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Environmental Monitoring Report

For Calendar Year 1977

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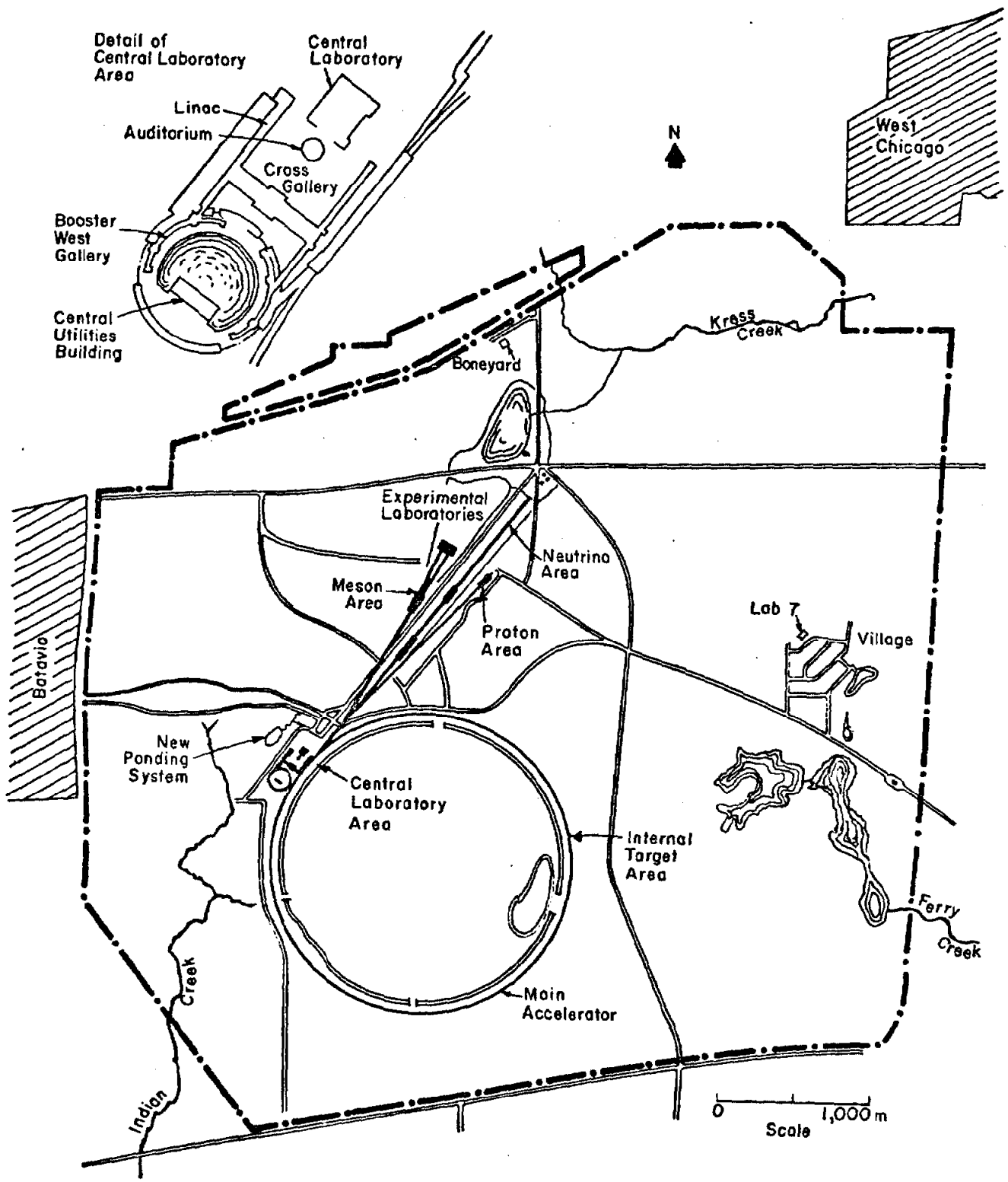
1. Introduction

This report gives the results of the environmental monitoring program at Fermi National Accelerator Laboratory (Fermilab) for Calendar Year (CY-) 1977. 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.

Figure I. - Fermilab Site



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Monitoring results are also reported for nonradioactive 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 mi) 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

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*1970 U.S. Census.

