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

Environmental Monitoring Report

For Calendar Year 1975

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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 proton energy was 400 GeV from July through December with periods of 300 GeV and 380 GeV operation earlier in the year. The primary purpose of the installation is fundamental research in high energy physics. It is located in the greater Chicago area (Fig. 1) 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 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 70 million gallons per day through Warrenville. The rainfall on site during 1975 was 91 cm (36 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 ground water and most of the surface water is toward the

* 1970 U.S. Census

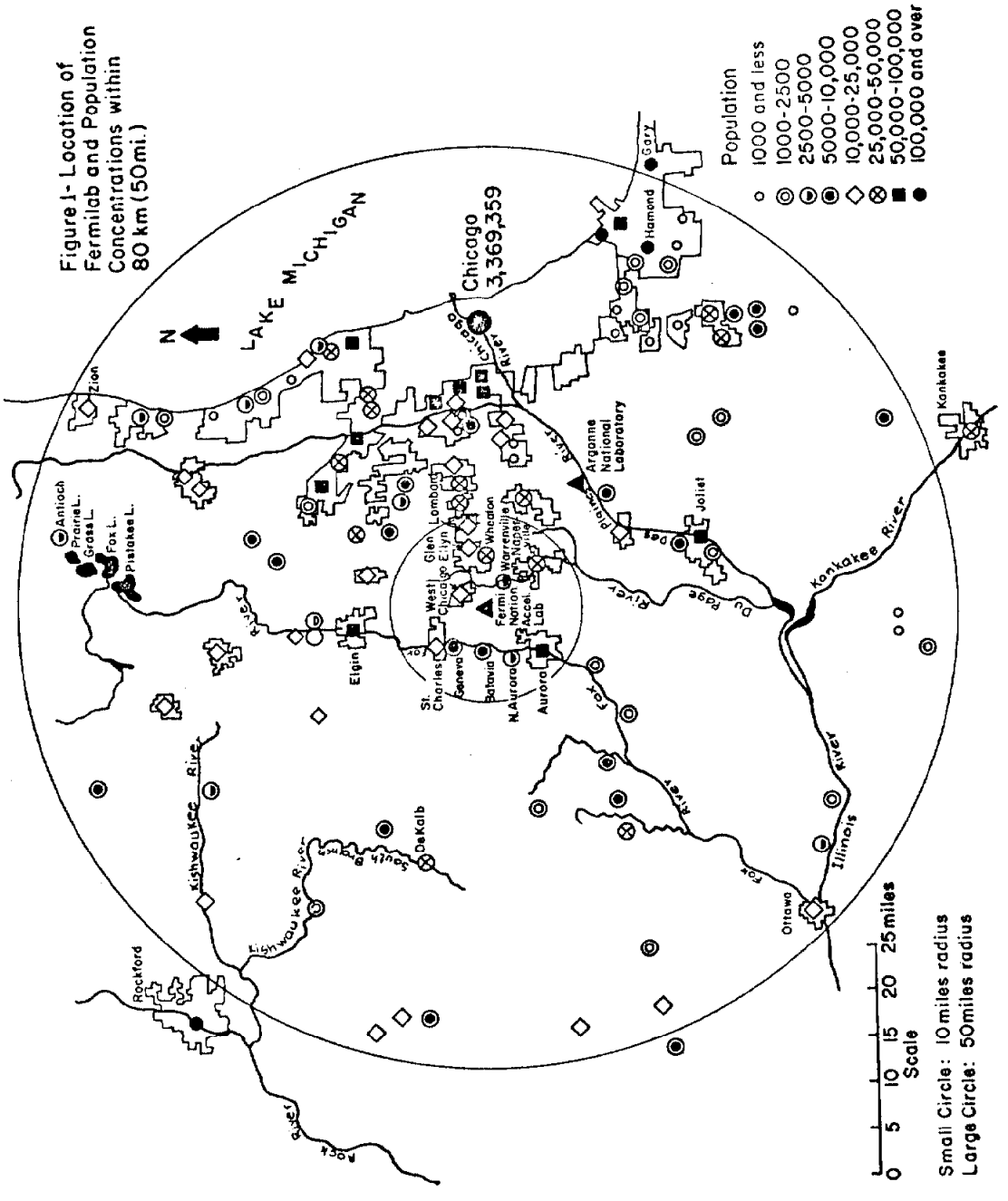
Figure 1- Location of Fermilab and Population Concentrations within 80 km (50 mi.)
N
LAKE MICHIGAN
Chicago 3,369,359
Population
1000 and less
1000-2500
2500-5000
5000-10,000
10,000-25,000
25,000-50,000
50,000-100,000
100,000 and over
Zion
Antioch
Prairie L.
Grass L.
Fox L.
Pistakee L.
Gary
Hamond
Argonne National Laboratory
Joliet
Kankakee
Kankakee River
Des Plaines River
Du Page River
Fox River
Illinois River
Elgin
St. Charles
Geneva
Batavia
N. Aurora
Aurora
West Chicago
Glen Ellyn
Lombard
Wheaton
Warrenville
Naperville
Fermi National Accel. Lab
DeKalb
Rockford
Kishwaukee River
Rock River
Ottawa
0 5 10 15 20 25 miles
Scale
Small Circle: 10 miles radius
Large Circle: 50 miles radius

