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

Environmental Monitoring Report
For Calendar Year 1976

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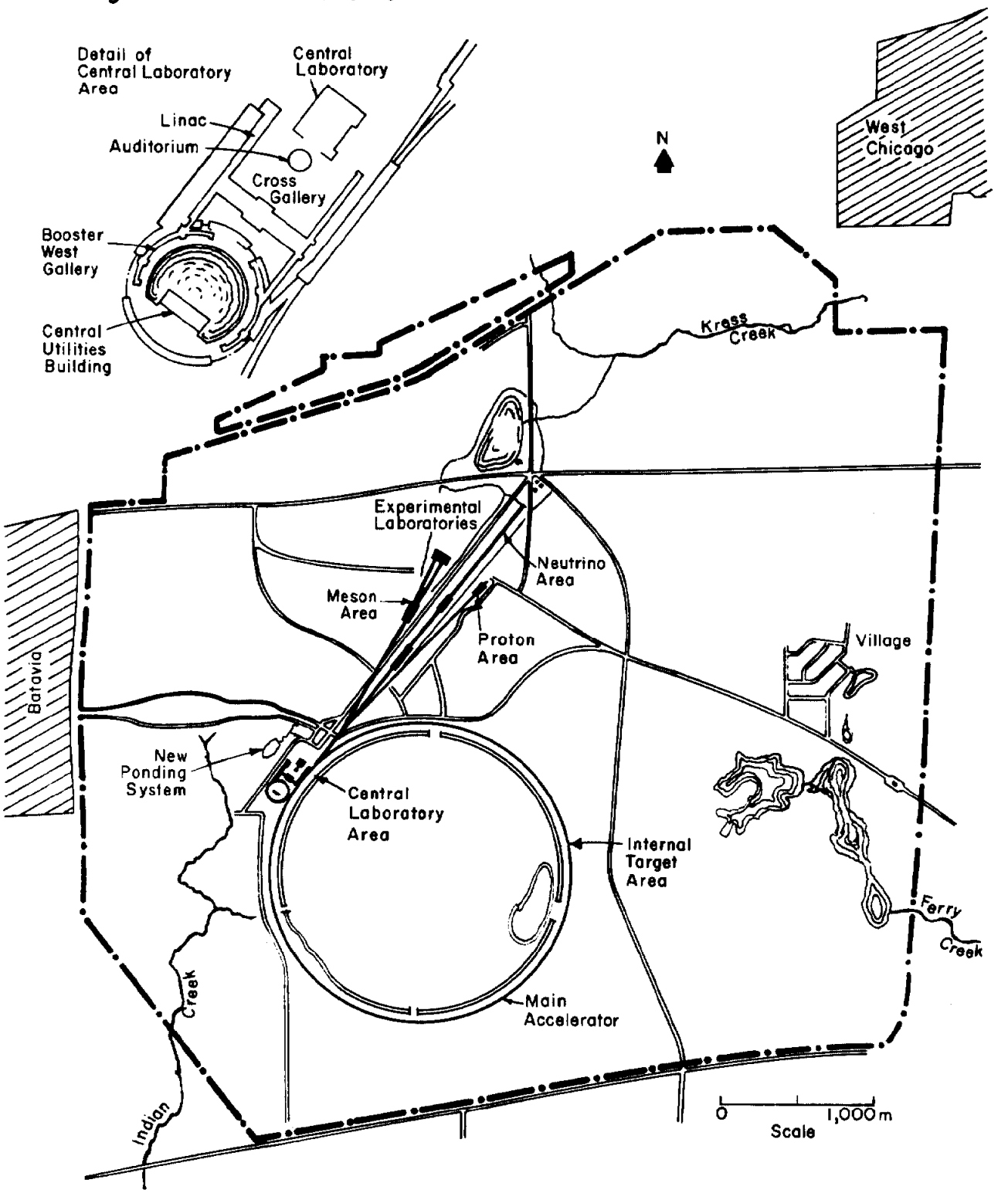
1. Introduction

This report gives the results of the environmental monitoring program at Fermi National Accelerator Laboratory (Fermilab) for Calendar Year (CY-) 1976. The Fermilab facility is a proton synchrotron with a design energy of 200 GeV (billion electron volts); however, the energy reached 500 GeV in 1976 and operation at 400 GeV is now routine. The primary purpose of the installation is fundamental research in high energy physics. In addition, cancer patients are being treated using neutrons released by interaction with protons from the accelerator.

The proton beam extracted from the 2 km (1.2 mi) diameter main accelerator is taken to three different experimental areas on site (Fig. 1). 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 water used to cool radioactive components and of the soil occurs. Since the Fermilab site is open to the public, this free access necessitates a thorough evaluation of our on-site discharges as well as our potential for off-site releases of radioactive effluents. Thus, an extensive monitoring program tailored to these needs is being maintained.

Monitoring results are also reported for nonradioactive

Figure I. - Fermilab Site



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pollutants. Included as pollutants are pesticides and copper used in weed, insect, rodent, and algae control Also, a corrosion inhibitor containing zinc and chromium (as chromate) has been used in one of the water systems. Discharge underground and subsequent surfacing has required monitoring. These results are reported as well as the performance of the two sewage treatment plants on site.

Fermilab is located in the greater Chicago area (Fig. 2) on a 27.5 km^2 (10.6 sq. mi.) tract of land 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. 3,000*) and West Chicago (pop. 10,000*) 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 1900 million liters (500 million gallons) per day, and the west branch of the DuPage River which passes east of the site flowing south with an average of 265 million liters (70 million gallons) per day through Warrenville. The rainfall on site during 1976 was 68 cm (27 in.).[1] The land on the site is relatively flat with a high area, elevation 244 m (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