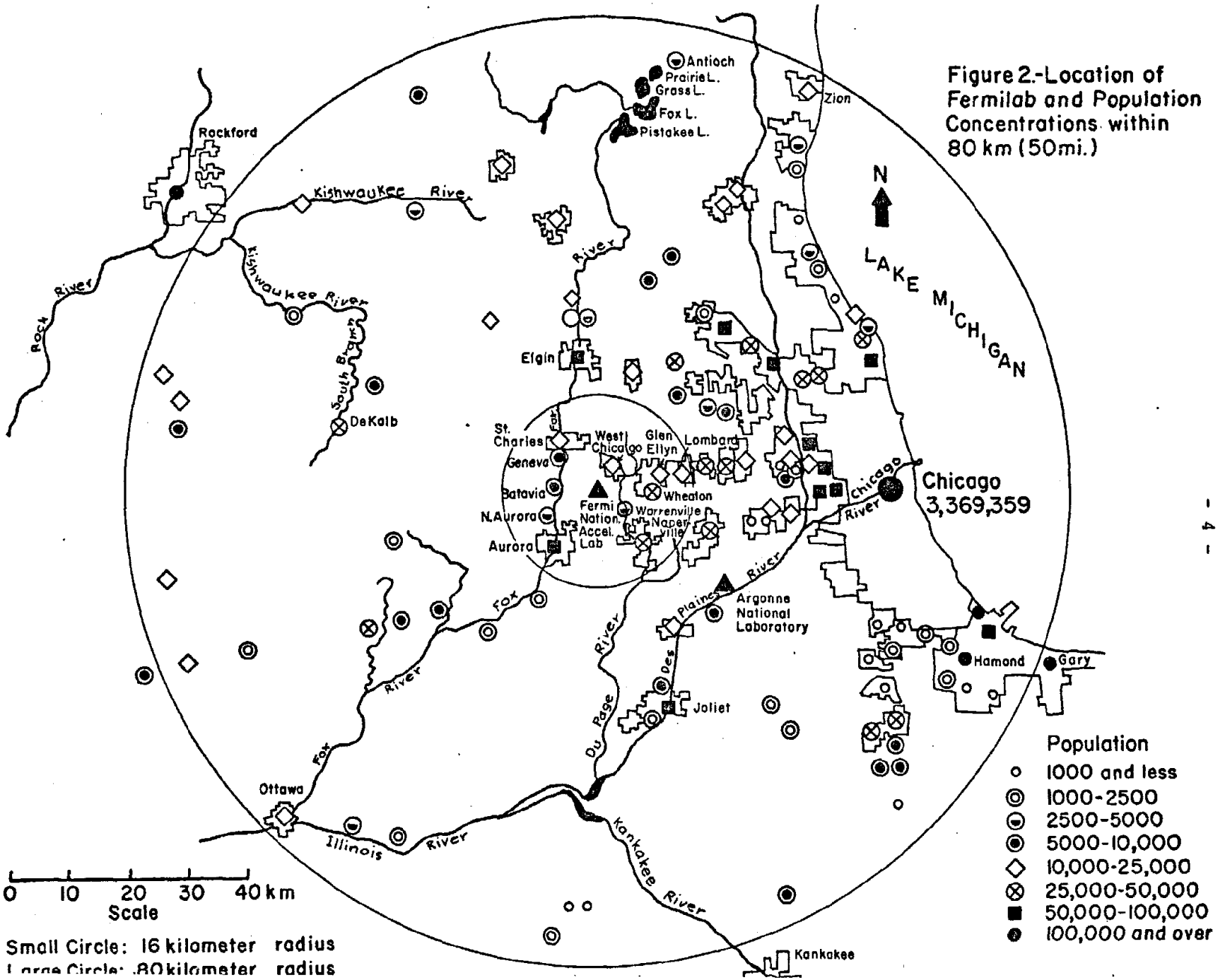


Figure 2.-Location of Fermilab and Population Concentrations within 80 km (50mi.)

Warrenville. The rainfall on site during 1977 was 92 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 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 mi/hr) at Argonne National Laboratory (ANL).[3] The direction is quite variable with the observation of more southwesterly winds than from any other direction. The mean wind speed was 4.0 m/sec (9.0 mi/hr) in CY-1977 with more southwesterly winds.[3] Fermilab is about 30 km (19 mi) from ANL and the terrain is relatively flat, 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

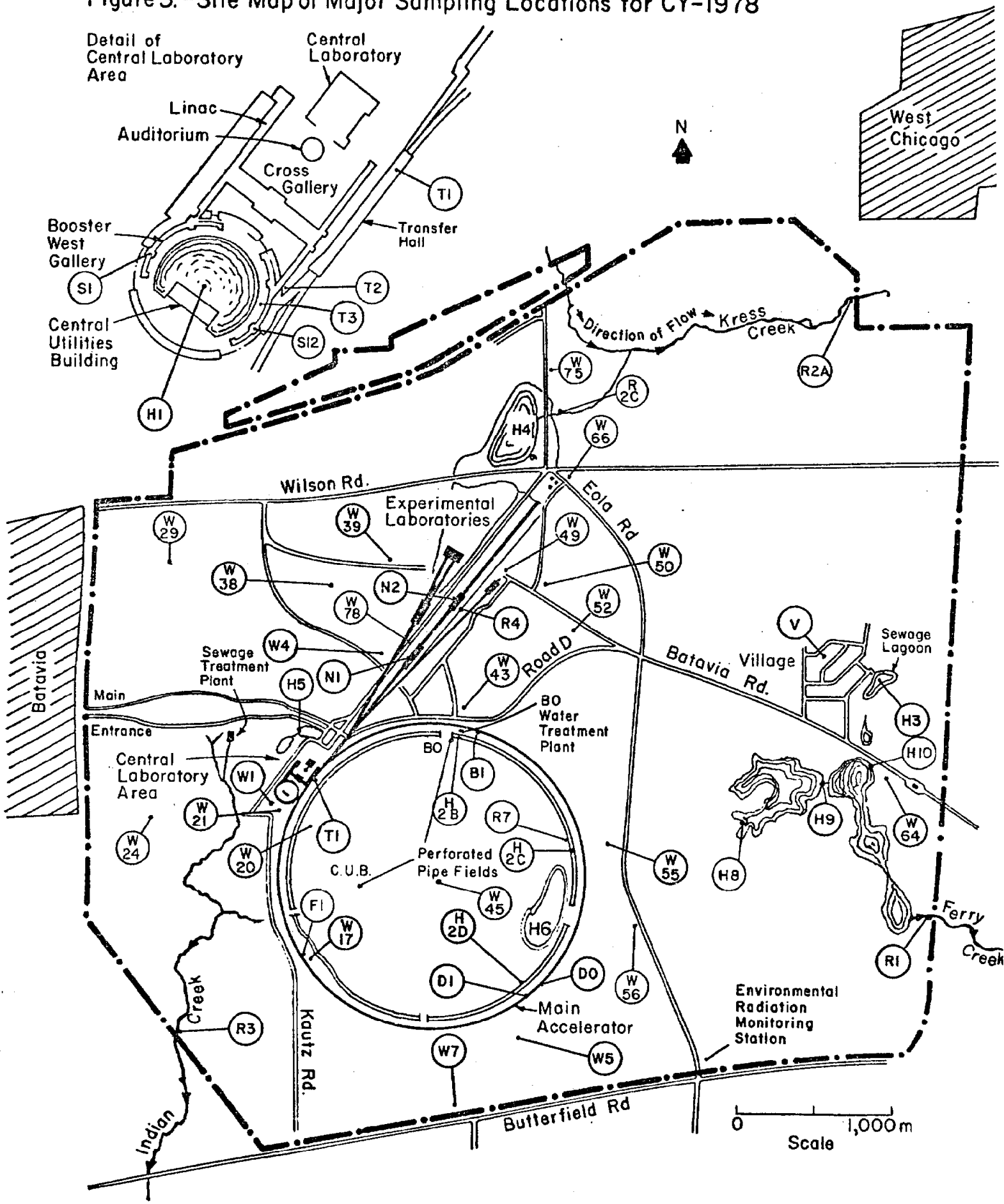
The accelerator operated routinely at 400 GeV during CY-1977 with about one third more protons during CY-1977 than in CY-1976. The total number of protons accelerated in 1977 was 2.5×10^{19}. The maximum number of protons accelerated at one time reached half of the planned or design intensity of 5×10^{13} protons per acceleration cycle and typical operation was at about one third. Thus, environmental monitoring in CY-1977 was done under operation conditions not grossly different from those expected in the future.

During CY-1977 there were no abnormal natural occurrences which could have had some impact upon the facility or its operation.

The new ponding system (Fig. 1) was in operation from January 1, 1977 to April 9 and from November 13 through the end of the year, reducing the amount of chromates put into the perforated pipe field inside the main accelerator (Fig. 3).[4] From April 9 to November 13 the cooling towers were used while improvements were made in the ponding system. The average concentration of chromates in on-site surface waters was below the State of Illinois Standard for waters in general use this year.

