi/g. Assuming 10 per cent of this activity is leached into a quantity of water ten times the weight of the leached sample, one would obtain a concentration of 2.2×10^{-4} μCi/ml or 22 times the Concentration Guide for the general population.

The water from the underdrains below the impervious membrane goes into the N1 sump. No ^{22}Na was detected during CY-1974 and ^{3}H levels at a maximum of one per cent (Table 2) of the Concentration Guide for the general population were seen in water samples from this sump. Thus, there is no evidence that radioactivity at high concentrations is being released.

Further soil borings will be made in CY-1975. In addition, a well will be drilled to monitor ground water in the vicinity of the primary target in the Meson Area. There is a large impervious membrane forming a bathtub under this target, and the underdrain inside the bathtub is carrying a lot of water to the sump. There is no evidence of any problem in that area. The well is an additional precautionary measure since, unlike the Neutrino Area bathtub which has underdrains below it, the underdrains outside the Meson Area bathtub are at a higher elevation than the bottom of the bathtub and could not be relied upon to warn of a leak in the bathtub.

3.4. Nonradioactive Pollutants

3.4.1. Water Treatment

The domestic water supply at Fermilab is provided essentially by two wells approximately 70 m (220 ft.) deep. One (W1 in Fig. 2) is located in the Central Laboratory Area and the other (V in Fig. 2) is in the village. In cases of low pressure, a third 70 m (220 ft.) deep well (W3 in Fig. 2) is used to supply the additional water in the Central

Laboratory Area. The average use from these three wells is approximately 570,000 ℓ/day (150,000 gal/day).

Samples of water taps at the closest distance and at the farthest location from each well have been analyzed throughout 1974. Tests are performed for coliform (bacterial contamination) once a month by our water laboratory and once a month by the EPA Division of Laboratory Service, Chicago. The coliform level was less than one per 100 ml.

The high purity necessary for drinking has been maintained in the Fermilab's domestic water supplies by keeping the residual chlorine between 0.1 and 0.3 mg/ℓ throughout this past year. With our automated chlorine gas feeders we maintain a uniform dose rate.

3.4.2. Tests for Pollutants in Water Leaving the Site

Tests for pollutants in water leaving the site have been conducted monthly in our water laboratory. Measurements have been made of the pH, DO (dissolved oxygen), BOD5 (biological oxygen demand for 5 days), suspended solids and coliform. The test data for CY-1974 are represented in Table 4.

Authorization permits to discharge under the National Pollutant Discharge Elimination System have been obtained for both sewage plants.

The discharge limits set by the State of Illinois for the Central Laboratory's package sewage plant with tertiary treatment are:

BOD5: 4 mg/ℓ avg., 6 mg/ℓ max.

Suspended Solids: 5 mg/ℓ avg., 8 mg/ℓ max.

Fecal Coliform Bacteria: 200/100 ml

Residual Chlorine, max: .5 mg/ℓ

pH not less than 6.0 or greater than 8.5

The set average discharge limits for the village sanitary aeration lagoon are:

BOD5: 30 mg/ℓ avg., 45 mg/ℓ max.

Table 4

SITE WIDE WATER QUALITY REPORT FOR CY-1974

		pH	DO mg/ℓ	BOD5 mg/ℓ	Susp. Solids mg/ℓ	Fecal Coliform # per 100ml	NOTES
	Max.	9.8	13	10.3	210	280	
FERRY CREEK	Ave.	8.1	10.5	5.8	5.9	83	Sampled Monthly
	Min.	7.1	4.9	2	2	0	
	Max.	8	12.6	4.8	125	2400	
INDIAN CREEK	Ave.	7.7	10.1	3.7	38	511	Sampled Monthly
	Min.	7.1	6	2	2	10	
	Max.	8.5	13.3	8.8	141	2000	
KRESS CREEK	Ave.	8	7.8	5.1	32	394	Sampled Monthly
	Min.	7.7	5.5	2	2	10	
	Max.	8.1	10.5	16	24	10	
CENTRAL LAB. SEWAGE	Ave.	7.7	6.9	3.9	6.2	5	Sampled Weekly
	Min.	7.5	4	.4	1	0	
	Max.	10	16.1	17	60	10	
VILLAGE SEWAGE LAGOON	Ave.	8.5	10.8	8.5	23	5	Sampled Weekly
	Min.	8	5.2	2	2	0	