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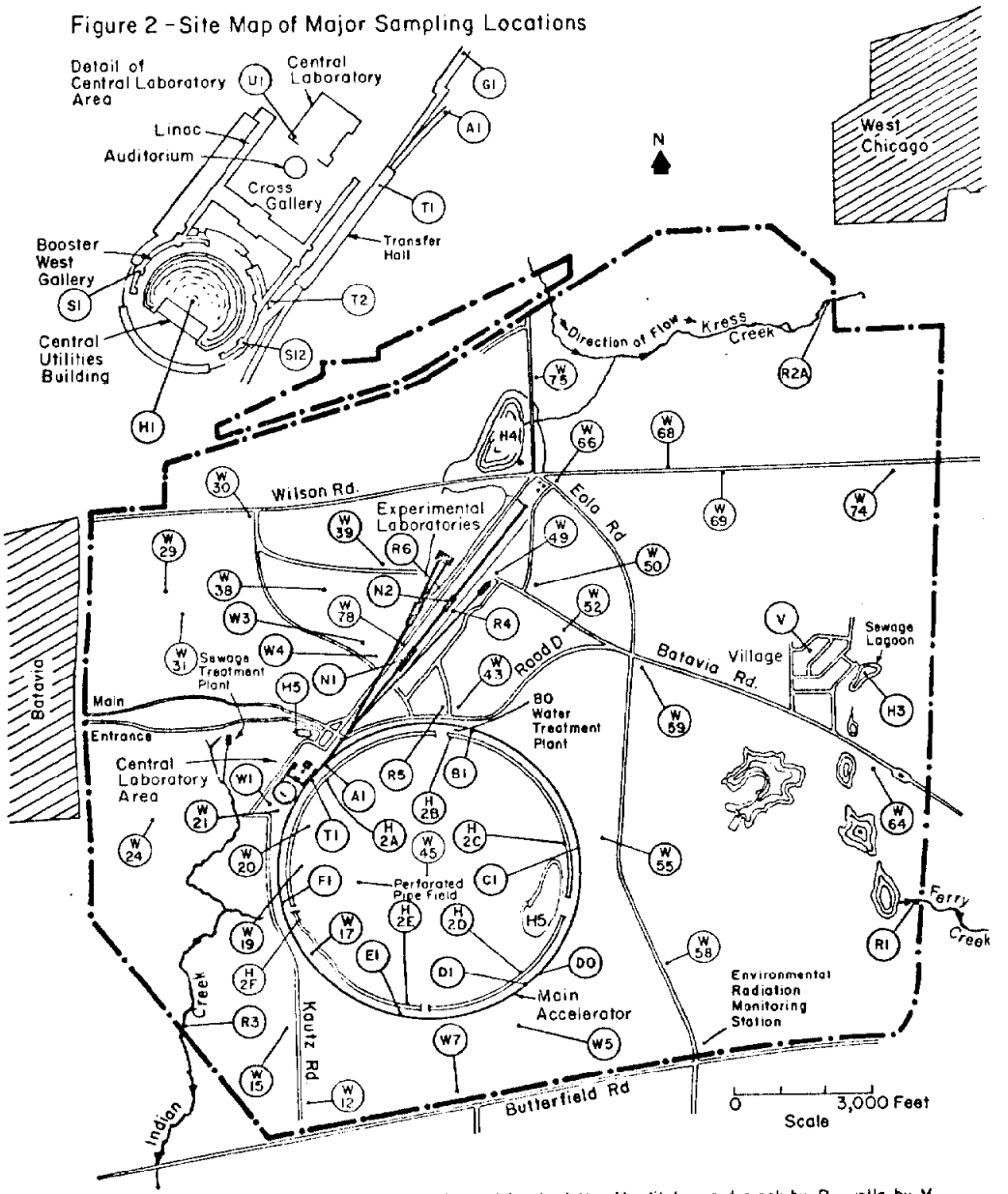
southeastern corner of the Laboratory, toward the DuPage River. A somewhat smaller amount drains to the southwest, toward the Fox River. The drinking water in many of the surrounding communities comes from deep wells usually drilled 1,200 feet deep into the Cambrian Ordovician aquifer system.[2]

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.

The proton beam extracted from the 2 km (1.2 mi) diameter main accelerator is taken to three different experimental areas on site (Fig. 2). 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.