Copper from regeneration of resins at the B0 Water Treatment Plant continues to surface.[4] The average concentration of copper in the C4 pond which receives this

Figure 3. - Site Map of Major Sampling Locations for CY-1978



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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discharge was slightly above the State of Illinois Standard for waters in general use. It is planned to move the B0 Water Treatment Plant to the Central Utilities Building in CY-1978 and install a holding tank for precipitation of the copper compounds.

The releases of copper and chromate 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-1977 were 7 mrem and 1 man-rem, respectively, compared to 13 mrem and 4 man-rem, respectively, last year. The site boundary dose rate is lower because the experimental area produced fewer off-site muons this year.[4] The potential dose at the site boundary corresponds to 1.4 percent of the standard of 500 mrem for an individual who is not a radiation worker. It is primarily from radioactive waste in temporary storage at the Boneyard (Fig. 1).

Since our site is open to the public, the potential for exposure to an individual while he is on the site is considered. Most of those coming here sleep elsewhere, but approximately 50 visiting experimenters and their families are housed in the Village (Fig. 1). An aerial radiation survey of our site in CY-1977 indicated levels above back-

ground in the vicinity of Lab 7 (Fig. 1). Further radiation surveys plus information on work done at Lab 7 and occupancy of houses across the street from Lab 7 resulted in a total of 0.2 man-rem to visitors from the radioactive components handled in Lab 7. The maximum individual exposure assuming 24 hr/day occupancy would have been 23 mrem from Lab 7 or about one third of the naturally occurring exposure inside one of the houses.

Airborne radioactivity was released across the site boundary in small amounts throughout the year from the stacks ventilating a Neutrino Area enclosure where the beam struck a target. The radioactive gas was primarilly ^{11}C, total quantity released was 10 kiloCuries, and the maximum dose at the site boundary was 0.3 mrem for 1977. The average concentration at site boundary based on measurements at the stack was 0.05 percent of the Concentration Guide (Sections 3.2 and 4). There was also a controlled release of tritium produced in helium gas near another target. The total amount of tritium released was 550 mCi. Tritium was released continuously from January 25, 1977 through December 31, 1977, with an average concentration at the site boundary of 0.00001 percent of the Concentration Guide (Sections 3.2 and 4), resulting in a negligible off-site exposure. No radioactivity was detected in the ground water and off-site releases of tritium of surface water totaled 128 mCi. The

large increase this year resulted from water bypassing Casey's Pond for about three months while the pond was full.

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-1977 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.

For several years a special radiation monitoring station with gamma-ray, charged particle and neutron detectors of high sensitivity was maintained near the site boundary (Fig. 3).[6] This station detected no accelerator-produced radiation. In CY-1977 all detectors except one gamma-ray scintillation counter were removed for use elsewhere on site. The remaining gamma-ray detector is identical to one used near the experimental areas (W43 in Fig. 3) to detect ^{11}C in the Neutrino Area radioactive gas releases. It provides background levels for comparison to those levels of ^{11}C and also 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 dose rates 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.

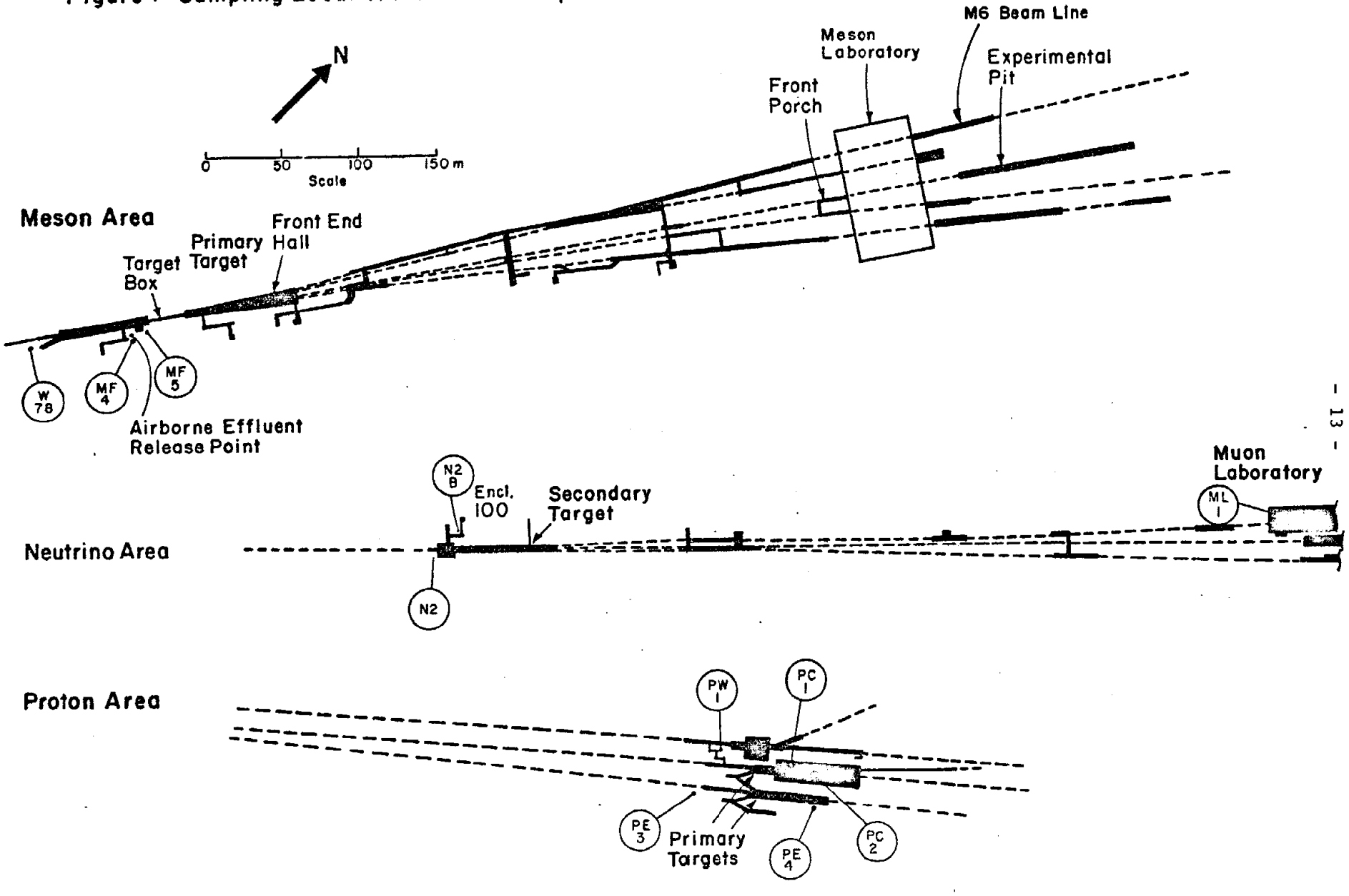
3.1.1 Muons

The MERL was used 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).[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 in CY-1977 resulted in radiation capable of delivering a total dose of 2 mrem over a region of about 50 m (160 feet) wide at the site boundary. Muon doses from Proton Area operations[4] were negligible in CY-1977.