1974

Suspended Solids: 30 mg/ℓ avg., 45 mg/ℓ max.
Fecal Coliform Bacteria: 200/100 ml
Residual Chlorine, max: .5 mg/ℓ
pH not less than 6.0 or greater than 8.5

The Central Laboratory's sewage plant exceeded its maximum limits twice on BOD5, twice on Suspended Solids, and twenty times on Residual Chlorine. The Village Lagoon exceeded its maximum limits three times on pH, three times on Suspended Solids and nine times on Residual Chlorine. The results for all other measurements were in compliance with the limit.

The observed values for Residual Chlorine, which are tested daily, never exceeded 3 mg/ℓ at the Central Laboratory's sewage plant and never exceeded 1.6 mg/ℓ at the Village Lagoon. Other maximum values are given in Table 4.

Programmed sewage water tests are performed by our sewage treatment works operator, who is licensed by the State of Illinois.

The site-wide water systems are supervised by a water engineer licensed by the State of Illinois as a sewage treatment works operator and as a public water supply operator.

Weekly test reports on our sewage waters are sent at the end of each month to the EPA Operators Report Section, Springfield, Illinois as directed by this agency. In addition to that, the Aurora EPA Agency collects water samples from our village sewage lagoon. The effluent from the Central Laboratory's sewage plant flows into Indian Creek. The effluent from the village sewage lagoon flows into Ferry Creek. There was no release of untreated sewage off-site from the sewage plant during CY-1974. However, due to the occasional excess flow into the main site sewage treatment plant, it has been necessary occasionally during CY-1974 to pump untreated sewage into the woods in the vicinity of the main

sewage treatment plant. This has been absorbed into the ground and has not been released off site. This discharge has been made at a considerable distance from any domestic wells; tests of water samples from water wells on the site have shown no indication of any effect from this occasional discharge. Fermilab personnel are presently conducting surveys of all cooling water sources and ground infiltration which contribute to the excess flow. It is felt that the flow can be reduced to a point where this practice can be discontinued.

Some chemical treatment of our water system was necessary during CY-1974, however, to reduce algae and weed growth and to inhibit corrosion. Copper sulfate, not exceeding one mg/ℓ was applied for algae control, and Diquat, not exceeding one mg/ℓ was used for weed control on the village sewage lagoon, reflecting ponds and Main Ring cooling ponds.

The decision was made to use chromium compounds to reduce the rate of corrosion in the cooling towers for the intermediate or booster accelerator (Booster) since these compounds have a proven history of effectiveness. Nalco 370 Corrosion Inhibitor, with a chromate residual in the system water (as CrO_4) not exceeding 15 mg/ℓ was added. Unfortunately, chromium is also highly polluting. Alternate solutions to the corrosion problem are being sought.

Through evaporation in the cooling towers, the mineral concentration of the water remaining behind increases and it becomes necessary to remove some of these minerals, mostly salts. In the case of the cooling towers this is done by discharging about 130 ℓ/hr (35 gal/hr) of this water into a perforated pipe field below the surface of the ground inside the Main Ring of the accelerator. Hence, the chromate is also released at the on-site location. Some chromate has reached the surface due to the inadequate capacity of the perforated pipe field. The extent of the

pollution from this occurrence is not known, but will be measured in CY-1975. Elimination of the problem, probably by increasing the capacity of the field, has been scheduled for CY-1975.

3.5. Environmental Impact

3.5.1. Assessment of Potential Dose to the Public

Fermi National Accelerator Laboratory is located in the densely populated Chicago area. The distribution of population in different directions from the center of the main accelerator is shown in Table 5, based on the 1970 census.[10] Note that there are about eight million people living within 80 km (50 mi.) of the site. There are only about 2000 within 5 km (3 mi.), but the number of people living close to the laboratory is rapidly increasing as a result of the housing construction now in progress to the east and west of the site. Also, a large city is planned several miles south of the laboratory. Consequently, a much higher total exposure is expected from an off-site release of the same magnitude in 1980 as in 1974. Since the large change of population expected has not yet taken place, the 1970 census figures have been used to evaluate the potential exposure to the public for CY-1974.