Figure 2 - Site Map of Major Sampling Locations



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

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2. Summary

The accelerator operated routinely at 400 GeV during the second half of 1975 with about two-thirds as many protons accelerated as in the first half of the year when lower energies were attained. The total number of protons accelerated in 1975 was 1.7×10^{19} or about 25 per cent higher than in the preceding year. The maximum number of protons accelerated at one time reached 40 per cent of the planned or design intensity of 5×10^{13} protons per acceleration cycle and typical operation was at about 30 per cent. Thus, environmental monitoring in Calendar Year (CY-) 1975 was done under operation conditions not grossly different from those expected in the future.

During CY-1975 there were no abnormal natural occurrences which could have resulted from or have had some impact upon the facility or its operation.

During a nine day period while the Central Laboratory's sewage plant was being modified, a fecal coliform level about ten times the limit on our treatment plant permit was found in Indian Creek. Also, the capacity of the sewage plant was exceeded several times during periods of high rainfall but these releases did not result in high coliform levels in Indian Creek, probably as a result of chlorination. Chromates continue to surface from an underground perforated pipe field inside the main accelerator (Fig. 2).[4] A similar problem was detected at another perforated pipe field inside the Main Ring (main accelerator) near the B0 Water Treatment Plant

(Fig. 2). At that point copper from regeneration of resins used to keep the recirculating cooling water pure was surfacing. The peak concentrations of chromates and copper in the Main Ring ponds which receive the effluents were found to be just below the State of Illinois Standard for waters in general use. The above releases have had little or no impact off-site.

The total potential radiation exposures at the point of highest dose rate at the site boundary and to the general population off-site from Fermilab operations during CY-1975 were 1 mrem and 1 man-rem, respectively. The potential dose at the site boundary corresponds to 0.2 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 during January and February.

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, total quantity released was 2.5 kiloCuries, and the maximum dose at the site boundary was less than 0.1 mrem for 1975. 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 three controlled releases of tritium produced in helium gas near another target. The total amount of tritium released was 148 mCi. The maximum concentration at the site boundary was 2.4×10^{-10} μCi/ml or 0.2 per cent 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 18 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 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 was used to monitor penetrating radiation. At the end of CY-1975 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 and sounded alarms when levels exceeded preset values.[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. 2).[6] This station detected no accelerator-produced radiation in CY-1975. 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).[7] 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