3.1.2 Neutrons

Neutrons were detected outside the shielding at several locations on-site in CY-1977. The only change occurred in the Meson Area where the M2 line was operated

Figure 4 - Sampling Locations in External Experimental Areas



at much higher intensities this year requiring the addition of concrete to reduce the exposure. All the locations where neutrons were detected were so far from site boundaries that the annual dose at site boundary from neutrons was negligible.

3.1.3 Gamma Rays

In May 1977 E G & G, Inc., under ERDA (now DOE) contract, conducted an aerial radiological survey of Fermilab and surrounding area.[9] The detection system used consisted of 20 NaI(Tℓ) scintillation counters each 12.7 cm diameter by 5.1 cm thick (5" x 2") mounted in a helicopter. Data were recorded on magnetic tape and analyzed with aid of computer techniques.

Flight paths were 100 m (300 ft) apart at an altitude of 100 m (300 ft) with location determined by referencing to radio beacons placed on nearby water towers. The area covered was approximately 6 km by 6 km (4 mi x 4 mi) with the Laboratory in the center. The preliminary results are shown in Fig. 5. The contours shown are regions greater than natural background. Natural soil activity[9] in the vicinity of Fermilab varied from 0.010 to 0.014 mrem/hr. This is in good agreement with 0.012 mrem/hr previously measured at Fermilab.[6] The region between the outermost contour lines corresponds to gamma-ray exposure rates between 0.0142 and 0.0180 mrem/hr. The values for regions between successive contour lines are given in Table 1.

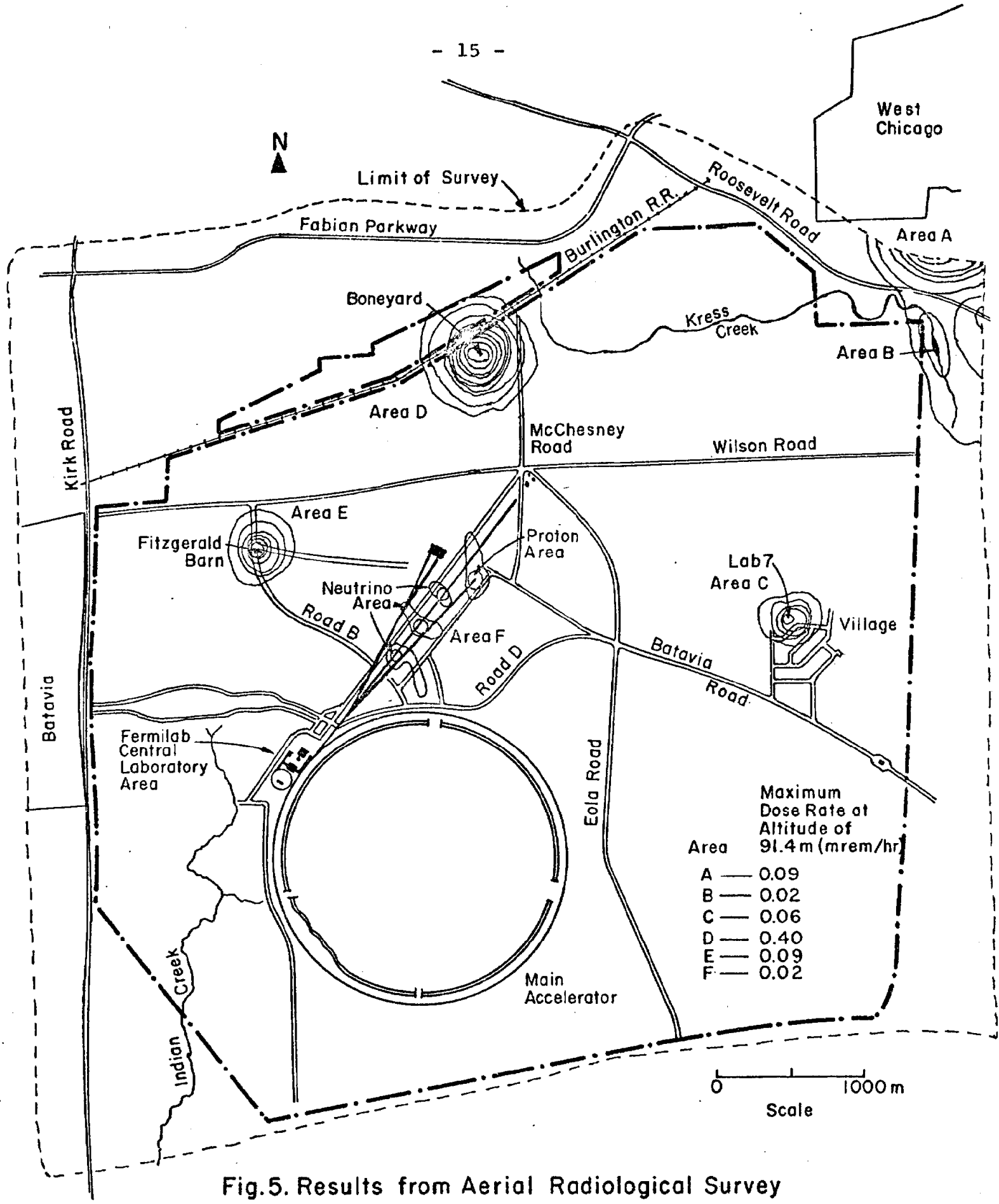


Fig. 5. Results from Aerial Radiological Survey

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TABLE 1

Gamma-Ray Exposure Rates Between

Successive Contour Lines in Fig. 5

Starting Contour Line	Gamma-Ray Exposure Rate Between Adjacent Contour Lines (mrem/hr)
Outermost	0.0142-0.018
	0.019-0.024
	0.025-0.032
	0.033-0.045
	0.046-0.062
	0.063-0.087
	0.088-0.125
	0.126-0.185
	0.186-0.269
	0.270-0.400

Areas A and B are outside the Laboratory boundaries. Thorium decay products were detected there and are from residue or "tailings" left from the manufacture of lighting products containing thorium. Since Area B was a pond along Kress Creek which flows through the northeast corner of our Laboratory, we made comparisons of silt samples at that point with silt samples upstream near our Laboratory. Since our Laboratory produces no thorium decay products, we did not expect to find, nor did we find, any evidence linking our Laboratory to the radioactivity found in Areas A and B.