* 1970 U.S. Census

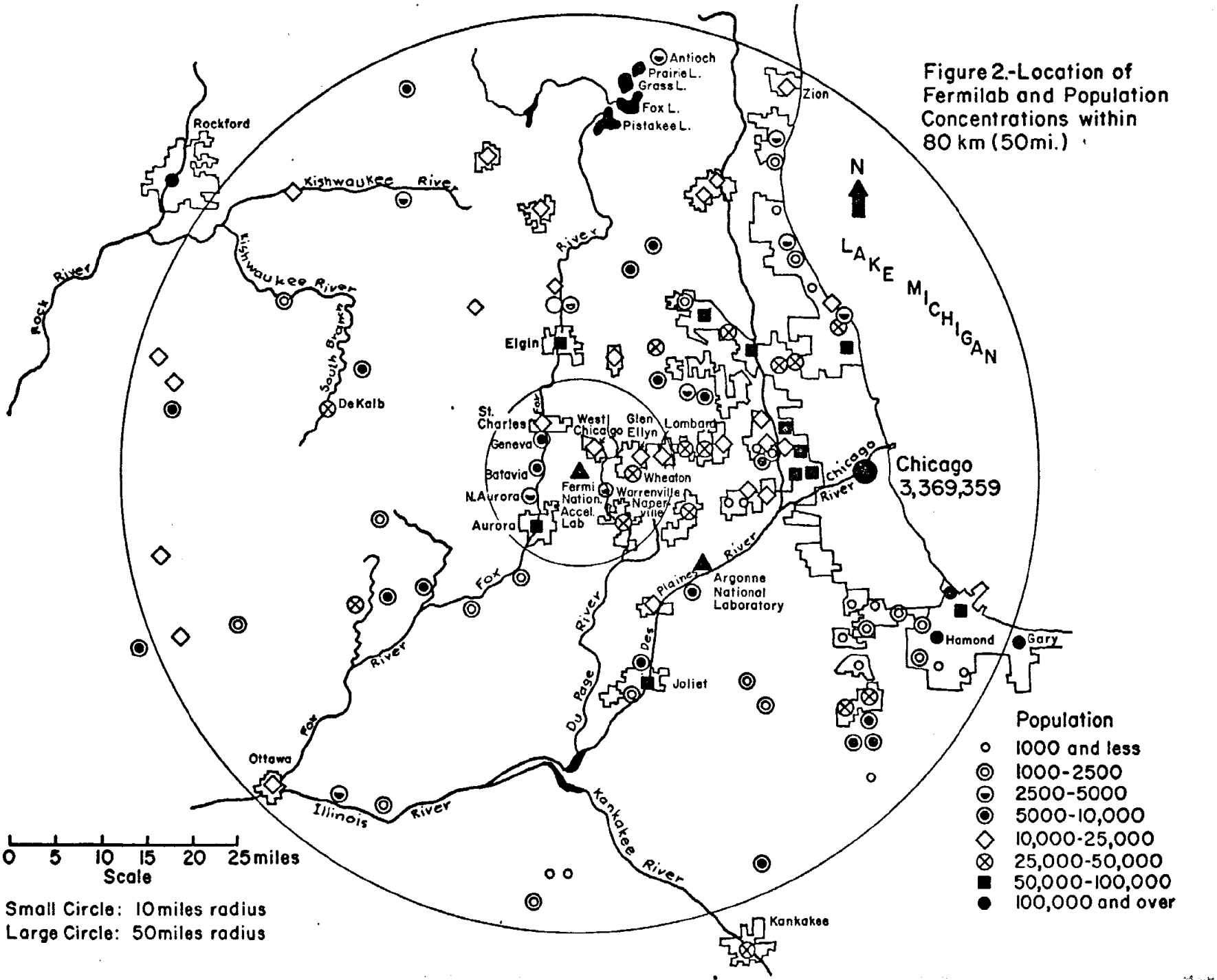


Figure 2.-Location of Fermilab and Population Concentrations within 80 km (50mi.)
N
LAKE MICHIGAN
Antioch
Prairie L.
Grass L.
Fox L.
Pistakee L.
Zion
Rockford
Kishwaukee River
Rock River
Kishwaukee River
South Branch
DeKalb
Elgin
Fox River
St. Charles
West Chicago
Glen Ellyn
Lombard
Geneva
Batavia
N.Aurora
Aurora
Fermi Nation. Accel. Lab
Wheaton
Warrenville
Naperville
Chicago River
Chicago
3,369,359
Plainfield
Argonne National Laboratory
Des Plaines River
Du Page River
Fox River
Joliet
Hamond
Gary
Ottawa
Illinois River
Kankakee River
Kankakee
0 5 10 15 20 25 miles
Scale
Small Circle: 10 miles radius
Large Circle: 50 miles radius
Population
1000 and less
1000-2500
2500-5000
5000-10,000
10,000-25,000
25,000-50,000
50,000-100,000
100,000 and over

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 mean wind speed for the 15-year period from 1950-1964 was 3.4 m/sec (7.6 miles/hr) at Argonne National Laboratory (ANL).[3] The direction is quite variable with the observation of more southwesterly winds than from any other direction. Fermilab is about 30 km (19 miles) from ANL, so similar wind conditions would be expected. Detections of radioactive gas plumes here have been strongly correlated with wind directions obtained from strip chart recordings made at ANL during our releases.

2. Summary

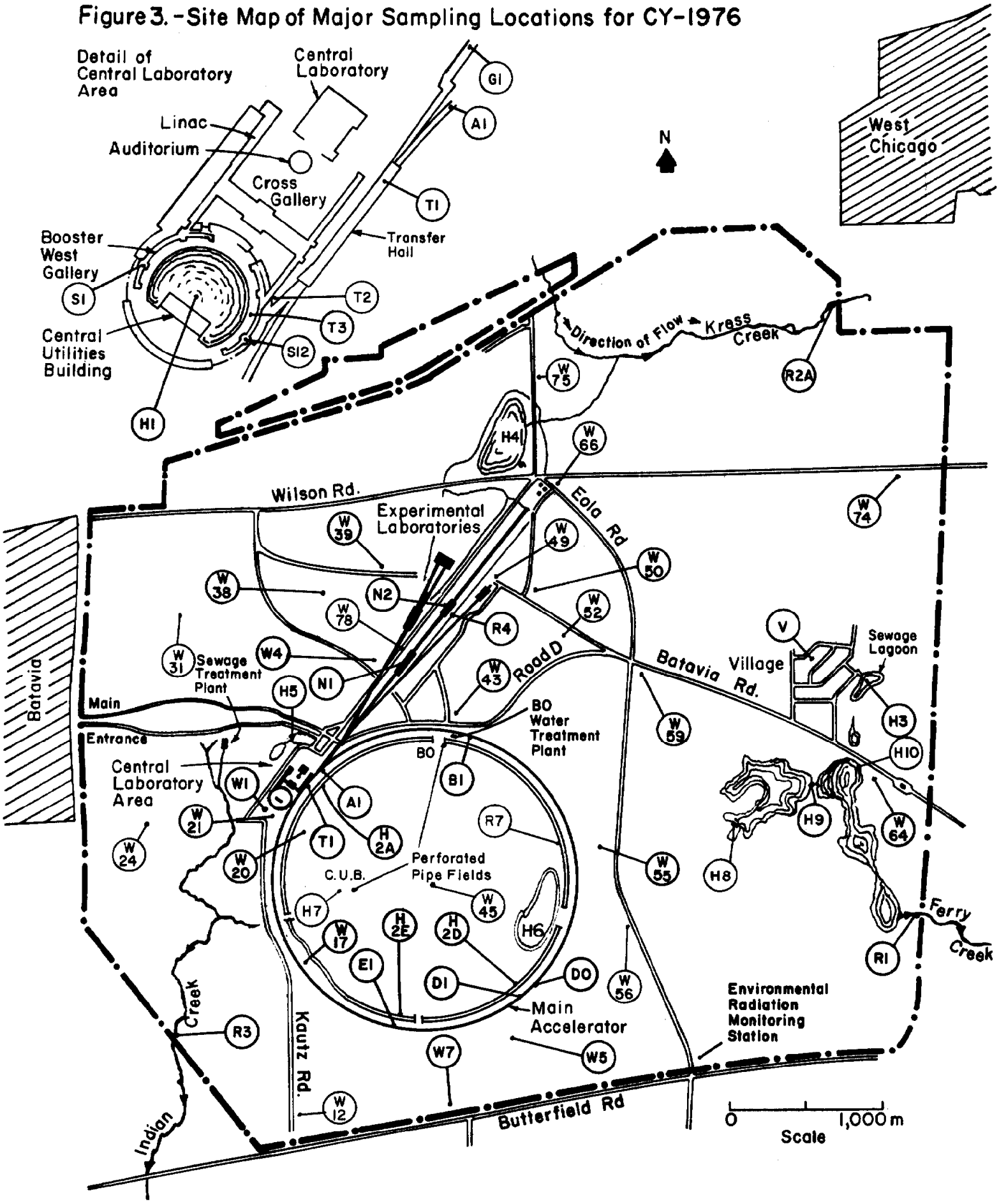
The accelerator operated routinely at 400 GeV during CY-1976 with about ten percent more protons during CY-1976 than in CY-1975 when half the year was spent at lower energies with more acceleration cycles per minute. The total number of protons accelerated in 1976 was 1.85×10^{19}. The maximum number of protons accelerated at one time reached almost half of the planned or design intensity of 5×10^{13} protons per acceleration cycle and typical operation was at about one third. Thus, environmental monitoring in CY-1976 was done under operation conditions not grossly different from those expected in the future.