The radiation exposure to the general population from operation of Fermilab in CY-1974 resulted almost entirely from penetrating radiation (Section 3.1) and was about 2 man-rem. Airborne releases continue to give low exposures both on- and off-site as expected. Several of the closed loop cooling systems are reaching levels where off-site releases, from these loops, should they occur, would be detectable but not hazardous. Some off-site release of radioactive water occurred in early 1974 while Casey's Pond, the reservoir receiving water from discharges in the three external areas to which protons are delivered, was full. Since that time the water level has been carefully managed and it has not been necessary to block the flow into

Table 5

INCREMENTAL POPULATION DATA IN VICINTY OF FERMILAB, 1970

DISTANCE, KILOMETERS FROM CENTER OF MAIN RING DISTANCE, MILES / DIRECTION	0-3.2 0-2	3.2-5 2-3	5-6.4 3-4	6.4-8 4-5	8-16 5-10	16-32 10-20	32-48 20-30	48-64 30-40	64-80 40-50	80-97 50-60	97-113 60-70
N	97	0	0	73	607	72549	59787	48373	28900	29156	25212
NNE	0	0	2306	1338	3728	75631	77070	108837	131661	102076	129086
NE	0	0	2692	4815	10321	63960	306836	123882	0	0	0
ENE	23	0	1587	20	44882	211107	864920	649681	0	0	0
E	0	0	0	0	11567	185533	1144118	1061396	0	0	13634
ESE	0	0	1998	2403	11764	74815	304494	629984	385309	193880	59602
SE	0	0	1657	0	22797	30689	39084	106622	30481	25141	10666
SSE	0	33	0	0	0	29540	124447	4559	15496	67239	11479
S	0	316	0	0	1338	4201	9058	10815	10829	8939	3087
SSW	0	45	1326	7579	44014	5063	1470	13488	6673	26103	15946
SW	0	0	3053	1009	34667	10155	14275	4543	27436	37847	10946
WSW	0	0	1671	3172	1733	4569	6054	5271	10716	6700	12863
W	0	0	3732	0	0	4059	2320	4039	11657	8043	29325
WNW	0	1143	5987	55	184	3109	48301	4087	11213	44197	11807
NW	69	0	890	3585	7003	1232	7547	3978	46860	165281	68082
NNW	0	0	362	3353	14633	20243	7256	23393	10634	28732	10542
TOTAL	189	1537	27261	27402	209288	796455	3017047	2802948	728965	743334	412277
CUMULATIVE TOTAL	189	1726	28987	56389	265677	1062132	4079179	6882127	7611092	8354426	8766703

the pond. The mean concentration of tritium during the period of release was less than one per cent of the concentration guide for the general public. Also, drinking water in the area is taken from wells rather than from the creek receiving the discharge. Hence, the dose from the release is expected to be negligible.

No accelerator-produced radioactivity has been found in the on-site wells, which are monitored frequently. Soil samples were taken from the area receiving the majority of protons and analysis for radioactivity showed no cause for alarm. Also, no accelerator-produced radioactivity was found in silt samples taken from the three creeks at the points where they leave the site.

Thus, the potential dose to the public from the operation of Fermilab in CY-1974 remained quite small as the accelerator reached a most significant level of operation, i.e., the highest energy proton beam in the world with more protons per acceleration cycle than any other accelerator of its type.

3.5.2. Evaluation of Nonradioactive Pollutant Releases

The results given in Table 4 indicate that there was no pollution of off-site waters from nonradioactive pollutant releases at the Laboratory in CY-1974. Some chemical treatment of our water system was necessary during CY-1974, however, to inhibit corrosion and reduce algae and weed growth (Section 3.4). The amount of chemicals added has been kept low to protect wildlife and fish. Chromates, mineral residues from evaporation in cooling towers, and salts from regeneration of water treatment resins have been discharged underground on site with some, as yet undetermined, amount reaching the surface in CY-1974. There is also a possibility that in periods of heavy precipitation some pollutants released inside the main accelerator could leave the site via Ferry Creek. Plans are being formulated for improvements which, it is hoped, will eliminate the surfacing

of these pollutants in CY-1975. The environmental impact of these releases is expected to be small.