Area C is the result of radioactive components being stored and worked on at Laboratories 6 and 7 in the Village. The exposure was essentially all from Lab 7. We measured the radiation levels in the vicinity of these Laboratories and found levels above background at three houses occupied by visiting experimenters. Tissue equivalent ion chamber measurements were made inside one of the houses, and background measurements were made in an identical house outside the radiation area. From these measurements we determined that for 24-hour occupancy throughout 1977 the doses received by individuals in two of the three houses would have been 23 mrem and in the third would have been 17 mrem due to the radioactive materials in Lab 7. These are five and three percent, respectively, of the standard of 500 mrem for an individual who is not a radiation worker.

Since the aerial survey, efforts have been made to reduce the inventory of radioactive components at Lab 7 by shipping many to the Nuclear Engineering Corporation burial ground at Sheffield, Illinois. As a result, the contribution to the dose rate on December 28, 1977 had been reduced to 4 mrem/year inside the house at 23 Neuqua.

Area D is the primary radioactive waste material storage area on site - the "Boneyard". As shown in Fig. 5, this area lies close to the site boundary and is the most radioactive source detected in the aerial survey. The storage area emits a conical radiation field; observers standing immediately outside the area are shielded by fences, walls, vegetation, etc. On the north side there is an earth berm to prevent any direct radiation from reaching persons on the ground. But the aircraft, at an altitude of 90 m, may enter this gamma-ray field more than 400 m from its physical boundary.[9] Hence, the actual exposure rate for an observer on the ground cannot be determined from these data.

A radiation survey was made subsequently by Fermilab personnel on the ground. The dose rate at the site boundary was measured. The material in the Boneyard is approximately 350 m (0.2 mi) from the nearest site boundary to the north. The rate of decrease at the site boundary is faster than inversely as the square of the

distance. The relationship used in determining the off-site dose was

$$\frac{e^{-\mu r}}{r^2}$$

where r is the distance from the source and μ is the attenuation factor. The value of μ determined from measurements made between 200 m and 350 m nearest (site boundary) from the source was 0.005 m^{-1}. The dose at the nearest site boundary was approximately 7 mrem for CY-1977.

Area E on the aerial survey map (Fig. 5) is the Fitzgerald Barn. It was used for storage of radioactive materials needing shelter from the weather. The material has recently been moved to a shielded area south of the Boneyard and the barn has been razed.

Area F is the experimental area. The survey was conducted while the accelerator was delivering protons to this area. Operating conditions were typical, hence the slight increases above background indicate that our shielding is doing an adequate job. The one radioactive region of Area F closest to the large ring of the main accelerator (Fig. 5) is an industrial area where radioactive magnets are rebuilt. The dose rates there are also quite low.

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 Department of Energy Manual, Chapter 0524 (DOE Manual 0524).

Radioactive gas, parimarily ^{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 1977. From measurements made at the stack and calculations based on a Gaussian plume diffusion model,[4,10] the expected dose at the site boundary for 1977 was 0.3 mrem, which corresponds to 0.05 percent of the applicable Concentration Guide[11] (Section 4).

Tritiated helium was released continuously as the tritium was produced from January 25, 1977 through the end of 1977 from the Meson Area Target Box. No release occurred between January 1 and January 25, 1977. The total activity released for the year was 550 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 average site boundary concentration for the release was less than 2×10^{-14} μCi/mℓ or a negligible percentage (0.00001 percent) of the applicable Concentration Guide given in the DOE Manual Chapter 0524.

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.[12] This group of radionuclides also includes those produced in water directly. Analyses are made for ^{3}H, ^{7}Be, ^{22}Na, ^{45}Ca, ^{54}Mn and ^{60}Co. The latter is hardly leachable (approximately 0.1 percent); however it has been detected in discharges during regeneration of water treatment resin.

Water samples were collected from the following types of wells on site:

1. Farm Wells - Approximately 30 m Deep - 37 Samples
2. Fermilab Water Supplies - Approximately 70 m Deep - 3 Samples
3. Fermilab Deep Well Emergency Supply - 436 m Deep - 1 Sample

Water samples were also collected from sumps, creeks, and rivers. Samples were analyzed by Eberline Instrument Corporation, Midwest Facility, West Chicago, Illinois, during CY-1977. Each monthly shipment included one sample containing known amounts of several of the accelerator produced radionuclides to check the accuracy of the assays.

The agreement of the reported concentration with known concentrations of radionuclides in control samples provided verification that the analyses were meeting the specifications agreed upon in the contract. In addition to the usual control samples, Fermilab forwarded water

samples received from the DOE Environmental Measurements Laboratory (EML)as part of a quality assurance program. The results for routine analysis by Eberline are shown in Table 2. Also included are results obtained by EML and by Fermilab where considerably more effort was expended.

Fermilab has no liquid scintillation counting apparatus, hence no tritium determinations in water were performed here. The mean value of the tritium measurements performed by Eberline, 43.25 pCi/mℓ is in excellent agreement with the mean value, 43.1 pCi/mℓ, obtained by all participants in the program[14] and is only 6.5% higher than the EML value.

The ^{7}Be result is poorer than the typical performance Eberline delivers for our controls, but it does indicate that for low levels of activity a routine analysis will occasionally deviate markedly from the mean.

3.3.1 Results of Analyses

The Fermilab CY-1977 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, four from Ferry and two from Indian. River water samples were obtained twice during CY-1977 from the Fox River in Aurora and from the west branch of the DuPage

Table 2

Comparison of Water Analyses

Sample Date	Radio-nuclide	Environmental Measurements Laboratory Result (pCi/mℓ)	Percentage of Concentration Guide (pCi/mℓ)	Fermilab Result (pCi/mℓ)	Eberline Result Routine Analysis (pCi/mℓ)	Mean Value for all Participants In Quality Assurance Program
10/76	^{3}H	40.6	4		45.5	43.1
01/77					39.0	
04/77					43.0	
07/77					44.5	
07/77	^{7}Be	40.3	6	40.0	91	45.2
07/77	^{22}Na	1.18	12	1.11	0.95	1.14
10/76	^{54}Mn	1.39	4	1.20	1.50	1.45
01/77		1.78	5	1.80	1.70	1.60
04/77		1.13	3	1.08	0.98	1.14
10/76	^{60}Co	0.65	7	0.75	0.55	0.705
01/77		5.72	57	5.80	4.50	5.31
04/77		1.89	19	1.97	1.85	1.79

River in Warrenville. Neither river is utilized as a drinking water supply. No evidence for accelerator-produced radionuclides was found.