During CY-1976 there were no abnormal natural occurrences which could have had some impact upon the facility or its operation.

A new ponding system (Fig. 1) was put into operation at the end of CY-1976 to reduce, and perhaps eliminate, the need for cooling towers which are resulting in the release of chromates into the perforated pipe field inside the main accelerator (Fig. 3).[4] The surfacing of chromates from the field had been a source of nonradioactive pollutants for several years. The average concentration of chromates in on-site surface waters receiving this discharge was slightly above the State of Illinois Standard for waters in general use. A similar problem exists at another perforated pipe field[4] inside the Main Ring (main accelerator) near the B0 Water Treatment Plant (Fig. 3). At that point copper from regeneration of resins used to keep the recirculating cooling water pure is surfacing. The average concentration of copper in the ponds which receive the discharges was found to be just below the State of Illinois Standard for waters in general use. Evidence was found that copper sulfate used to reduce algae and weed growth could also be a major contributor to the copper in the Main Ring Ponds. See Section 3.4. The above releases have had little or no off-site impact.

The total potential radiation exposures at the point of highest dose rate at the site boundary and to the general off-site population from Fermilab operations during CY-1976 were 13 mrem and 4 man-rem, respectively. The potential dose

Figure 3. - Site Map of Major Sampling Locations for CY-1976



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

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at the site boundary corresponds to 2.6 per cent of the Standard of 500 mrem for an individual who is not a radiation worker. This potential dose was almost all from muons leaving the site in a northeasterly direction toward West Chicago.

Since our site is open to the public, the potential for exposure to an individual while he is on the site must be considered. Most of those coming here sleep elsewhere, but approximately 50 visiting experimenters and their families are housed in the Village (Fig. 1). Since they are not in the path of the muons while in the Village, their dose from accelerator operation would be primarily from airborne radioactivity. The distance to the Village from the source is farther than to the nearest site boundary. Thus, the doses from airborne radioactivity discussed below are applicable. Other visitors would be within the site boundaries a much shorter time. Since radiation areas are posted and high radiation areas are fenced, it is unlikely that a visitor would receive a total dose as high as 20 mrem or four percent of the Standard for non-radiation workers. In fact, 80% of those not assigned permanent film badges who entered radiation areas at Fermilab in CY-1976 received radiation exposures which were less than the film badge detection limit of 20 mrem.*

Airborne radioactivity was released across the site boundary in small amounts throughout the year from the stack

* Group of 900 included visitors, experimenters, sub-contractors, and Fermilab personnel who do not normally work in radiation areas.

ventilating a Neutrino Area enclosure where the beam struck a target. The radioactive gas was primarily ^{11}C, total quantity released was 4 kiloCuries, and the maximum dose at the site boundary was less than 0.4 mrem for 1976. The average concentration at site boundary based on measurements at the stack was less than 0.02 per cent of the Concentration Guide (Sections 3.2 and 4). There were also four controlled releases of tritium produced in helium gas near another target. The total amount of tritium released was 340 mCi. The maximum concentration at the site boundary was 6×10^{-11} μCi/ml or 0.03 percent of the Concentration Guide, resulting in a negligible off-site exposure. No radioactivity was detected in the ground water and off-site releases of tritium in surface waters totaled 2 mCi.

3. Monitoring, Data Collection, Analysis and Evaluation

The three types of accelerator-produced radiation chosen for environmental monitoring are discussed below. These radiations have direct pathways to the off-site population. Other more indirect pathways, such as through the food chain, have received little attention to date. The decision on what to monitor is based on the type of operation, radionuclides released, and monitoring results from this and other high energy physics laboratories.

3.1 Penetrating Radiation

Operation of the accelerator at current energies and intensities results in production of some penetrating radiation (primarily muons and neutrons) outside the

shielding. Although the shielding has been designed to be adequate for this operation, monitoring for purposes of determining actual radiation levels both on and off the site is necessary.

A large network of detectors was used to monitor penetrating radiation. At the end of CY-1976 there were approximately 200 detectors deployed around the site for the main purpose of protecting on-site personnel. The majority of these detectors were connected to a data logger which automatically recorded the radiation levels for subsequent examination.[5] Approximately 20 detectors were used primarily for environmental radiation monitoring. Most of these were deployed at the ends of the paths traveled by the protons or near the site boundary. Of the latter, nine were large volume, 110 liter, ionization chambers for gamma-ray and charged particle detection.

A special radiation monitoring station with gamma-ray, charged particle and neutron detectors of high sensitivity is maintained near the site boundary (Fig. 3).[6] This station detected no accelerator-produced radiation in CY-1976. The station, which can detect small changes in radiation level, provides background levels for comparison to levels detected by a scintillation counter near the experimental areas (at W43 in Fig. 3) and 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. 4).[7,8] The MERL was equipped with two 26 cm x 26 cm (8" x 8") scintillation counters, one behind the other, with associated electronics to verify 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. Dose measurements were made at the site boundary with the scintillation counters while recording the number of counts from one of the 110 liter ionization chambers placed in the path of the muons much closer to the source. The counts from that ionization chamber were recorded for the entire year through the data logger to determine the annual dose at the site boundary. The operation with muons resulted in radiation capable of delivering a total dose of 13 mrem over a region about 50 m (160 feet) wide at the site boundary during CY-1976. See Fig. 5.

