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

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Environmental Monitoring Report

For Calendar Year 1981

May 1, 1982

Samuel I. Baker

Operated by Universities Research Association Inc.
Under Contract with the United States Department of Energy

Fermi National Accelerator Laboratory
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ENVIRONMENTAL MONITORING REPORT
For Calendar Year 1981

by
Samuel I. Baker
May 1, 1982

Laboratory Work
by
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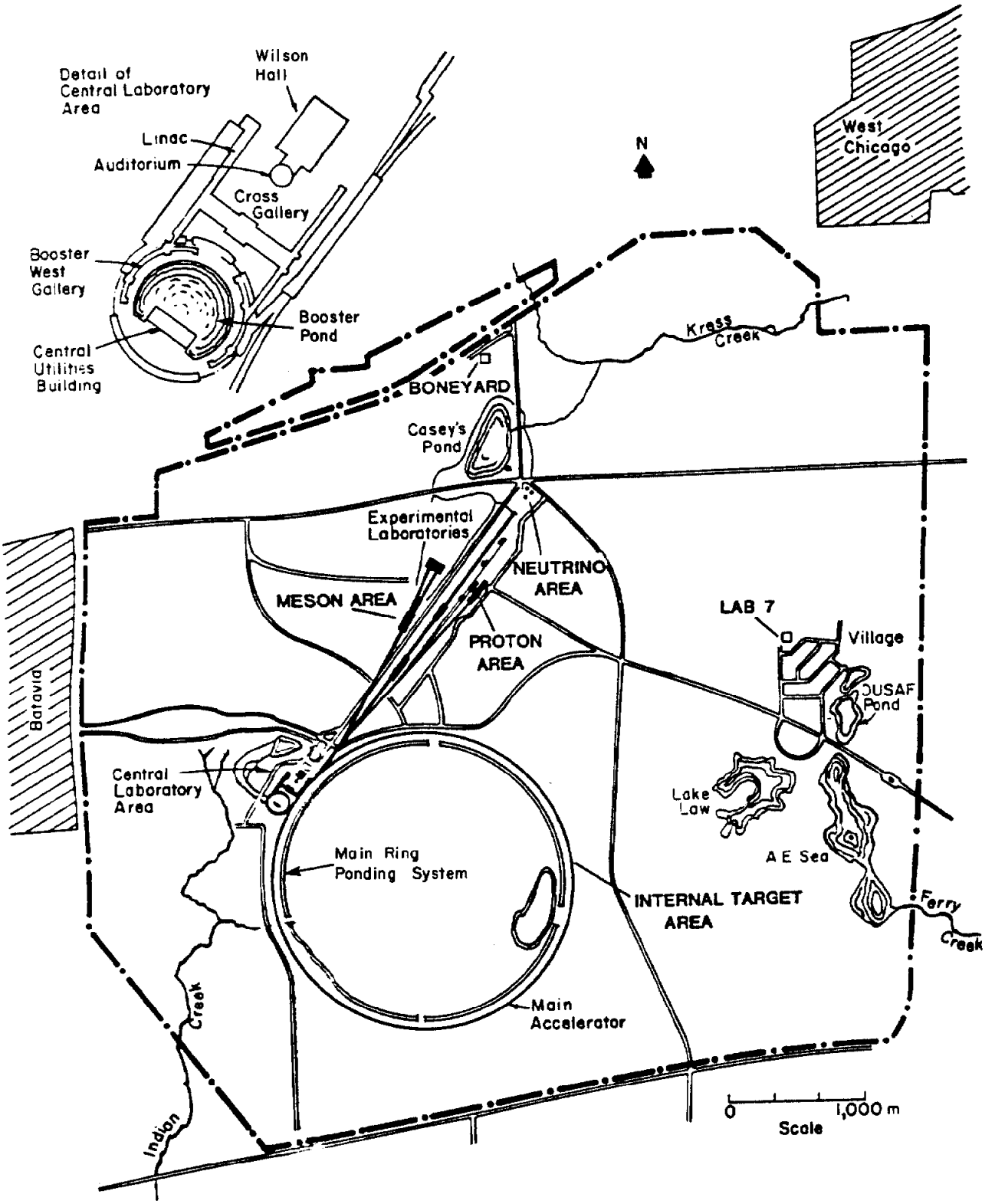
1. Introduction