3.3.1.1 Tritium

The results for on-site tritium measurements yeilding detectable levels in surface waters are given in Table 3. All other sampling points were essentially at background levels. The total off-site release in surface waters was 128 mCi of tritium this year compared with 2 mCi last year and 18 mCi in CY-1975. The increase was partially the result of more rainfall. For approximately three months in CY-1977 Casey's Pond (H4 in Fig. 3) was full and water from the experimental areas left the site via the spillway leading to Kress Creek. The release occurred at less than 0.3 percent of the Concentration Guide (Section 4 below) and made a negligible contribution to the potential off-site dose. A leak in the Meson Area Target Box closed loop on November 5, 1977, coupled with a failure of the plug in the retention pit resulted in a tritium concentration of 3700 pCi/mℓ in the MF5 sump discharge (Fig. 4). A water sample taken at the Kress Creek spillway had less than 3 pCi/mℓ indicating a dilution factor of greater than 1000 at that time before the water left the site.

A tritium level at the detection limit (Section 4) was reported for the sample taken from the well at Site 5

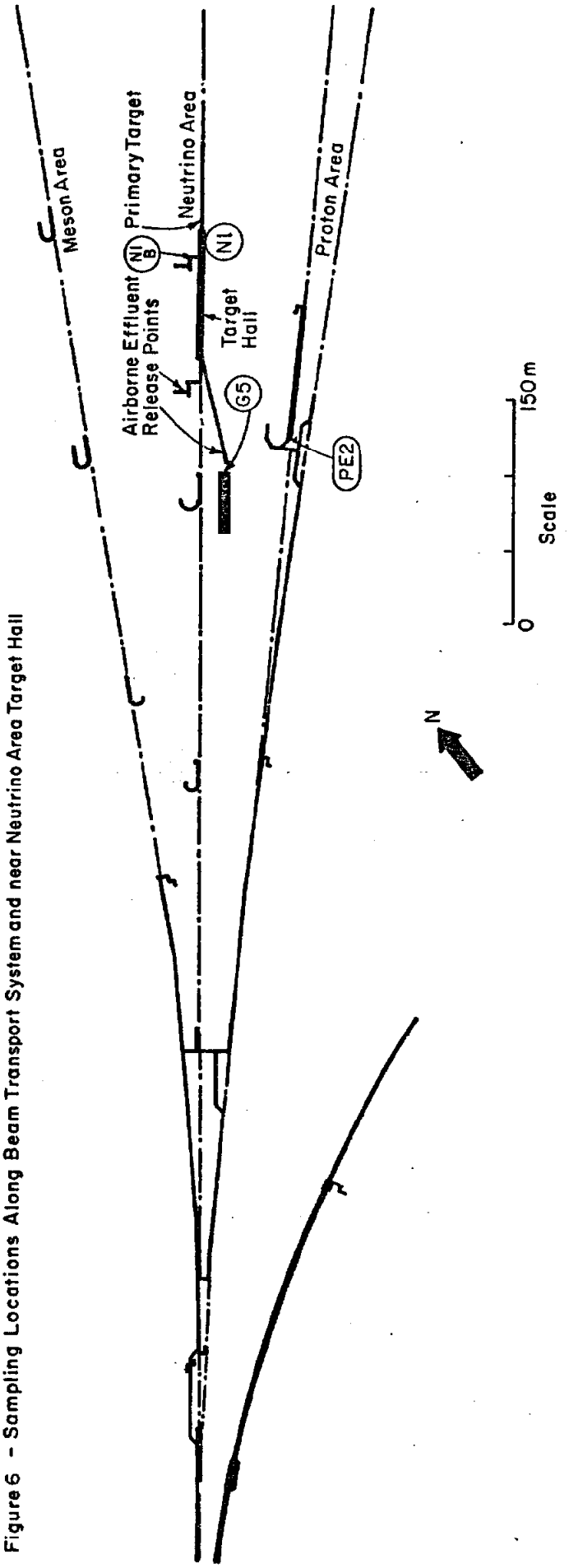

Figure 6 - Sampling Locations Along Beam Transport System and near Neutrino Area Target Hall

TABLE 3

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
G5 Sump	1	7.0×10^{-6}	7.0×10^{-6}	7.0×10^{-6}	0.2
MF4 Sump	2	1.7×10^{-5}	3.0×10^{-6}	1.0×10^{-5}	0.3
MF5 Sump	8	3.7×10^{-3}†	$< 3 \times 10^{-6}$	8.9×10^{-4}	30.0
N1 Sump	8	9.2×10^{-5}	$< 3 \times 10^{-6}$	1.8×10^{-5}	0.6
N1B Sump	1	3.0×10^{-6}	3.0×10^{-6}	3.0×10^{-6}	0.1
N2 Sump	9	4.7×10^{-5}	$< 3 \times 10^{-6}$	2.2×10^{-5}	0.7
N2B Sump	3	2.5×10^{-5}	5×10^{-6}	1.4×10^{-5}	0.5
PC1 Sump	6	2.5×10^{-4}	1.3×10^{-5}	7.4×10^{-5}	2.5
PC2 Sump	1	3.6×10^{-5}	3.6×10^{-5}	3.6×15^{-5}	1.2
PE4 Sump	3	1.8×10^{-5}	4.0×10^{-6}	1.3×10^{-5}	0.4
PW1 Sump	4	6.0×10^{-5}	3.0×10^{-6}	4.3×10^{-6}	0.1
S1 Sump	2	4.0×10^{-6}	$< 3 \times 10^{-6}$	3.5×10^{-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 one-day release in November when water was going off site.

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(W5 in Fig. 3) late this year. It will be sampled again in early CY-1978. None of the three wells for which tritium levels at the detection limit were reported in CY-1976 had any tritium reported for CY-1977.

3.3.1.2 Beryllium

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 B0 Water Treatment Plant, Fig. 3) 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 ensure 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 CY-1977 (Fig. 3). At B0 the surfacing occurs at the entrance to the field. There the concentration of ^{7}Be in the silt was 2200 pCi/g. The surfacing occurs primarily at the end of

the CUB perforated pipe field. There the ^{7}Be concentration was only 1 pCi/g in CY-1977. The B0 Water Treatment Plant is scheduled to be moved to the Central Utilities Building in CY-1978. A large settling tank is to be added for removing copper from the regeneration effluent. Since the concentration of ^{7}Be is a maximum at the same time copper appears in the discharge, most of the ^{7}Be should be removed with the copper.

On August 26, 1977, a break was discovered in the line to the CUB perforated field. The discharge water went into the main ring pond near the CUB (Fig. 3). Silt samples around the break yielded a peak concentration of 170 pCi/g.

From December 8 until December 20, 1977, the line to the CUB perforated pipe field was frozen and the discharge water ended up in the Booster Pond (H1 in Fig. 3). A total of 44 mCi of ^{7}Be was discharged during this period.

3.3.1.3 Cobalt

Following the replacement of the water-cooled block of porous tungsten[4] which resulted in 30 radioactive resin tanks in the Proton Area, tests were made to see if the long half-life radionuclides were still present. They were present at much lower levels. In addition, there have been no regenerations of these resins since the ten least radioactive tanks were regenerated around the beginning of

CY-1977. To date only a trace of long half-life ^{60}Co has been detected in the silt where water is surfacing at the end of the CUB perforated pipe field (0.2 pCi/g).