The MERL was also used to measure muons leaving the site

Figure4- Sampling Locations in External Experimental Areas

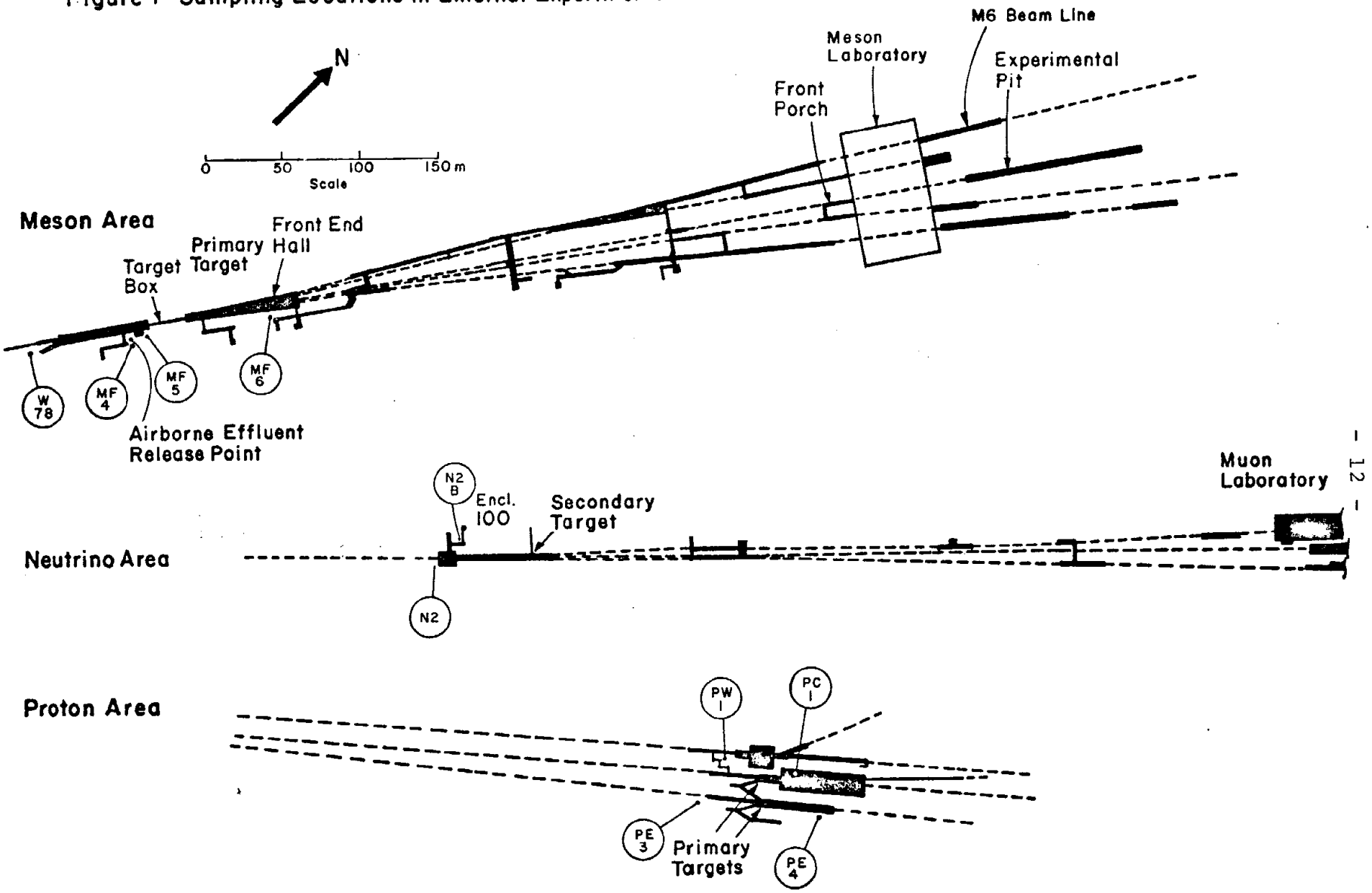
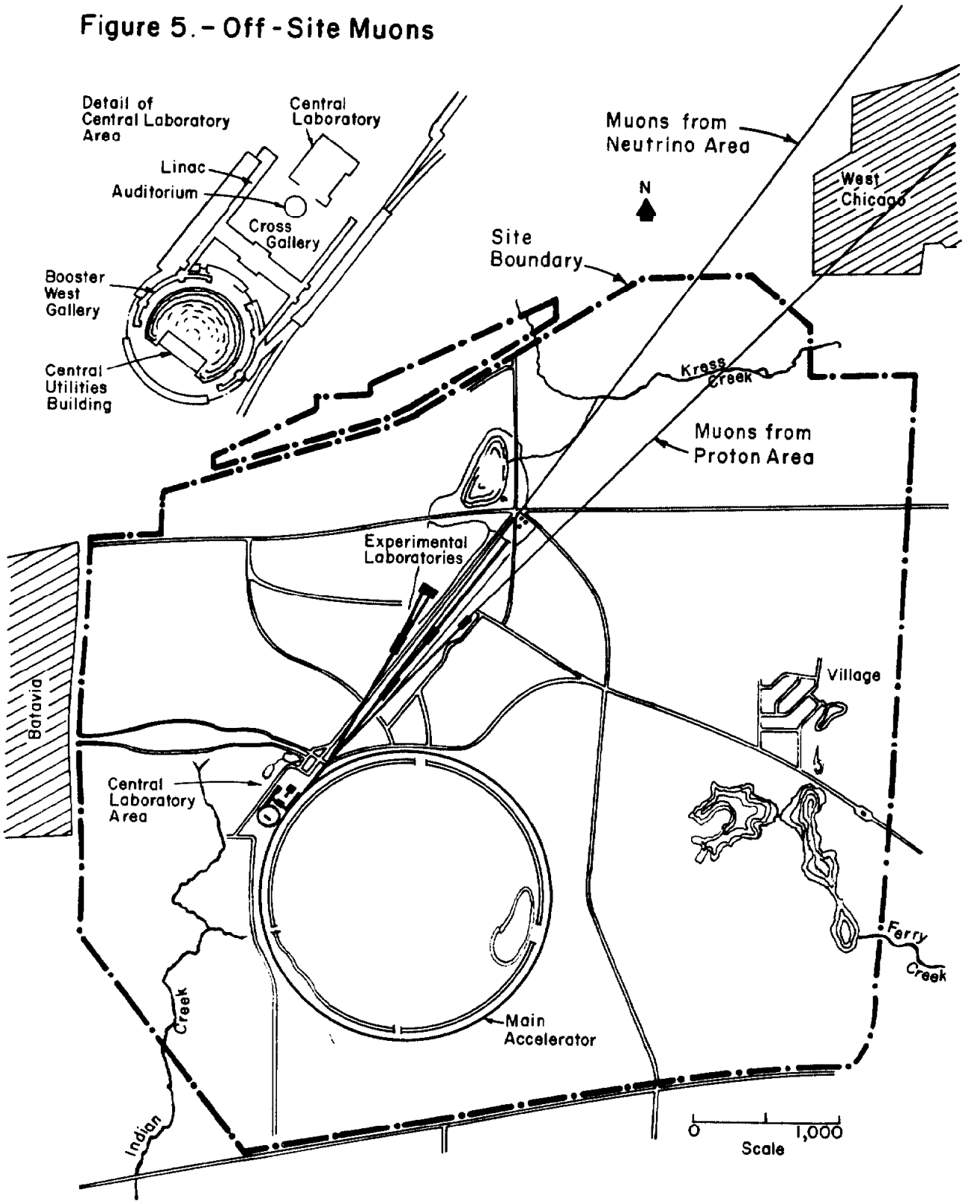


Figure 5. – Off-Site Muons



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from the Proton Area in CY-1976. Since the targets in the Proton Area are more than 3 m below the ground surface, the majority of the muons stop in the soil. Only those escape which travel in an upward direction where the soil thickness is not sufficient to stop them. At the site boundary those muons pass above the MERL and are not detected. However, there is a hill in West Chicago where the elevation is high enough to intercept a few muons, probably some lower energy ones scattered by interactions in air. With the sensitive detectors in the MERL, muons could be detected on the hill. The dose delivered during CY-1976 to a small number of people living on the hill was 0.07 mrem. Using the entire population[9] of that section in Winfield Township of DuPage County, 3061 people in 1975, as the exposed population, gave a conservatively safe estimate of 0.2 man-rem for the potential dose in CY-1976.

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 for

uncontrolled areas set forth in the Energy Research and Development Administration Manual, Chapter 0524 (ERDAM 0524).