This report gives the results of the environmental monitoring program at Fermi National Accelerator Laboratory (Fermilab) for Calendar Year (CY-) 1981. The Fermilab Facility is a proton synchrotron with an original design energy of 200 GeV (billion electron volts). As a result of accelerator improvements, protons were accelerated to an energy of 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 the interaction of 66 MeV protons from the second stage of the accelerator. A major program is in progress to construct, install, and operate a ring of superconducting magnets. The goal is to produce higher energy protons using less electrical power.

The proton beam extracted for high energy physics from the 2 km (1.2 mi) diameter main accelerator is taken to three different experimental areas on site (Meson, Neutrino and Proton Areas in 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.

Figure 1. - Fermilab Site



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Operation of the accelerator produces some radiation which penetrates the shielding material as well as some airborne radioactivity. Also, some radioactivation occurs in the soil and in the water used to cool radioactive components. Since the Fermilab site is open to the public, this free access necessitates a thorough evaluation of the on-site discharges as well as the potential for off-site releases of radioactive effluents. Thus, an extensive monitoring program tailored to these needs is being carried out.

The Fermilab environmental radiological monitoring program follows, in general, the guidance given in the Department of Energy (DOE) report A Guide for Environmental Radiological Surveillance at DOE Installations.[1] This includes adherence to the standards given in DOE orders, in particular, DOE Order 5480.1, Chapter XI, which pertains to permissible doses and concentration guides, and gives guidance on maintaining exposures to as low as reasonably achievable (ALARA).[2]

The emphasis has been placed on exposure pathways appropriate to high energy physics laboratories. These pathways include external exposure from direct penetrating radiation and airborne short-lived ^{11}C, and internal exposure from ^{3}H and ^{22}Na in water, primarily drinking water. There is one unique characteristic at Fermilab which

requires consideration and that is the use of large volumes of sand and gravel in two locations to assist in stopping the high energy protons and secondary particles. Although the ground water beneath these two areas is protected by membranes impervious to water and by underdrain systems to collect the water, monitoring is necessary.

Monitoring results are also reported for nonradioactive pollutants. Included as pollutants are pesticides used in weed, insect, rodent, and algae control. Also, another pollutant, a corrosion inhibitor containing zinc and chromium (as chromate), was formerly used in one of the water systems. Discharge underground and subsequent surfacing required monitoring. Although the use of chromate has been discontinued, monitoring for chromate has continued in CY-1981. The CY-1981 result is reported as well as those from monitoring the performance of the sewage treatment plant on site. Discharges of suspended solids from this plant have sometimes exceeded permit limits.

Fermilab is located in the greater Chicago area (Fig. 2) on a 27.5 km^2 (10.6 mi^2) 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.