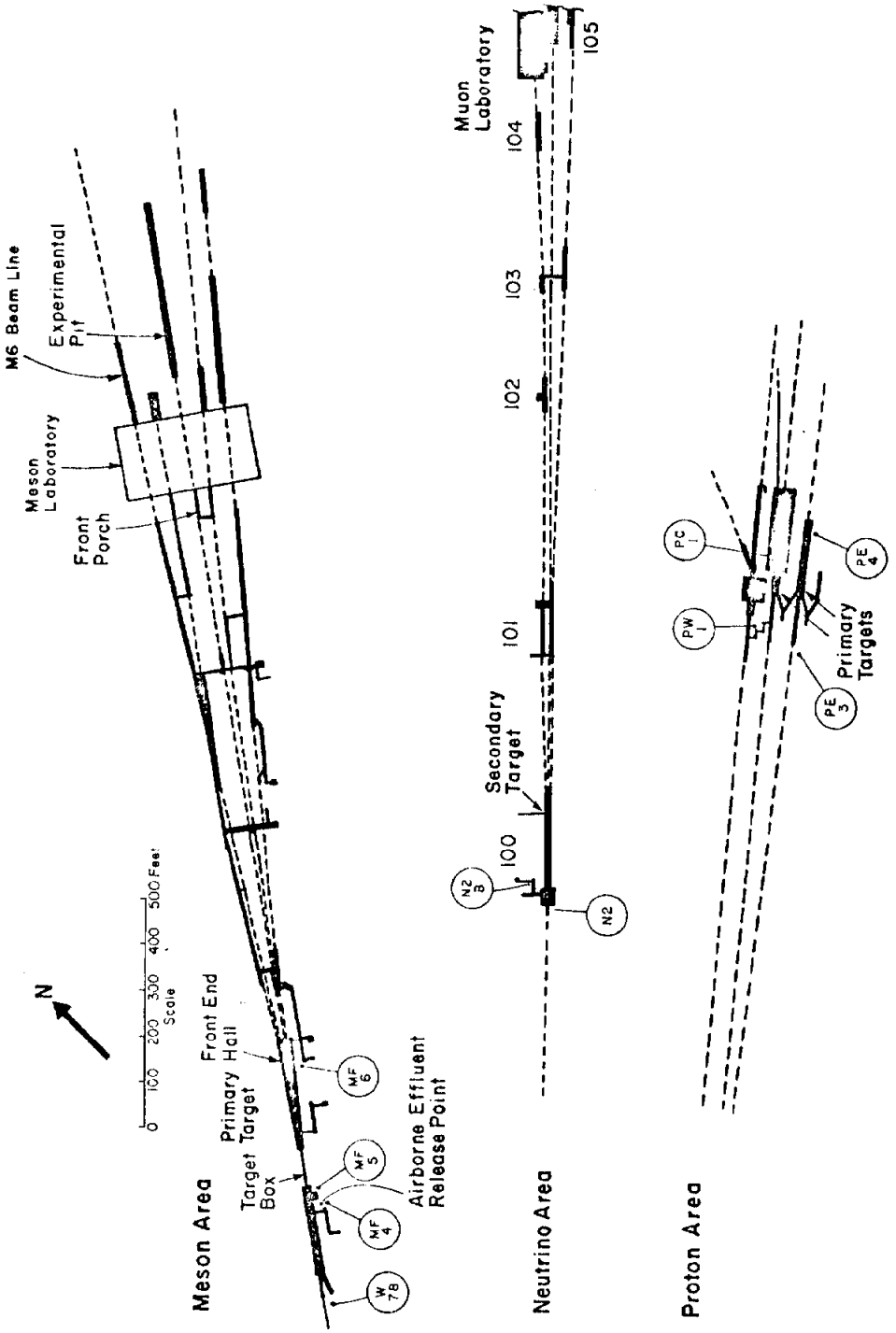


Figure3 - Sampling Locations in External Experimental Areas

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 of less than 3 per cent of the applicable standard of 500 mrem/year for an individual at the site boundary. The operation with muons continued until February 17, 1975, and resulted in radiation capable of delivering a total dose of 1 mrem over a region about 50 m (150 feet) wide at the site boundary during CY-1975.

The MERL was also used to measure neutron "skyshine." Between August 8 and September 1, 1975 an experiment produced copious quantities of neutrons in the Proton Area where the targets are about four meters below ground level. The neutrons came up from an unshielded pit near the targets. Subsequently, concrete shielding was placed over the pit eliminating the locally high radiation levels. Because of the long distances to the site boundary, the radiation levels at the site boundary were expected to be minimal even without the shielding. Data taken with a precision reproducible long counter[6] in the MERL supported this expectation, as shown below.

Neutron measurements were made perpendicular and parallel to the proton beam direction with similar results, indicating a sea of neutrons (skyshine) rather than a preponderance of higher energy neutrons penetrating the earth in the forward (beam) direction. Background rates were taken concurrently using accelerator timing signals transmitted to the MERL. The 400 GeV protons were extracted

for about one second every ten seconds, so background measurements could be made between proton beam pulses.