Radioactive gas, primarily ^{11}C, was produced by interaction of secondary particles with air. Monitoring was carried out by detecting the beta particles emitted in the radioactive decay.[6] Release occurred from the stacks (Fig. 5) in the Neutrino Area during 1976. From measurements made at the stack and calculations based on a Gaussian plume diffusion model,[10] the expected dose at the site boundary for 1976 was 0.2 mrem. The calculation assumed neutral wind conditions, i.e., neither unstable nor stable. The results of the calculation were better than those which could have been obtained if measurements of the very low concentrations were attempted at the site boundary. The Concentration Guide for exposure to radiations from ^{11}C was taken from the calculations of Yamaguchi.[11] The result is 5.8×10^{-7} μCi/ml for "submersion" of an individual member of the general population in a cloud of ^{11}C. Thus, the 0.2 mrem exposure for continuous occupancy at the site boundary from stack releases in the Neutrino Area in 1976 corresponded to 0.04 percent of the applicable Guide.

Controlled releases of tritiated helium from the Meson Area Target Box occurred on January 8, January 28-March 22, July 26, and December 28. Peak ^{3}H concentrations at the release point, the vacuum pump exhaust line, were limited to 1×10^{-4} μCi/ml by controlling the flow rate. The long period of release from January 28 to March 22

occurred while dry helium was slowly passed through in an attempt to decrease the Target Box humidity following a water leak. The total activity released for the year was 340 mCi of ^{3}H. The Gaussian plume diffusion model[10] was used with neutral wind conditions to calculate the site boundary ^{3}H concentration. The site boundary concentrations for the releases were less than or equal to 6×10^{-11} μCi/ml or 0.03 percent of the applicable Concentration Guide given in the ERDA Manual Chapter 0524.

On December 28, 1976, the overheating of a component struck by the proton beam generated airborne radioactivity requiring an extensive clean-up of the Neutrino Area Target Hall (Fig. 5). About ten milliCuries of particulates, primarily short half-life ^{24}Na, were released from one of the stacks at a concentration of 6×10^{-5} μCi/ml at the release point without including any mixing with outside air. The calculated site boundary concentration was less than two percent of the applicable Concentration Guide for uncontrolled areas (5×10^{-9} μCi/ml in ERDA Manual, Chapter 0524) during the ten hour release. Much of the activity was found inside the stack dome, which was subsequently decontaminated. The concentration of radioactive gases released during the ten hour period averaged ten times higher than the annual average with a peak 25 times higher during one six minute period.

3.3 Waterborne Radioactivity

During accelerator operations, some radioactivation of the soil will occur.[12,13] Leaching of these radionuclides

into the ground water provides a possible mechanism for transport of Fermilab-produced radionuclides into the surface run-off waters and aquifer. Hence, a broad program of ground water monitoring for radioactivity is maintained. Measurements are also made of on-site concentrations of radionuclides in our surface waters and in closed loop (recirculating) cooling systems which are sources of potential off-site releases.

Water samples are collected periodically on-site and in surface waters off-site. They are analyzed for the presence of those radionuclides which are produced in and leachable from Fermilab soils in measurable quantities. This group of radionuclides also includes those produced in water directly.

The locations chosen for surface and ground water sampling were as follows:

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. 3). Samples were also obtained for the DuPage River and the Fox River into which these streams flow (Fig. 2).

2. Silurian aquifer. These samples were taken from farm wells which tap the 21 m (70 ft) silurian dolomite aquifer

*Bimonthly from Kress Creek and three times a year from Ferry and Indian Creeks.

which is a prime water supply for many private residences in the area. One deep well (436 m or 1432 ft) sample was also collected.

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 by 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 Eberline Instrument Company, Midwest Facility, West Chicago, Illinois during CY-1976.

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 indication of the presence of radionuclides at concentrations far below the applicable concentration guides. The agreement between the reported and prepared concentrations for tritium, the most prevalent radionuclide, was somewhat poorer than last year.[4] While all were within 7% last year, nine of 12 were within 7% this year. The ^{45}Ca analyses reported by Eberline usually disagreed with the prepared concentrations by more than 25% even when separations were requested, while analyses for the other radionuclides showed better agreement. The low Concentration Guide for ^{45}Ca and its lack of gamma ray emission combine to make detection of concentrations much less than the Guide difficult. See Section 4.

As a result of activation studies made on Fermilab soils[12], ^{3}H, ^{7}Be, ^{22}Na, ^{45}Ca and ^{54}Mn were selected as potential radioactive pollutants. Subsequently, ^{60}Co was detected in discharges from water treatment resin regeneration and was added to the list.

Consequently, 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 most 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 naturally occurring

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 emits only beta particles of very low energy (19 keV maximum), 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 CY-1976 water sampling locations for detection of accelerator-produced activity are shown in Figs. 3, 4, and 6. No accelerator-produced radionuclides were reported in water samples taken from the three creeks leaving the site (Fig. 2). Six samples were obtained from Kress Creek, three from Ferry, and only one from Indian. Indian Creek was dry the last two times it was scheduled for sampling. River water samples were obtained twice during

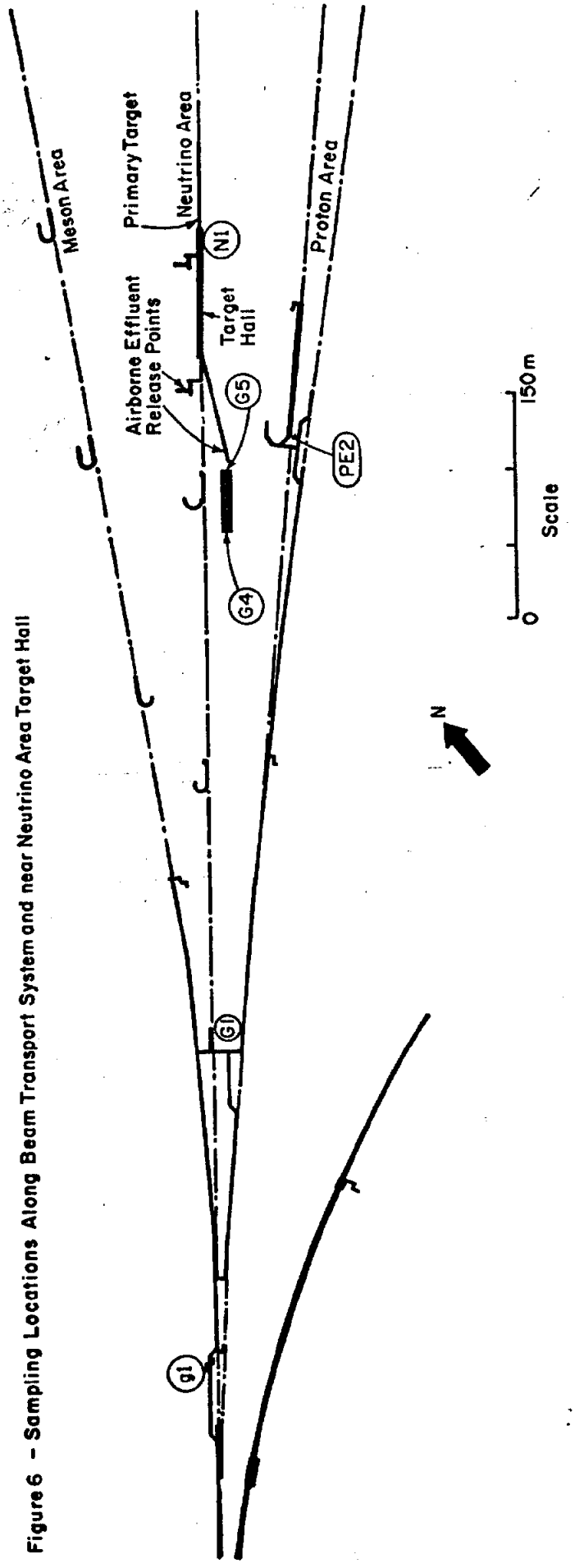

Figure 6 - Sampling Locations Along Beam Transport System and near Neutrino Area Target Hall

CY-1976 from the Fox River in Aurora and from the west branch of the DuPage River in Warrenville. Neither river is utilized as a drinking water supply. No evidence for accelerator-produced radionuclides was found.