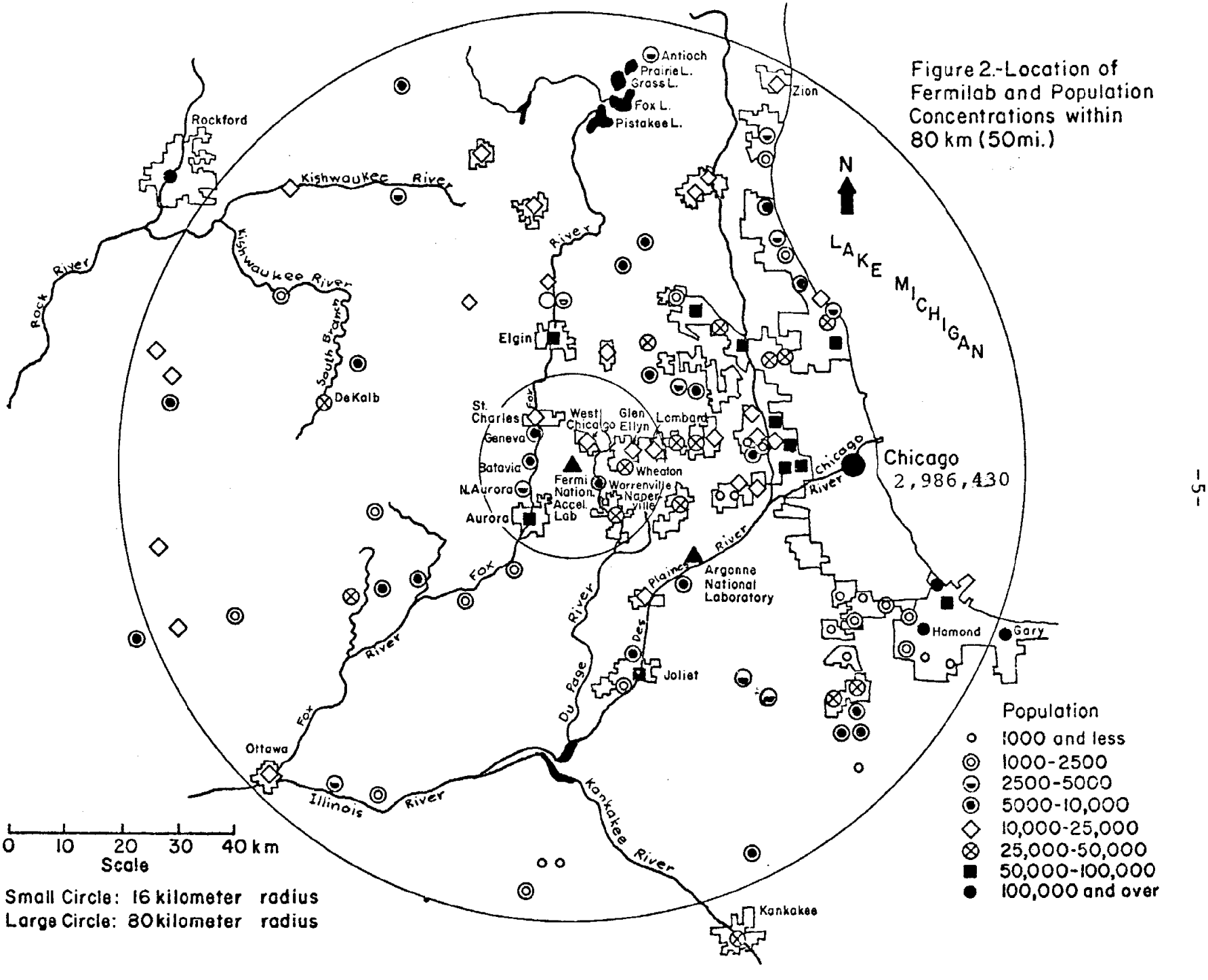


Figure 2.-Location of Fermilab and Population Concentrations within 80 km (50mi.)

(47)

Within a 3 km (2 mi) distance from the Laboratory boundaries, Batavia (pop. 12,169*), Warrenville (pop. 7,185*), and West Chicago (pop. 12,444*) can be found.

The two major environmental features near the Laboratory are the Fox River to the west, which flows south through Batavia with an average of 1900 million liters (500 million gallons) per day, and the west branch of the DuPage River which passes east of the site flowing south with an average of 265 million liters (70 million gallons) per day through Warrenville. The rainfall on site during 1981 was 91 cm (36 in).[3] The land on the site is relatively flat with a high area, elevation 244 m (800 ft) above mean sea level (MSL), near the western boundary and low point, elevation 218 m (715 ft), above MSL, 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 360 m (1200 ft) deep into the Cambrian/Ordovician aquifer system.[4]