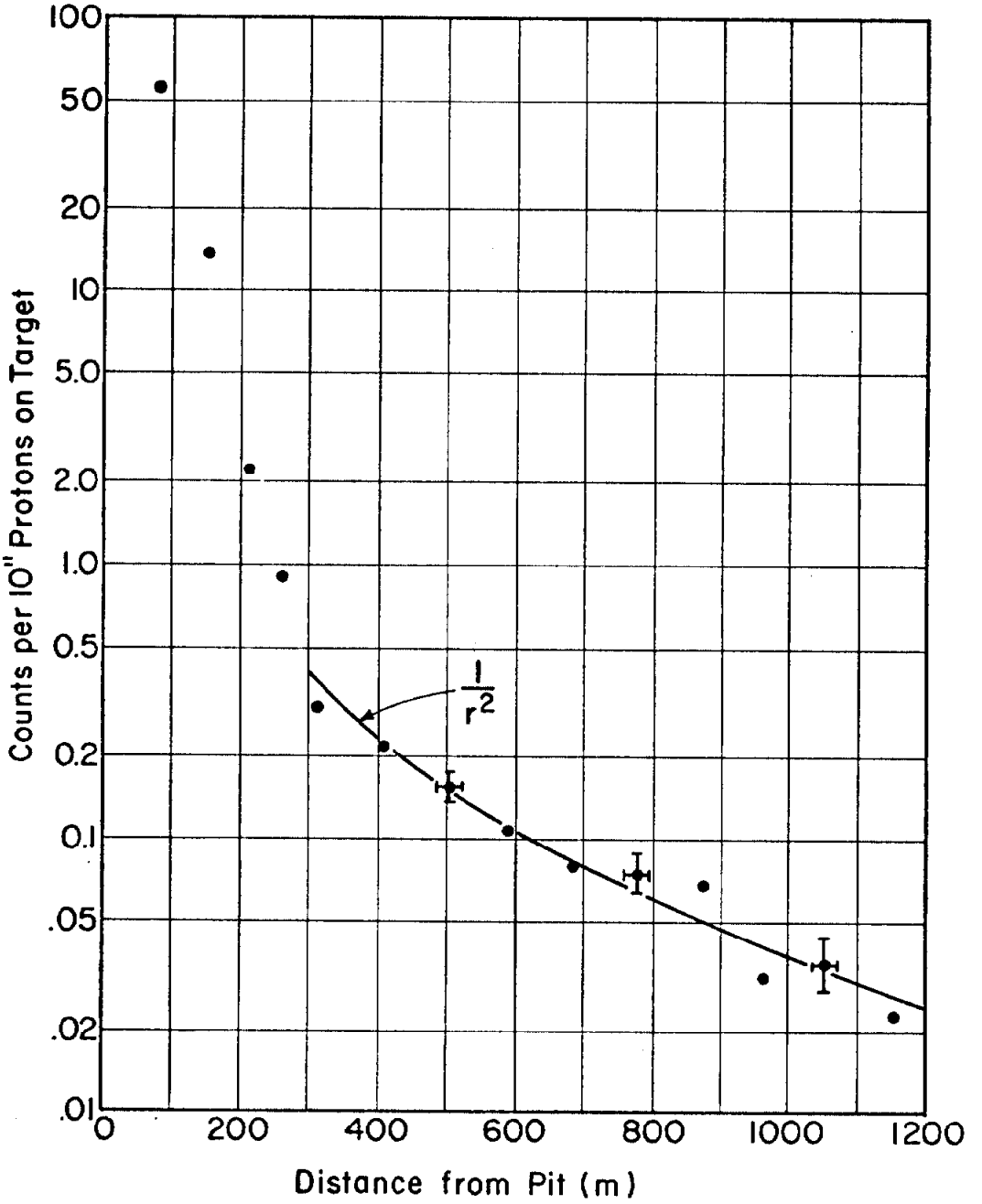
The number of long counter counts per incident proton is plotted in Fig. 4 at distances up to 1200 m from the source of neutrons. At distances greater than 500 m the number of counts per incident proton decreases with distance r from the pit as approximately inverse r^2. This is a less rapid decrease than observed at other high energy accelerators.[8] Usually an additional exponential factor is included which is attributed to neutron attenuation in air.

The dose equivalent D(r) was determined using our cosmic ray results for the precision long counter[6] and converting from a cosmic ray spectrum to the neutron spectrum from a high energy proton accelerator.[9] The biological potency of neutrons in a cosmic ray spectrum is lower by 1.5 times.[9] The highest value of the total dose which could have been delivered at the site boundary during the one-month period of high neutron production (10^{17} protons delivered to the Proton Area) was 0.1 mrem or 0.02 per cent of the appropriate annual standard for penetrating radiation (Section 4).

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.

Figure 4 – Neutron Skyshine Measurements in the Proton Area



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.[6] Radioactive gas, primarily ^{11}C, was monitored continuously during all periods of release from the stack in the Neutrino Area during 1975. From measurements made at the stack and calculations based on a Gaussian plume diffusion model,[10] the expected dose at the site boundary for 1975 was less than 0.1 mrem. The calculation assumed neutral wind conditions, i.e., neither unstable nor stable. A worse case would be moderately stable conditions where the smaller amount of diffusion would result in a five times increase in the concentration at the site boundary. 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 to radiations from ^{11}C was taken from the calculations of Yamaguchi.[11] The result is $5.8 \times 10^{-7} \mu Ci/ml$ for "submersion" of an individual member of the general population in a cloud of ^{11}C. The exposure for continuous occupancy at the site boundary from stack releases in the Neutrino Area in 1975 would have been less than .02 per cent of the applicable Guide.

Controlled releases of tritiated helium from the Meson Area Target Box occurred on March 7, July 11, and November 4, 1975. Peak ^{3}H concentrations at the release point, the vacuum pump exhaust line, were limited to $1 \times 10^{-4}\mu Ci/ml$ by controlling the flow rate. In each case 27.2 m^3 of gas was released with a total for the three releases of 148 mCi of ^{3}H. During the first two releases wind velocities were high (6.7 m/sec or 15 miles/hr) from the north and west respectively; however the third release was under adverse conditions (1.8 m/sec or 4 miles/hr winds from the south) as a result of vacuum pump failure during favorable wind conditions. The Gaussian plume diffusion model[10] was used with moderately stable wind conditions to calculate the site boundary ^{3}H concentration. The site boundary concentrations for the first two releases were less than 0.01 per cent of the applicable Concentration Guide given in ERDA Manual Chapter 0524. The result for the third release was $3.5 \times 10^{-10}\mu Ci/ml$ or 0.18 per cent of the applicable Concentration Guide.

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 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. 2). Samples were also obtained for 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 was also collected semiannually.

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.