The results for on-site tritium measurements yielding detectable levels in surface waters are given in Table 1. All other sampling points were essentially at background levels. The total off-site release in surface waters was 2 mCi of tritium this year compared with 18 mCi last year. The reduction was primarily the result of less rainfall and better water management at Casey's Pond (H4 in Fig. 3). The release occurred at less than 0.1 percent of the Concentration Guide (Section 4 below) and made a negligible contribution to the potential off-site dose. The high concentrations in the N2 Sump were from the same vacuum pump that caused high concentrations in CY-1974 and CY-1975.[4] This time a workman ran a drain hose from the vacuum pump directly into the sump by mistake, rather than into the retention pit. The water went into Casey's Pond.

Concurrent with the production of ^{3}H with 12 year half life is the production of ^{7}Be with 53 day half life in the closed cooling water systems. The ^{7}Be is chemically active and is easily removed from the water by the resins used to maintain water purity. These resins are regenerated at two locations on site (Central Utilities Building and BO Water Treatment Plant, Fig. 3) and the discharge containing ^{7}Be is released into the soil in perforated pipe fields six

Table 1

RESULTS OF ON-SITE WATER SAMPLE ANALYSES

Collection Point	Number of Samples Collected	Tritium Concentration C (μCi/ml)* C max	C min	C mean	Percentage of Relevant Standard
D1 Sump	1	1.1×10^{-5}	1.1×10^{-5}	1.1×10^{-5}	0.4
G5 Sump	1	2.5×10^{-5}	2.5×10^{-5}	2.5×10^{-5}	0.8
MF4 Sump	5	1.3×10^{-4}	$<3 \times 10^{-6}$	2.8×10^{-5}	0.9
MF5 Sump	10	8.7×10^{-5}	$<3 \times 10^{-5}$	1.8×10^{-5}	0.6
N1 Sump	12	4.0×10^{-5}	$<3 \times 10^{-6}$	1.4×10^{-6}	0.5
N2 Sump	12	3.4×10^{-3}**	$<3 \times 10^{-6}$	3.0×10^{-4}	10.0
N2B Sump	4	6.2×10^{-4}	$<3 \times 10^{-6}$	1.6×10^{-4}	5.3
PC1 Sump	5	1.1×10^{-4}	7×10^{-6}	4.0×10^{-5}	1.3
PE4 Sump	5	2.4×10^{-5}	$<3 \times 10^{-6}$	1.2×10^{-5}	0.4
PW1 Sump	4	7.8×10^{-4}	$<3 \times 10^{-6}$	2.0×10^{-4}	6.7
S1 Sump	3	5×10^{-6}	$<3 \times 10^{-6}$	4×10^{-6}	0.1
S12 Sump	3	4×10^{-6}	$<3 \times 10^{-6}$	3×10^{-6}	0.1
T1 Sump	3	3×10^{-6}	3×10^{-6}	3×10^{-6}	0.1

*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

**Measured during a five day release in December, when water was going to Casey's Pond and not off-site.

feet below the surface inside the main accelerator. The short half life of the ^{7}Be and its strong chemical affinity with the soil insure that the release will place no burden on the environment. Sampling,where some of the effluent discharged into the perforated pipe field is surfacing, has yielded only small amounts of ^{7}Be and none has been detected in nearby wells.

There continued to be some surfacing of this water containing ^{7}Be in both perforated pipe fields during the first half of CY-1976 (Fig. 3). In the summer the surfacing from the C.U.B. perforated pipe field (receiving discharge from the Central Utilities Building) stopped as the result of reduced rainfall. The water table had receded enough to allow the water injected into the field to remain below the surface.

A special problem arose late in the year with respect to resins regenerated at the Central Utilities Building in CY-1976. A water-cooled block of tungsten used to stop protons and dissipate their 400 GeV energy had produced a backlog of 30 resin tanks in the Proton Area which were more radioactive than any regenerated up to that time. The porous block of tungsten was to be replaced in early CY-1976 with one which would eliminate the leaching of radionuclides from the tungsten. Also, there was no surfacing of water in the perforated pipe field at that time and the discharge of cooling tower "blowdown" was soon to be stopped when a new ponding system replaced the towers (Section 3.4.2.).

Consequently, the ten least radioactive resin tanks were regenerated in one batch. The peak concentrations in the effluent were: ^{7}Be, 1.5 x 10^{-3} μCi/ml; ^{45}Ca, 1.85 x 10^{-4} μCi/ml; and ^{60}Co, 1.0 x 10^{-4} μCi/ml. The total amounts released were: ^{7}Be, 59 mCi; ^{45}Ca, 7 mCi; and ^{60}Co, 2 mCi. To date no activity has surfaced. Following this test the decision was made to regenerate the remaining resin tanks one at a time during CY-1977.

Tritium levels at the detection limit were reported for one sample from wells #39, #75, and #78 this year (Fig. 3). Since the direction of ground water flow from a study of water levels made on the site[1] is toward the southeast and southwest, one would not expect to find activity in well #75. This is also true for well #39 although it is much closer to the experimental laboratories. Well #78 is the new monitoring well for the Meson Area so one would expect to see activity there if any problem existed. No activity was found in a subsequent sample of well #78. All three will be sampled again in CY-1977.

Since the percolation rates for water in Fermilab soils are calculated to be very low--less than 1 m (3 ft) per year[14]--analyses of well waters do not provide the early warning desired for detection of accelerator-produced radioactivity in the ground water. To provide such a warning we have taken soil samples from the vicinity of targets and other locations where proton interactions result in some radioactivation of the soil. Many radionuclides were detected

but since the major long-lived ones leachable from Fermilab soils were ^{3}H and ^{22}Na, qualitative measurements were made only on those.[12] Most of the results have been presented elsewhere.[4, 15] The ^{3}H and ^{22}Na analyses for the most recent soil boring have been done subsequently and results are presented in Table 2.

The most recent soil boring was made just outside the Transfer Hall (Fig. 3) where the protons are extracted from the accelerator. Just beyond the extraction point those protons to be sent to the Proton Area are separated from the others. In the process of extracting the proton beam and separating a portion (splitting the beam), some protons interact with the beam handling components. These protons and the secondary particles released then penetrate the wall of the Transfer Hall and activate the soil outside. The soil boring was made parallel to the 0.76 m (2.5 ft) thick wall and 0.76 m from it. The boring extended down through approximately 8 m (26 ft) of earth shielding to the concrete casing housing the pipe through which the protons travel. The highest concentration was at the casing (0.5 m above the proton beam).