*1980 U. S. Census; Preliminary Report PHC 80-P-15

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). The mean wind speed from 1976-1980 was 3.6 m/sec (8.1 mi/hr).[5] The direction is quite variable with the observation of more southwesterly winds than from any other direction. In CY-1981 the mean wind speed was 3.8 m/sec (8.6 mi/hr).[5] Fermilab is about 30 km (19 mi) from ANL and the terrain between them is relatively flat. From April 1979 until April 1980 a meteorological tower was in operation at the northeast corner of the Fermilab site.[6] Wind speeds determined using an anemometer mounted on this tower were in good agreement with those obtained at ANL. However, wind directions averaged over one hour were within 40^{o} only about half the time.

Although the Laboratory is open to the public, no hunting is permitted on the site. Fishing is permitted in all lakes and ponds except the Booster Pond and Main Ring ponding system (Fig. 1) where access is restricted because of electrical and mechanical safety considerations. A large number of other recreational activities, such as hiking, baseball, and other sports, is permitted.

Earth shielding has been used to eliminate the radiation hazards in most places. Fences and interlocked enclosures are in place where access still needs to be controlled.

2. Summary

The accelerator operated routinely at 400 GeV during CY-1981 with about the same number of protons accelerated during CY-1981 as in CY-1980.[7] The total number of protons accelerated in 1981 was 1.4×10^{19}. This total is lower than the average of 2.0×10^{19} for the preceding five years. The lower total was the result of an extended shutdown from June 1 until the end of the year for construction and because of a shortage of operating funds. Typical operation was at about 45 percent of the design intensity of 5×10^{13} protons per acceleration cycle. Thus, environmental monitoring in CY-1981 was done under operation conditions not grossly different from those in the past and those expected in the future.

During CY-1981 there were no abnormal occurrences which had an impact on the facility and its operation. Chromate corrosion inhibitors, which were used in the past in water treatment systems and have a potential for environmental pollution, were not used this year. Copper sulfate was used this year to control algae and weed growth in ditches and is suspected of causing the death of three birds. Spraying for noxious weeds with 2,4D was not done this year. Last year 0.24 km^2 (60 acres) was sprayed. In the past as much as 10 km^2 (2500 acres) was sprayed with 2,4D.

The maximum potential radiation exposure at the site boundary during CY-1981 (fence line assuming 24 hr/day occupancy) was 1.8 mrem compared to 0.3 mrem last year. This dose would correspond to 0.4 percent of the standard of 500 mrem for an individual who is not a radiation worker (Section 5).

The total potential radiation exposure to the general off-site population from Fermilab operations during CY-1981 was 11 person-rem compared to 1 person-rem last year. The increase in potential exposure occurred as a result of the off-site neutron dose this year. All exposure was from external radiation, as was the case in the past. Thus, the 50 year dose commitment from operations in 1981 is expected to be the same as the exposure received in 1981.

Airborne radioactivity was released across the site boundary in small amounts throughout the year from the stack ventilating a Neutrino Area enclosure where the proton beam strikes a target. The radioactive gas was primarily ^{11}C, total quantity released was 1.45 kCi, and the maximum dose at the site boundary was 0.3 mrem for 1981. The average concentration at site boundary based on measurements at the stack was 0.06 percent of the Concentration Guide (Sections 3.2 and 5). There was also a controlled release of tritium in tritiated water evaporated as a means of

disposal for the first time at Fermilab in CY-1981. The total quantity released to the atmosphere was 420 mCi. The concentration at the site boundary was less than 0.01 percent of the Concentration Guide (Sections 3.2 and 4), resulting in a negligible off-site exposure. The off-site release of tritium in surface water totaled approximately 650 mCi, about twice last year's release, primarily because the average concentration in water from one sump discharging in the Neutrino Area (which contributes most of the tritium) was about twice as high this year.