3.3.2 Soil Activation

Since the percolation rates for water in Fermilab soils are calculated to be very low - less than 1 m (3 ft) per year[15] - 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, quantitative measurements were made only on those.[12] The results have been presented elsewhere.[4,16]

In CY-1977 excavations were made in the soil near the Transfer Hall (Fig. 3) and near Enclosure 100 (Fig. 4). A tunnel was constructed connecting the Transfer Hall, where the protons are extracted from the accelerator, with Enclosure B, the next enclosure along the path the protons take to the experimental area. Leaching of a sample of the most radioactive soil from the excavation gave a tritium concentration of 300 pCi/mℓ compared to 210 pCi/mℓ from the

most radioactive boring hole sealed sample[4] retrieved just before the excavation destroyed the boring hole 0.76 m from the Transfer Hall wall. The Concentration Guide for consumption by the general population is 1000 pCi/mℓ for tritium. There was no evidence found for percolation of water through this region. The radioactive soil from the excavation was transferred to a portion of the excavation above and to the west of the Transfer Hall and covered with nonradioactive soil.

At Enclosure 100 a new spur train tunnel was constructed for transferring the highly radioactive dumps from the Enclosure 100 Upstream Dump Box to the Target Service Building (approximately from N2 to N1 in Fig. 3). The radioactive soil from the vicinity of the dumps was placed back in the excavation after the tunnel was completed. As at the Transfer Hall, the leaching of a sample from the excavation gave no evidence for percolation.

A portion of the impervious membrane[16] had to be cut in order to construct the tunnel. A connection was made to the old section and a new region of impervious membrane was constructed in the vicinity of the tunnel. Inspection of the old section of impervious membrane showed evidence for separation of the plies. The center ply of green plastic was visible at many places along the cut. Since there are three underdrains below this section, as

well as the drain above, these should collect any water percolating down through the soil at this point. The sump collecting water from these underdrains is N2 (Fig. 4). The peak tritium concentration seen there in CY-1977 was 4.7×10^{-5} μCi/mℓ or only five percent of the Concentration Guide for consumption by the general population.

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. 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 704,000 ℓ/day (186,000 gal/day).

3.4.2 Test for Pollutants in Water Leaving the Site

Tests for pollutants in water leaving the site have been conducted 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. 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 from monthly to a

semi-annual frequency and on coliform were continued on a monthly basis. The test results for CY-1977 are presented in Table 4, and sampling locations listed in Table 4 are shown in Fig. 3.

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

The Central Laboratory's sewage plant exceeded its maximum limits eleven times on BOD5 (limit 10 mg/ℓ), nine times on suspended solids (12 mg/ℓ) and two times on residual chlorine (.2 to .75 mg/ℓ). The Village Lagoon exceeded its maximum limits once on suspended solids and four times on residual chlorine. The results for all other measurements were in compliance with the limit. Maximum values are given in Table 4 for other water quality parameters which are measured in sewage plant effluents and on-site creek waters. The effluent from the Village sewage lagoon flows into Ferry Creek. The effluent from the Central Laboratory's sewage plant is reused for cooling the main ring.

Due to the occasional excess flow into the main sewage treatment plant from infiltration of rain water, it has been necessary occasionally during CY-1977 to pump untreated sewage into our 115,000 ℓ (30,000 gal) reservior. However, when the influx exceeded the reservoir's capacity, the diluted untreated sewage was redirected into our

Table 4

SITE WIDE WATER QUALITY REPORT FOR CY-1977

	pH	BOD5 mg/ℓ	Susp. Solids mg/ℓ	Chlorine Residual mg/ℓ	Fecal Coliform # per 100 mℓ
Ferry Creek	Max. 8 Ave. 8 Min. 8	10.9 9.8 9.4	25 23 20		200 45 0
Indian Creek	Max. 7.7 Ave. 7.7 Min. 7.6	2.3 1.6 1	3 3 3		200 51 0
Kress Creek	Max. 8.3 Ave. 8.2 Min. 8.2	10.8 10.7 10.7	18 11 3		160 76 0
Main Ring	Max. 8.7 Ave. 8.5 Min. 8.3				70 15 0
Central Lab. Sewage	Max. 7.9 Ave. 7.7 Min. 7.4	7.0 7.2 1.6	93 8 3	.75 .54 0	30 4 0
Village Sewage Lagoon	Max. 9 Ave. 8.3 Min. 7.7	17.2 5.6 1.9	49 12 3	.75 .52 .1	36 3 0

chlorine contact tank for chlorination and then discharged into Indian Creek. A dam built in the creek diverted the effluent to a pump station near the RF Building where it was discharged into the main ring cooling system. This dam and pump station have been in operation throughout CY-1977 and are designed to keep the effluent from the Central Laboratory's sanitary plant on site for reuse.

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, ring seals have been resealed and sanitary pipes were replaced between two manholes.

3.4.3 Chemical Treatment of Water Systems

Some chemical treatment of our water system was necessary during CY-1977, however, to reduce algae and weed growth and to inhibit corrosion.

3.4.3.1 Copper Sulfate and Diquat

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 main ring ponds. The State of Illinois EPA Standard for total copper in effluent is 1 mg/ℓ (Section 4 below). This type of weed control was used on the main ring water bodies only since they are off limits to the public and fishing is not allowed.

3.4.3.2 Aquazine

The new pond system, comprised of the newly excavated West Pond which is located west of the Central Laboratory, the Swan Lake and the Booster Pond (Fig. 1 plus H5 and H1 in Fig. 3), was treated once with the Ciba Geigy's Aquazine for weed and algae control. It is non-toxic as per EPA Registration No. 100-437.

In addition, Aquazine was used once to treat the VIllage Lagoon (H3 in Fig. 3) and the two reflecting ponds north of the Central Laboratory.

3.4.3.3 Chromate

In CY-1977 the cooling water for the Central Utility Plant was provided from January 1 to April 8 and from November 14 to the end of CY-1977 by the new cooling pond system. During the remaining time, from April 9 to November 13, while the cooling pond system was modified, the cooling towers were in operation.

Chromium compounds continue to be used 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 Utility 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 3.57 mg/ℓ or about twelve 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 5.

3.4.4 Other Applications of Pesticides

Few changes were made for CY-1977 in the Fermilab pest control plan.[17] A total of approximately 3 kg (6 lbs) of a pesticide called ABATE was used to kill mosquito larvae in CY-1977. Also, approximately 7 kg (15 lbs) of Malathion was used to kill adult mosquitos. Use of Dursban 2E has been dropped. The amount of Pramitol for killing weeds and grasses at power stations and in parking lots was approximately 180 kg (400 lbs) as proposed.