*Monthly from Kress Creek until September 1975 then bimonthly; and three times a year from Ferry and Indian Creeks.

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-1975.

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 within seven per cent except when concentrations of beta particle emitters such as ^{22}Na or ^{45}Ca were present in excess of the Concentration Guide for the general population and no distillation was performed. Under those

conditions low concentrations of tritium were reported when none had been added. The analyses clearly showed the need for chemical separation of ^{45}Ca in the presence of other radionuclides. Without chemical separation the reported results were always higher than the prepared concentrations, once by seven times. Thus, the need for chemical separation when ^{45}Ca is detected was demonstrated. Results for other radionuclides were within or close to specifications.

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 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 detection of accelerator-produced activity are shown in Figs. 2, 3, and 5. No accelerator-produced radionuclides were reported in water samples taken from the three creeks leaving the site (Fig. 2). Each was sampled in March, June, and September. River water samples were obtained twice during CY-1975 from the Fox River in North Aurora and from the west branch of the DuPage River in Warrenville. Neither River is utilized as a drinking water supply. No positive 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 18 mCi of Tritium this year compared with 8.2 mCi last year. The release occured at less than 0.1 per cent of the Concentration Guide (Section 4 below) and made a negligible contribution to the potential off-site dose. Routine examination of the water from a sump (N2) Neutrino Area revealed elevated concentrations in CY-1974.[4] These continued in the early months of 1975 and were traced to water from a vacuum pump exhaust

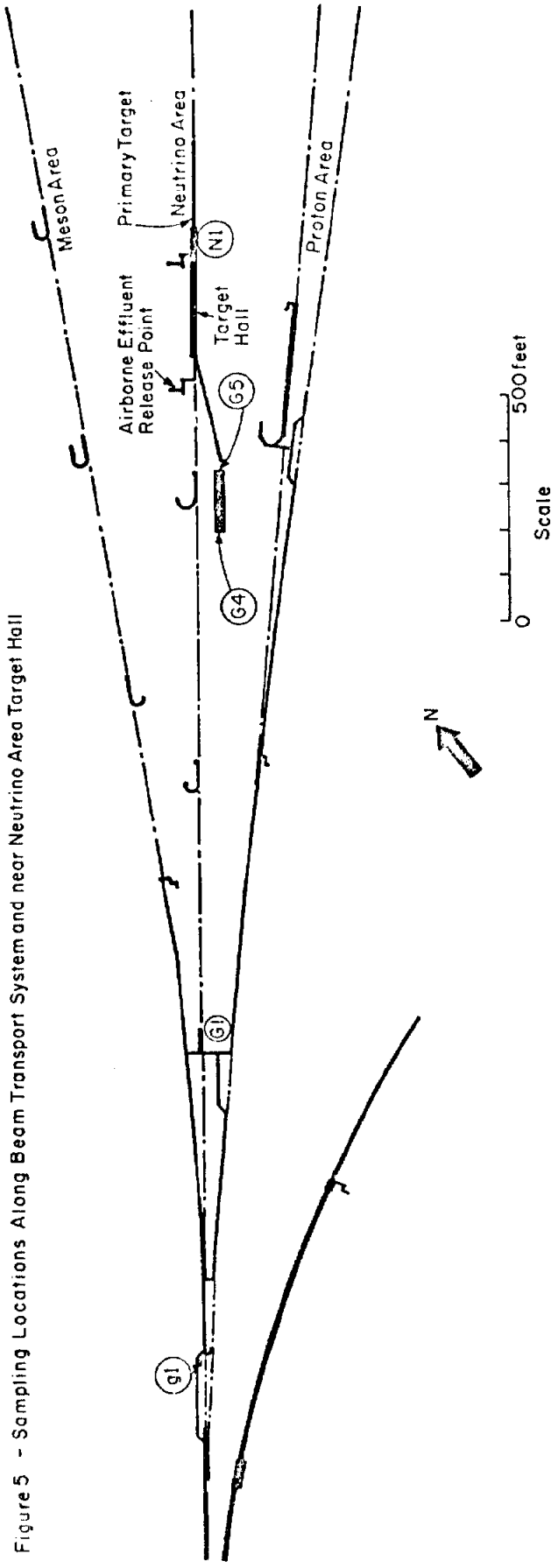


Figure 5 - Sampling Locations Along Beam Transport System and near Neutrino Area Target Hall