3. Monitoring, Data Collection, Analyses, and Evaluation

The three types of accelerator-produced radiation requiring 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 much less attention to date. The decision on what to monitor is based on the type of operation, radionuclides released, potential hazard, 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-1981 there were approximately 120 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.[8] Seven detectors were used primarily for environmental radiation monitoring. Five were large volume, 110 liter, ionization chambers for gamma-ray and charged particle detection. Three of the five were located in the Neutrino Area (Fig. 3), one was at the Boneyard (Fig. 1), and one was at Lab 7 (Fig. 1). The remaining two detectors were large scintillation counters. One of these is located near the site boundary (Environmental Monitoring Station in Fig. 4). The other is used near the experimental areas (W43 in Fig. 4) to detect ^{11}C in the Neutrino Area radioactive gas releases.

The Mobile Environmental Radiation Laboratory (MERL) was used for determining the exposure levels at the site boundary and for locating the sources of penetrating radiation such as muons and neutrons.[7,9,10,11] The MERL is a four-wheel-drive vehicle equipped with two 20 cm x 20 cm (8 in x 8 in) scintillation counters, one approximately 15 cm (6 in) behind the other, for muon detection. It also has a dePangher "long counter" for neutron detection.[12]

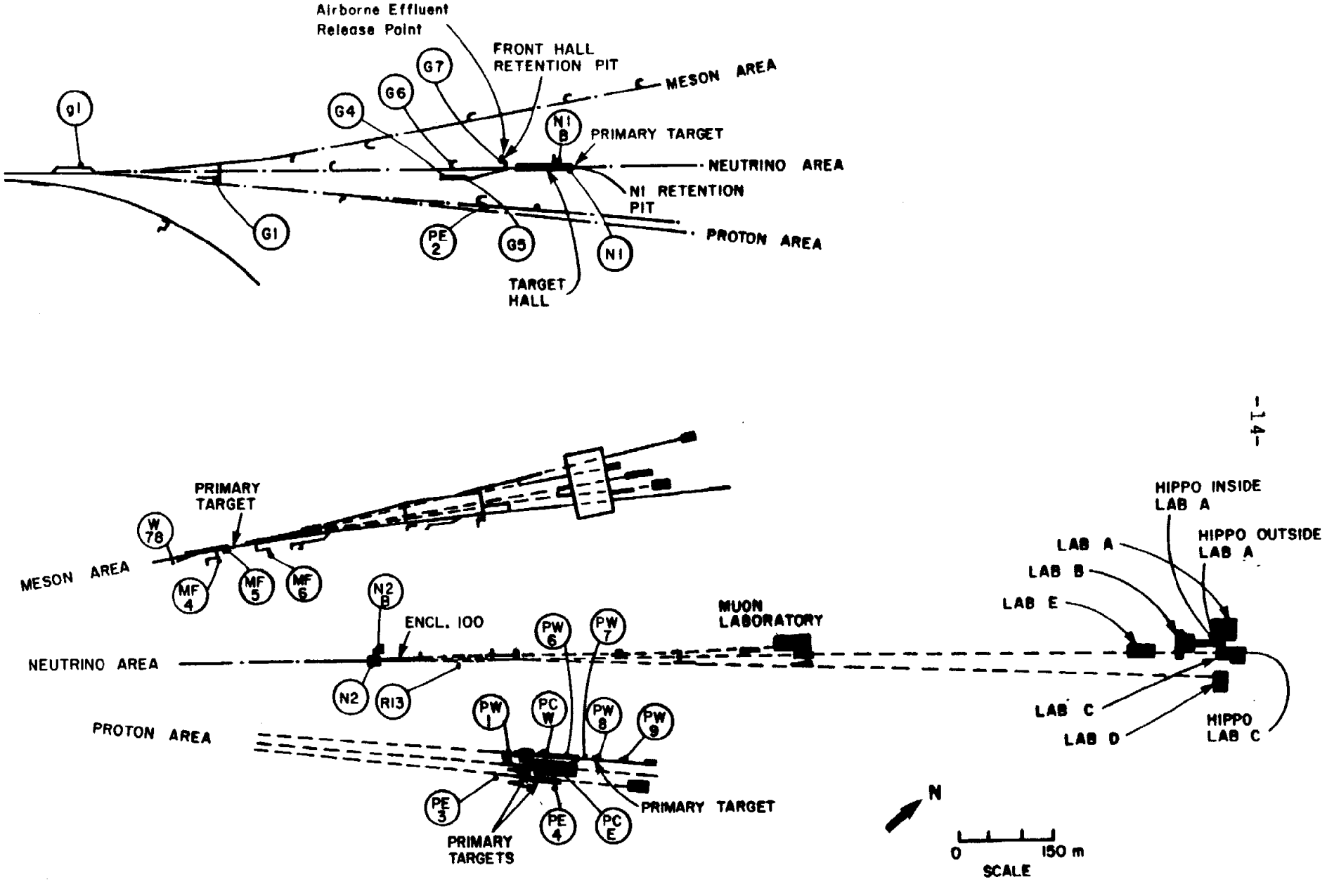
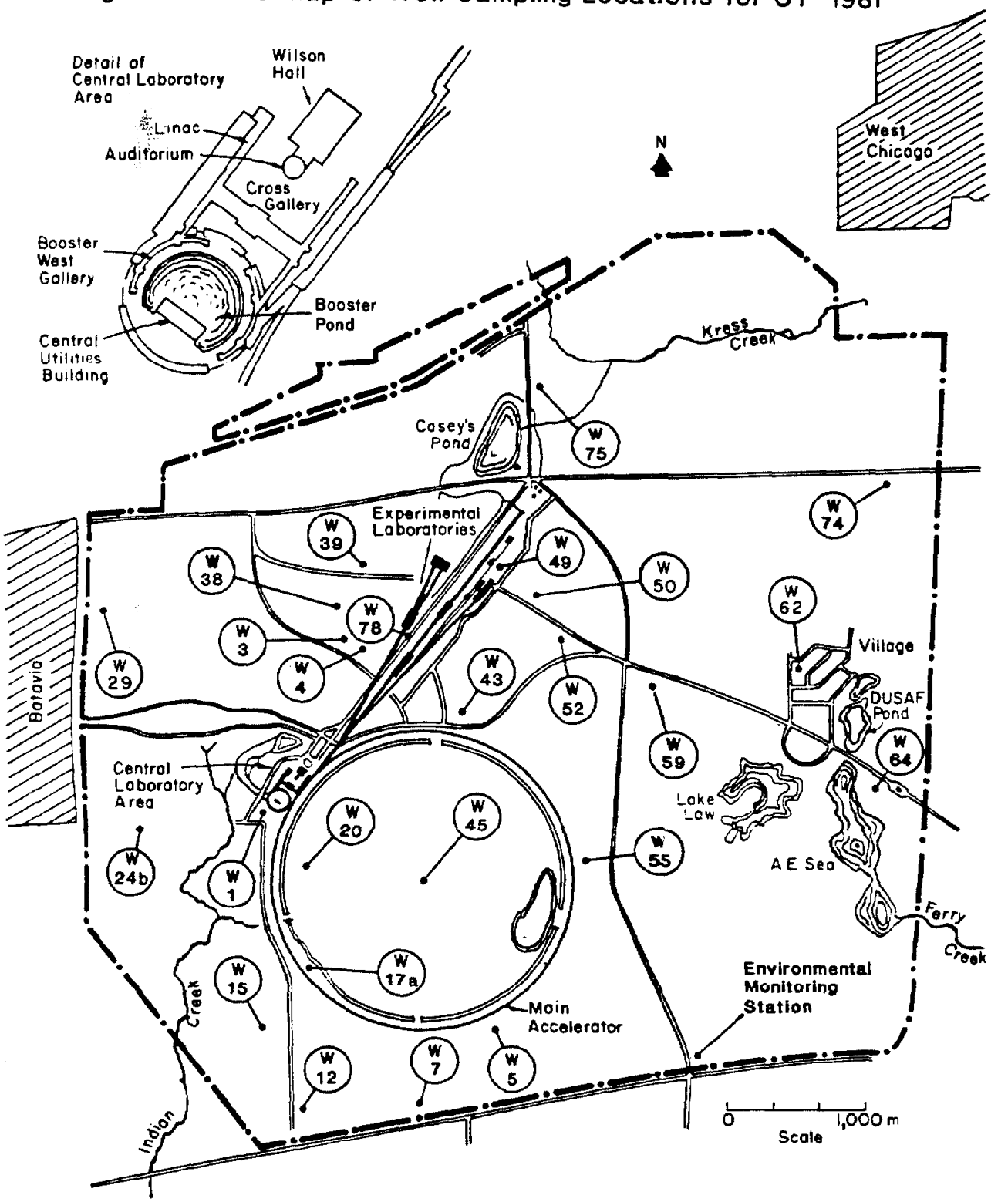