There is no impervious membrane under the soil where the boring was made, as is found under the Neutrino Area primary target.[15] Any radioactivity leached from the soil might be picked up by the underdrains around the Transfer Hall, but there is no guarantee that the activity would be

Table 2

RESULTS OF SOIL BORING 0.76m FROM TRANSFER HALL WALL

SAMPLING REGION Vertical Distance to Ground Water (m)	(ft)	^{22}Na CONCENTRATION (pCi/g) Dry Weight*	^{3}H CONCENTRATION (μCi/ml)**
11.1	36.5	312	6.6×10^{-5}
10.4	34	663	9.5×10^{-5}
10.1	33.2	1003	16.0×10^{-5}

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

**Mixed for one hour with equal amounts of soil and water by weight and distilled before analysis.

collected. The peak tritium concentration observed (1.6×10^{-4} μCi/ml) was 16% of the Concentration Guide for uncontrolled areas (Section 4). The region having this concentration is small. Eleven meters away, in the direction the protons are traveling, the levels are 100 times lower.[4] Based on previous results elsewhere on site, there is no evidence for leaching. The soil samples have been sealed and returned to the hole for future comparison with fresh soil samples to determine leaching rates.

3.4. Nonradioactive Pollutants

3.4.1. Water Utilization

The domestic water supply at Fermilab is provided esentially by two wells approximately 70 m (220 ft) deep. One (W1 in Fig. 3) is located in the Central Laboratory Area and the other (V in Fig. 3) is in the Village. In cases of low pressure, a third 70 m (220 ft) deep well (near W4 in Fig. 3) is used to supply the additional water in the Central Laboratory Area. The average use from these three wells is approximately 900,000 l/day (238,000 gal/day).

3.4.2. Test 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 (biochemical oxygen demand for 5 days), suspended solids and coliform monthly until May 1976. Since the data from the previous years' tests of the waters from Ferry Creek, Kress Creek, Casey's Pond, Fox River and Indian Creek varied only

slightly on pH, DO, BOD5 and suspended solids, the tests were reduced to a semi-annual frequency and on coliform continued monthly starting June, 1976. The test results for CY-1976 are presented in Table 3, and sampling locations listed in Table 3 are shown on Fig. 3.

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

The discharge limits set by the Federal Environmental Protection Agency (EPA) for the Central Laboratory's package sewage plant were changed by the Federal EPA, effective November 17, 1976 for residual chlorine sample frequency from twice weekly to 5 times weekly and the effluent limitation from 0.5 mg/l to a range of 0.2 - 0.75 mg/l.

Suspended Solids maximum limitation was changed from 8 mg/l to 12 mg/l. The daily average discharge limit remained 5 mg/l.

BOD5 maximum effluent limit was changed from 6 mg/l to 10 mg/l. The daily average limit remained 4 mg/l.

Fecal coliform bacteria sample frequency was changed from twice weekly to once per month.

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

BOD5: 30 mg/l avg., 45 mg/l max.

Suspended Solids: 30 mg/l avg., 45 mg/l max.

Fecal Coliform Bacteria: 200/100 ml avg., 400/100 ml max.

Table 3

SITE WIDE WATER QUALITY REPORT FOR CY-1976

		pH	BOD5 mg/l	Susp. Solids mg/l	Fecal Coliform # per 100 ml
FERRY CREEK	Max.	8.3	8	130	200
	Ave.	8	4.9	52	52
	Min.	7.2	3.3	2	0
INDIAN CREEK	Max.	7.9	3.7	18	370
	Ave.	7.8	2.6	10	44
	Min.	7.6	2	3	0
KRESS CREEK	Max.	8.1	7.2	8	2000
	Ave.	8	4.2	6	365
	Min.	7.8	2.4	3	40
CENTRAL LAB. SEWAGE	Max.	8	8.2	11	1500
	Ave.	7.6	5.8	4.8	199
	Min.	7.3	2.4	1	2
VILLAGE SEWAGE LAGOON	Max.	9.5	13.8	59	0
	Ave.	8.4	6	21	0
	Min.	7.7	2	1.5	0

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 thirteen times on B0D5, four times on Suspended Solids, and twenty times on Residual Chlorine and once on coliform. The Village Lagoon exceeded its maximum limits fourteen times on pH, five times on Suspended Solids and once 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 4 mg/l at the Central Laboratory's sewage plant and never exceeded 2 mg/l at the Village Lagoon. Maximum values are given in Table 3 for other water quality parameters which are measured in sewage plant effluents and on-site creek waters.

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 operator and as a public water supply operator.

Quarterly test reports on our sewage waters are sent at the end of each quarter to our local ERDA office as directed by this agency. In addition to that, the Aurora EPA Agency collects water samples from the Central Laboratory's sewage plant and from our Village sewage lagoon. The effluent from the Village sewage lagoon flows into Ferry Creek. The effluent from the Central Laboratory's sewage plant flows

into Indian Creek. Due to the occasional excess flow into the main site sewage treatment plant from infiltration of rain water, it has been necessary occasionally during early CY-1976 to pump untreated sewage into the woods in the vicinity of the main sewage treatment plant. It has been established by test that this effluent leaving the site via Indian Creek has been contained to zero counts of fecal coliform per 100 ml. In fact, the yearly average counts on fecal coliform in Indian Creek were 44 compared with 365 counts in our Kress Creek into which no sewage is discharged. We assume that the lower counts in Indian Creek are attributed to the discharge of chlorinated sewage effluent from the sewage plant. The on-land 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 have conducted surveys on all cooling water sources and ground infiltration. In order to reduce the infiltration of storm water into the sanitary waste collection system, collars on manholes have been reset at a higher elevation and ring seals have been resealed. Since May 1976 no sewage has been discharged on land.

Some chemical treatment of our water system was necessary during CY-1976, however, to reduce algae and weed growth and to inhibit corrosion. Copper sulfate, not exceeding 1 mg/l except in one case, when 10 mg/l was detected, was applied for algae control, and Diquat, not exceeding

1 mg/l was used for weed control on the Village sewage lagoon, reflecting ponds (Swan Lake and the two small reflecting ponds just east of it), and the Main Ring cooling ponds. The State of Illinois EPA Standard for total copper in effluent is 1 mg/l (Section 4 below).

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.

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/min (35 gal/min) of this water by way of the Central Utilities Building sump into a perforated pipe field below the surface of the ground inside the Main Ring of the accelerator (Fig. 3). Some chromate has reached the surface due to the inadequate capacity of the perforated pipe field. Samples were taken at the points where the water was welling up, and tested on chromate content. The average concentration was found to be 9.4 mg/l or about 30 times the State of Illinois Standard for discharges (Section 4 below). The average concentrations

of the site wide quarterly tests on heavy metals are presented in Table 4.

Since December 1, 1976, the above cooling water treatment was discontinued and a month later the cooling water was recirculated through the new cooling pond system. That cooling system includes the newly excavated ponds on the parking lot west of the Central Laboratory, the Swan Lake and the Booster Pond (Fig. 1 plus H5 and H1 in Fig. 3).

3.4.3. Other Applications of Pesticides

The Fermilab pest control plan was carried out substantially as proposed.[16] The use of Pramutol for killing weeds and grasses at power stations and in parking lots was restricted to 30 to 40% of the amount proposed (around 60 kg [130 lbs.] instead of the 180 kg [400 lbs.] proposed). No Dursban 2E was used in the mosquito control program, only Malathion (approximately 7 kg or 15 lb. total).

To maintain good relationships with neighboring farms and voluntarily comply with local weed commission requests, we have been controlling noxious weeds, primarily Canadian and sow thistle. In 1976 a total of approximately 900 kg (2000 lbs.) of 2-4D (low volatility Amine form) was used at 1% strength in water applied to approximately 8 km^2 (3 sq. mi.) on site.