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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	4×10^{-6}	4×10^{-6}	4×10^{-6}	0.1
G5 Sump	1	6×10^{-6}	6×10^{-6}	6×10^{-6}	0.2
MF4 Sump	10	9.3×10^{-5}	$<3 \times 10^{-6}$	2.1×10^{-5}	0.7
MF5 Sump	11	4.6×10^{-5}	$<3 \times 10^{-6}$	1.6×10^{-5}	0.5
N1 Sump	12	3.7×10^{-5}	$<3 \times 10^{-6}$	8×10^{-6}	0.3
N2 Sump	12	5.3×10^{-4}	$<3 \times 10^{-6}$	8.4×10^{-5}	2.8
N2B Sump	3	4.0×10^{-4}	5×10^{-5}	2.0×10^{-4}	6.7
PC1 Sump	4	7.5×10^{-5}	3×10^{-6}	3.1×10^{-5}	1.0
PE4 Sump	4	1.8×10^{-5}	$<3 \times 10^{-6}$	8×10^{-6}	0.3
PW1 Sump	4	4×10^{-6}	$<3 \times 10^{-6}$	3×10^{-6}	0.1
S1 Sump	3	7×10^{-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	2.6×10^{-5}	$<3 \times 10^{-6}$	1.1×10^{-5}	0.4
T2 Sump	3	7×10^{-6}	$<3 \times 10^{-6}$	4×10^{-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.

oil separator. The valve to the retention pit leading into the sump was closed and the water subsequently released at a time when surface waters went into Casey's Pond (H4 in Fig. 2) rather than off the site.

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. 2) and the discharge containing ^{7}Be is released into the soil in perforated pipe fields six 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.

There continues to be some surfacing of this water containing ^{7}Be in both perforated pipe fields. The one shown in Figure 2 receives discharge from the Central Utilities Building. The other is close to the BO Water Treatment Plant. The amount of ^{7}Be discharged from the Central Utilities Building was limited in CY-1975 by storing the resin tanks until the ^{7}Be (half life 53 days) had decayed to lower concentrations before regeneration. As a result, the peak concentration was limited to 500 pCi/g in the silt at the point where the water reached the surface and the concentration in the surface water was below the detection limit.

No radioactivity has been detected in any of the 56 well water samples obtained during CY-1975. Most of these are farm wells about 30 meters deep. This year a new well was drilled in the Meson Area (W78 in Fig. 2) to monitor the ground water in the vicinity of the primary target. There is a large impervious membrane forming a "bathtub" under this target and a drain (perforated pipe) inside it. There are underdrains outside the bathtub but, unlike the Neutrino Area bathtub which has underdrains below it, the ones in the Meson Area 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. The new monitoring well will serve this function.

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 activation of 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, quantitative measurements were made only on those.[12] Most of the results have been presented elsewhere.[8,15] The tritium analyses for the most recent holes have been done subsequently and are essentially the values expected from earlier results (Table 2).

Table 2

RESULTS OF RECENT SOIL BORINGS

LOCATION ALONG DIRECTION OF MOTION OF PROTONS	SAMPLING REGION		^{22}Na CONCENTRATION		^{3}H CONCENTRATION (μCi/ml)††
	Distance to Ground Water*		Max. pCi/g Dry Weight**	Per Cent Leachable†	
	(m)	(ft)			
50 m from Neutrino Area Primary Target	15.2 - 14.7	49.8 - 48.3	180	2.9	6.3×10^{-5}
80 m from Neutrino Area Primary Target	15.8 - 15.3	51.9 - 50.4	214	2.4	2.7×10^{-5}
110 m from Neutrino Area Primary Target	15.5 - 14.9	50.9 - 48.9	71	-	1.0×10^{-5}
8 m from Meson Area Primary Target	16.0 - 15.5	51.5 - 51	31	-	3×10^{-6}
12 m from Transfer Hall‡	9.1 - 8.7	30 - 28.5	12	-	$<3 \times 10^{-6}$

*Ground water level is 211.5 m or 694 ft. above mean sea level, and the Neutrino Area Primary Target is at 15.5 m or 51 ft. above the ground water at these locations.

**The dry weight determined after heating in an oven for three hours at 200^{o}.

†Deionized water percolated through a 100 g sample in a burette.

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

‡No impervious membrane at this location (Fig. 2).

There is no indication of production or leaching rates which would suggest much higher releases than those predicted.[13]

3.4. Nonradioactive Pollutants

3.4.1. Water Utilization

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 670,000 l/day (175,000 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. The test results for CY-1975 are presented in Table 3, and sampling locations listed in Table 3 are shown on Fig. 2.

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 with tertiary treatment are:

BOD5: 4 mg/l avg., 6 mg/l max.