Table 5

ON-SITE QUARTERLY TEST

FOR HEAVY METALS IN WATER, CY-1977

LOCATION (Fig. 3)	AVERAGE CONCENTRATION (mg/ℓ)		
	Hexavalent Chromium	Copper	Zinc
CUB Perforated Pipe Field	3.570	.406	1.21
C4 Pond at H6	<.010	.023	.008
C4 Main Ring Pond at H2C	.027	.008	.011
Lake Law at H8	<.010	<.001	.011
Lake Law at H9	<.010	.001	.008
Ephemeral Lake at R1	<.010	<.001	.010
Ephemeral Lake at H10	<.010	<.001	.010
Swan Lake at H5	<.010	.001	.010
Casey's Pond at H4	<.010	<.001	.010
Well 17A	<.010	<.001	1.2
Well 20	<.010	.007	.007
Well 43	<.010	<.001	.051
Well 45	<.010	-	-
Well 55	<.010	.005	.002
Well 56	<.010	<.001	.423
Well 1	<.010	<.001	.810
Well 21	<.010	.006	.006
Village Sewage Lagoon at H3	-	.073	-

To maintain good relationships with neighboring farmers and voluntarily comply with local week commission requests, noxious weeds, primarily Canadian and sow thistle, have been controlled. In 1977 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 and Diazinon to kill larvae and some spot application of Piperonyl, Butoxide and Pyrethin to kill adult household pests such as flies and wasps was required in CY-1977. In addition, Prelin, Diphacin and Wafarin were used in bait to kill mice and rats in buildings not occupied by children in CY-1977.

Corn was planted on approximately 25% of the site by licensees who agreed to apply only herbicides and fertilizers on an approved list compiled for the Laboratory by an outside consultant. In addition, the rate of application and total amounts applied had to be approved before application, and these were checked at the time of application by Fermilab.

3.5 Environmental Impact

3.5.1 Assessment of Potential Radiation 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 7 based on the 1970 census.[18] 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 dose rates at the site boundary were highest from radioactive materials in temporary storage at the Boneyard and from penetrating muons, resulting in large contributions to the total off-site potential dose. 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.[19] The site boundary closest to the Boneyard is to the north, where the 30 percent increase is also applicable. The population distribution obtained from the 1970 census was used to evaluate the potential exposure to the public for CY-1977 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-1977 was about 1 man-rem.

Approximately 0.5 man-rem was from muons and 0.2 man-rem from gamma rays. The latter was determined using the site boundary dose rate, the rate of decrease given in Section 3.1 and the fact that the closest occupants live 750 m from the source. Airborne releases continue to give low exposures both on and off site as expected. The off-site exposure was approximately 0.5 man-rem from airborne releases in CY-1977. The exposures are given in detail in Table 6.

The exposure from muons 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 (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 7. The region that was considered contained approximately 100,000 people. The exposure from radioactive waste materials temporarily stored at the Boneyard was determined in a manner similar to that for muons with two exceptions. First, the source is isotropic so all directions had to be considered. The second exception was a rate of decrease much faster than inversely as the square of the distance because the gamma ray spectrum was far less penetrating. The dose resulted from air-scattered radiation or "skyshine" because the population was shielded against direct line-of-flight exposure from

Table 6

Summary of Population Exposures for CY-1977

Source	Contribution to Population Exposures (man-rem)
Penetrating Muons From Neutrino Area	0.5
Airborne Radioactivity From Neutrino Area	0.5
Gamma Rays From Boneyard	< 0.1
Gamma Rays From Lab 7*	0.2
Total man-rems	< 1.3

*On-site exposure to individual members of the general population assuming 24 hour per day occupancy.

Table 7

INCREMENTAL POPULATION DATA IN VICINTY OF FERMILAB, 1970

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

the most radioactive components by an earth berm or concrete or both.

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 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.

A trace amount of tritium reported in one of 40 samples of water from on-site wells pumped in CY-1977. This well (W5 in Fig. 3) was sampled in late 1977. The tritium concentration reported was $(5\pm2) \times 10^{-6}$ μCi/mℓ. Our detection limit is 3×10^{-6} μCi/mℓ (Table 8). The well at Site 5 is near the sector of the main ring where the proton beam is dumped when some problem occurs during the acceleration cycle. However, the amount of soil activation at that point would not lead us to expect any tritium in the well water. More samples will be taken in CY-1978.

Thus, the potential radiation dose to the public from the operation of Fermilab in CY-1977 remained small.

3.5.2 Evaluation of Nonradioactive Pollutant Releases

Some chemical treatment of our water system was necessary during CY-1977, 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. An average chromate concentration about 12 times the State of Illinois Water Pollution Standard for effluent release (Table 5) was found in the waters welling up to the surface in the Central Utilities Building 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 eliminate chromates (and zinc). For five months in CY-1977 this ponding system replaced the cooling towers. This reduced the amount of chromates released into the CUB perforated pipe field. Also, on August 26, just when chromates in high concentration were being added to the cooling

tower water, a broken line with a hexavalent chromium concentration of 15 mg/ℓ was discovered. Discharge water was going into the main ring pond instead of the perforated pipe field. The break was fixed the next day without causing an environmental problem.

Two other releases of nonradioactive pollutants occurred in CY-1977. A leak of about 10,000 ℓ (3000 gal) of water containing ethylene glycol as an anti-freeze (near W49 in Fig. 3) and an oil spill (near W66 in Fig. 3) of approximately 300 ℓ (79 gal) were discovered in the Neutrino Area. The ethylene glycol disappeared into the soil, and the oil was cleaned up by Fermilab employees without any particular environmental impact.

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 DOE

Manual, 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 8. 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 tritium the Concentration Guide from Table II, Column 1, is 2×10^{-7} μCi/mℓ. For ^{11}C the Concentration Guide, 5.8×10^{-7} μCi/mℓ, 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 the DOE Manual, Chapter 0524, Paragraph II.A. The annual dose for whole-body exposure is 0.5 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

Table 8

SPECIFICATIONS FOR THE ANALYSES

OF RADIONUCLIDES IN WATER

RADIONUCLIDE	CONCENTRATION GUIDE FOR POPULATION Individual (μCi/ml)	CONCENTRATION GUIDE FOR POPULATION 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.

1971

at the discharge point and for general water quality are 0.3 and 0.05 mg/ℓ respectively. The Standards for total copper are 1.0 and 0.02 mg/ℓ respectively, and for zinc are both 1.0 mg/ℓ for surface water and 5.0mg/ℓ for well water. The Air Quality Standards limit the releases of SO_2 oxides of nitrogen to 816 g (1.8 lbs) and 136 g (0.3 lbs) respectively, per 252 million calories (per million btu's) of actual heat input in any one hour.

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