Some spot application of Baygon to kill larvae of household pests and some use of bait containing Eaton or Diphacin to kill mice and rats in buildings not occupied by children was required in CY-1976.

Table 4

ON-SITE QUARTERLY TESTS
FOR HEAVY METALS IN WATER, CY-1976

LOCATION (Fig. 3)	AVERAGE CONCENTRATION (mg/l)		
	Hexavalent Chromium	Copper	Zinc
Perforated Pipe Field	9.30	.204	1.694
Pond G at H7	.040	.004	.002
C4 Pond at H6	.250	.015	.002
C4 Main Ring Pond at H2C	.100	.012	.003
Lake Law at H8	.060	.010	--
Lake Law at H9	.057	.013	.002
Ephemeral Lake at R1	.092	.004	--
Ephemeral Lake at H10	.084	.017	--
Swan Lake at H5	.040	.006	.002
Casey's Pond at H4	.020	.006	.002
BO Treatment Plant	--	47.2	--
BO Tile Field at H2B	--	17.5	--
B4 Ditch at R7	--	.007	--
Well 17A	.013	.010	1.430
Well 20	.010	.018	.206
Well 43	.010	.005	.035
Well 45	.010	.006	.203
Well 55	.020	.003	.227
Well 56	.020	.003	.396
Well 1	.014	.010	.734
Well 21	.001	.007	.052
Village Sewage Lagoon at H3	.010	.184	--

Corn was planted on approximately 25% of the site by licensees who agreed to apply only herbicides and fertilizers approved by the Laboratory. In addition, the rate of application and total amounts applied had to be approved before application.

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.[17] 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 housing construction now in progress to the east and west of the site. The contribution to off-site potential dose from penetrating muons (Section 3.1) was by far the largest contribution. The direction of the muons was northeast toward West Chicago, where the increase has not been as rapid. The projected population for West Chicago in 1975 was 13,000 or approximately 30 percent higher than the 1970 census.[9] The population distribution obtained from the 1970 census was used to evaluate the potential exposure to the public for CY-1976 and the man-rem dose obtained using the 1970 census was increased by 30 percent to reflect the increase in population.

The radiation exposure to the general population from operation of Fermilab in CY-1976 was about 4 man-rem. This exposure was determined by starting with the dose to an individual at the site boundary and calculating dose versus distance from the point on site where the penetrating radiation (muons, Section 3.1) originated to 80 km (50 miles) from the site using the inverse square of the distance and summing over the appropriate numbers of individuals from Table 5. The region considered contained approximately 100,000 people. Airborne releases continue to give low exposures both on- and off-site as expected. The off-site exposure was approximately 0.4 man-rem from airborne releases in CY-1976. 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 February 1976 while Casey's Pond (H4 in Fig. 3), the reservoir receiving water from discharges in the three external areas to which protons are delivered, was full. The mean concentration of tritium during the period of release was less than one percent of the Concentration Guide for uncontrolled areas. 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.

Traces of tritium were reported in three of 45 samples of water from on-site wells pumped in CY-1976. Each of the three was from a different well. Lack of reproducibility

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

1970

in the sample from well #78 plus absence of activity in a subsequent sample make it doubtful that the report is correct. The locations of the other two wells also make it unlikely that accelerator-produced tritium was actually in the ground water. Measurable concentrations of ^{22}Na and ^{3}H were detected in soil samples from a boring near the main accelerator. See Section 3.3. The concentrations observed agreed well with expectations.

Thus, the potential radiation dose to the public from the operation of Fermilab in CY-1976 remained small.

3.5.2. Evaluation of Nonradioactive Pollutant Releases

Some chemical treatment of our water system was necessary during CY-1976, 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, although high concentrations occurred one time this year (Section 3.4). The impact of that one time was small. A few small fish were killed by copper sulfate in a ditch inside the Main Ring and one fish-eating bird subsequently died. Chromates, mineral residues from evaporation in cooling towers, and salts from regeneration of water treatment resins have been discharged underground on site. An average chromate concentration about 30 times the State of Illinois Water Pollution Standard for effluent release (Table 4) was found in the waters welling up to the surface in the C.U.B. perforated pipe field. There is evidence of copper, chromate, and zinc in the on-site waters.

In some cases levels in excess of the State of Illinois Standards have been reported. These existing levels are not expected to have a large impact on off-site waters. Further evaluation is continuing via an extended water sampling program. A new ponding system has been placed in operation to reduce the use of chromates (and zinc).

No facility on site has been a problem with respect to nonradioactive airborne effluents. The bulk of the heating is provided by natural gas in boilers located in the Central Utilities Building (Fig. 1). Other smaller gas-fired units plus electric boilers and heaters are located throughout the site. Analyses are done annually on the gas-fired boilers at the Central Utilities Building with releases well below the applicable standards (Section 4 below).

4. References

The Concentration Guides used in the analyses of the water samples for radioactivity were taken from the ERDAM, Chapter 0524, Annex A, Table II, Column 2 (Water in Uncontrolled Areas) and reduced by a factor of three where appropriate for a suitable sample of exposed population. The smaller of the values given for soluble and insoluble 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 determining the total

off-site potential dose to the public. For ^{11}C the Concentration Guide was taken from the calculation by Yamaguchi.[11]

The appropriate Radiation Protection Standard for penetrating radiation applied to individuals in uncontrolled areas was taken from ERDAM, Chapter 0524, Paragraph II.A. The annual dose for whole body exposure is 0.5 rem. The Standard is three times less or 0.17 rem when applied to a suitable sample of the exposed population.

The Water Pollution Standards for nonradioactive pollutants were taken from Chapters 2 and 3 of the State of Illinois Pollution Control Board Rules and Regulations. The waters on site were considered to be in the "general use" category. The values for total hexavalent chromium at the discharge point and for general water quality are 0.3 and 0.05 mg/liter, respectively. The Standards for total copper are 1.0 and 0.02 mg/l, respectively, and for zinc are both 1.0 mg/l. The Air Quality Standards limit the releases of SO_2 oxides of nitrogen to 816 g (1.8 pounds) and 136 g (0.3 pounds), respectively, per 252 million calories (million b.t.u.'s) of actual heat input in any one hour.

Table 6

SPECIFICATIONS FOR THE ANALYSES

OF RADIONUCLIDES IN WATER

RADIONUCLIDE	CONCENTRATION GUIDE FOR POPULATION Individual (μCi/ml)	Suitable Sample (μCi/ml)	SPECIFIED* SENSITIVITY (μCi/ml)	SPECIFIED* PRECISION (μCi/ml)
^{3}H	3×10^{-3}	1×10^{-3}	3×10^{-6}	3×10^{-6}
^{7}Be	2×10^{-3}	6.7×10^{-4}	5×10^{-7}	5×10^{-7}
^{22}Na	3×10^{-5}	1×10^{-5}	3×10^{-7}	3×10^{-7}
^{45}Ca	9×10^{-6}	3×10^{-6}	3×10^{-7}	3×10^{-7}
^{54}Mn	1×10^{-4}	3.3×10^{-5}	5×10^{-8}	5×10^{-8}
^{60}Co	3×10^{-5}	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. The detection limit for ^{3}H is lower than the specified sensitivity; however, the specified sensitivity is still only 0.3 per cent of the lower Concentration Guide, and the number of spurious detections of ^{3}H is reduced.

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