Table 3

SITE WIDE WATER QUALITY REPORT FOR CY-1975

		pH	DO mg/l	BOD5 mg/l	Susp. Solids mg/l	Fecal Coliform # per 100 ml	Notes
FERRY CREEK	Max.	8.3	13.4	9.1	102	1450	Sampled
	Ave.	8.0	9.8	5.5	43	222	Monthly
	Min.	7.7	6.3	3.1	5	0	
INDIAN CREEK	Max.	8.0	12.5	6.5	32	5000*	Sampled
	Ave.	7.7	9.4	3.8	12.1	166	Monthly
	Min.	7.4	6.5	1.6	2	0	
KRESS CREEK	Max.	8.3	14.3	11.1	473	1500	Sampled
	Ave.	7.8	9.6	5.2	90.0	304	Monthly
	Min.	7.4	6.4	2.2	2	10	
CENTRAL LAB. SEWAGE	Max.	8.4	10.8	11.8	20	350	Sampled Weekly
	Ave.	8.0	7.3	5.2	3.4	60	but Coliform
	Min.	7.3	5.0	1.3	1	0	Monthly
VILLAGE SEWAGE LAGOON	Max.	9.3	15.0	20	57	350	Sampled Weekly
	Ave.	8.4	12.0	8.4	18	41	but Coliform
	Min.	7.6	3.5	2	2	0	Monthly

*This coliform count was for nine days in September while the sewage plant was being modified. This result was not included in the calculated average.

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

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

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.

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

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

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 eight times on BOD5, once on Suspended Solids, and seventy-one times on Residual Chlorine. The Village Lagoon exceeded its maximum limits nineteen times on pH, three times on Suspended Solids and thirteen 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 4 mg/l at the Central Laboratory's sewage plant and never exceeded 2 mg/l at the Village Lagoon. Other maximum values are given in Table 3.

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, it has been necessary occasionally during CY-1975 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 166 compared with 304 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 are presently conducting surveys of all cooling water sources and ground infiltration in an effort to reduce the excess flow. Additional storage capacity has also been added so that now the practice of on-land discharge has been discontinued.

Some chemical treatment of our water system was necessary during CY-1975, however, to reduce algae and weed growth and to inhibit corrosion. Copper sulfate, not exceeding 1 mg/l was applied for algae control, and Diquat, not exceeding 1 mg/l was used for weed control on the Village sewage lagoon, reflecting ponds and 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. 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/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. 2). 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

maximum concentration was found to be 22 mg/l or about 60 times the Concentration Guide for discharges (Section 4 below).

Samples were taken in December 1975 from the pond (H5 in Fig. 2) which acts as a reservoir in the Main Ring and from the perforated pipe field identified in Fig. 2. The former receives the water surfacing from the regeneration of resins at the B0 Water Treatment Plant, the latter from resin regenerations at the Central Utilities Building. The test for copper yielded a maximum of 0.019 mg/l in the Main Ring waters. This concentration is approximately equal to the State of Illinois EPA Standard for copper (Section 4 below). In addition to copper added for algae control, some copper is discharged during resin regenerations. As a result of these tests, a more extensive program of measuring chromium and copper concentrations has been initiated.

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 4, based on the 1970 census.[16] 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. The contribution to off-site potential dose from

Table 4

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

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 per cent higher than the 1970 census.[17] The population distribution obtained from the 1970 census was used to evaluate the potential exposure to the public for CY-1975 and the man-rem dose obtained was increased by 30 per cent.

The radiation exposure to the general population from operation of Fermilab in CY-1975 was about 1 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 4. 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 0.1 man-rem from airborne releases in CY-1975. 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 late February, March, and late December 1975 while Casey's Pond, 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 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 over 50 samples of water from on-site wells pumped in CY-1975. This includes a new well drilled this year to sample the aquifer near a target in the experimental area (Section 3.3). Measurable concentrations of some accelerator-produced radionuclides, primarily ^{3}H, ^{7}Be, and ^{22}Na were detected on-site in soil and silt samples. 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-1975 remained quite small.

3.5.2. Evaluation of Nonradioactive Pollutant Releases

The results given in Table 4 indicate that during nine days in September there was a high level of coliform in Indian Creek. There is no evidence for an adverse impact as a result of this pollution. The stringent limits set by the Federal EPA on our NPDES permits for our sewage treatment plants have resulted in a number of other periods of noncompliance. These had much less potential for environmental impact than the high coliform levels mentioned above.

Some chemical treatment of our water system was necessary during CY-1975, 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 a peak chromate concentration more than 60 times the State of Illinois Concentration Guide for effluent release (Section 4) in the waters welling up to the surface. A sample taken in early 1976 from the Main Ring pond showed a chromium level less than the State of Illinois standard for waters in general use (Section 4 below). Thus, the chromate releases to date have had little impact on waters in the Main Ring pond system from which the releases could eventually find their way off-site. Further evaluation is continuing via an extended water sampling program.

No facility on the site has been a problem with respect to nonradioactive airborne effluents. The bulk of the heating is provided by natural gas in boilers located at the Central Utilities Building (Fig. 2). 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 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 unsoluble forms has been used in each case. The specifications are given in Table 5. 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 Concentration Guides 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 Concentration Guides for total copper are 1.0 and 0.02 mg/l, respectively. 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 5

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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