All facilities on the site generate negligible amounts of nonradioactive airborne effluents. The heat is provided by natural gas. Thus, the direct burden placed on the environment by operation of Fermilab is minimal, in spite of its size and the number of employees and outside users, about 1300 and 500, respectively.

4. References

The concentration guides used in the analyses of the water samples were taken from the ERDAM, Chapter 0524, Annex A, Table II, Column 2 (Water in Uncontrolled Areas) and reduced by a factor of three as appropriate for a suitable sample of exposed population. The smaller of the values given for soluble and unsoluble forms has been used in each case. The specifications are given in Table 6. The concentration guides for airborne activity were taken from the same source, Table II, Column 1 (Concentrations in Air in Uncontrolled Areas), and divided by a factor of three for application to populations. For ^{11}C the concentration guide for radiation workers was taken from CERN Report 71-21.[6] The appropriate concentration guide for the general population was obtained by converting from 40 to 168 hours per week and from 5 rem to 0.17 rem, based on the appropriate standards for penetrating radiation taken from the ERDAM, Chapter 0524, Paragraph II.A. The exposure from ^{11}C is primarily external, from penetrating radiation.[11] The resulting concentration guide for ^{11}C exposure of the general population is 4.8×10^{-7} μCi/ml.

The appropriate standard for penetrating radiation applied to populations was taken from the ERDAM, Chapter 0524, Paragraph II.A. The value is 0.17 rem per year, per person.

Table 6

SPECIFICATIONS FOR THE ANALYSES OF RADIONUCLIDES IN WATER

RADIONUCLIDE	CONCENTRATION GUIDE FOR GENERAL POPULATION (μCi/ml)	SPECIFIED* SENSITIVITY (μCi/ml)	SPECIFIED* PRECISION (μCi/ml)
^{3}H	1×10^{-3}	3×10^{-6}	3×10^{-6}
^{7}Be	6.7×10^{-4}	5×10^{-7}	5×10^{-7}
^{22}Na	1×10^{-5}	3×10^{-7}	3×10^{-7}
^{45}Ca	3×10^{-6}	3×10^{-7}	3×10^{-7}
^{54}Mn	3.3×10^{-5}	5×10^{-8}	5×10^{-8}
^{60}Co	1×10^{-5}	1×10^{-7}	1×10^{-7}

* The precision and sensitivity are stated for the 68% confidence level (one standard deviation). The precision required is the value specified or ± 10 per cent, whichever is the lesser precision. The sensitivity is taken to be the minimum concentration which can be detected within the 68 per cent confidence level.

References to material cited in the text:

1. Measurements made on-site by State of Illinois Water Survey Division, P.O. Box 409, Warrenville, Illinois 60555.

2. A. J. Zeizel, et al., Cooperative Ground-Water Report #2, Illinois State Water Survey, Urbana, Illinois. (1962)

3. M. Awschalom, et al., CERN Report 71-16 p. 1035, Geneva, Switzerland (1971).

4. National Accelerator Laboratory Environmental Monitoring Report in Environmental Monitoring at Major U.S. Atomic Energy Commission Contractor Sites, Calendar Year 1973, WASH-1259.

5. F. A. Gifford, Jr. in "Meterology and Atomic Energy", 1968, D. H. Slade, Ed., TID-24190, Chapter 3 (1968).

6. K. Goebel, CERN Report 71-21, p. 3, Geneva, Switzerland (1971).

7. T. B. Borak, et al., Health Physics 23, 679 (1972).

8. M. Awschalom, et al., Fermilab Report TM-306 (1971).

9. Measurements and Calculations by Soil Testing Services, Inc., 111 Phingston Rd., Northbrook, Illinois.

10. Obtained from U.S. Census Bureau tapes by Civil Defense Research Section of the Health Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1973.

11. M. Hofert, Second International Conference on Accelerator Dosimetry and Experience, U.S. Energy Research and Development Administration Report CONF 691101, 1969, p. 111.

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