Figure 3. Sampling Locations In External Experimental Areas

Figure 4.- Site Map of Well Sampling Locations for CY-1981



W-62 Formerly V (Village Well)

1981

3.1.1 Muons

Coincidence electronics associated with the scintillation counters in the MERL was used to determine the direction and radiation levels of the penetrating radiation (muons). Information on the expected arrival time and intensity of the particles, based on the accelerator operation, was sent to MERL via transmitter to aid in the measurements. 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 and the natural background subtracted to determine the annual dose at the site boundary. Muons from the Neutrino Area in CY-1981 resulted in negligible exposures, primarily because the Muon Laboratory was not in operation.

Measurements of muons from the Proton Area (Fig. 3) which were made in CY-1980 with 350 GeV protons were repeated in CY-1981 with 400 GeV protons.[11] Measurements were made both on and off the site, and yielded a maximum fence line dose rate which would correspond to an annual dose of 1.1 mrem for CY-1981 based on 24 hour per day occupancy.

Measurements were also made for the Meson and Neutrino Areas. These muons did not expose the same people as those from the Proton Area. Muons from a given area typically were spread over one or two hundred meters at the site boundary. Fence line annual maximum doses for CY-1981 were 0.2 mrem for the Meson Area and negligible for the Neutrino Area, based on 24 hour per day occupancy.

3.1.2 Neutrons

Neutrons penetrated the shielding in the most easterly of the external experimental areas (Proton East) in the vicinity of the primary target (Fig. 3) in the Proton Area in CY-1981. The fence line maximum dose at the site boundary from these neutrons was 0.4 mrem for CY-1981, based on 24 hour per day occupancy. On-site exposures were kept low by fencing the areas having measurable dose rates and excluding the public from these areas. The neutrons originated in a secondary beam dump used to stop high energy neutral particles. The latter were obtained from the primary target and used to produce electromagnetic radiation for a particular experiment.

3.1.3 Gamma Rays

In May 1977 E G & G, Inc., under Energy Research and Development Administration (now U. S. Department of Energy) contract, conducted an aerial radiological survey of Fermilab and surrounding area.[13] 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 the 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 results indicated three areas where radiation was significantly higher than natural background.[7] All three of these were locations where radioactive materials were stored. One of these, the Fitzgerald Barn, has been razed and the material moved to the Lundy Barn just south of the Boneyard (Fig. 1). The Lundy Barn was constructed of shielding blocks, hence it reduced the environmental radiation levels. The second of the three areas is Lab 7 in the Village (Fig. 1).

Most of the radioactive material has been removed from Lab 7 and sent off site for burial. Dose rates in all nearby occupied houses have now been reduced to background levels.[7]

The third of the three areas detected during the aerial survey is the primary radioactive waste disposal storage area on site - the Boneyard. As shown in Fig. 1, this area lies close to the site boundary. On the north side there is an earth berm to prevent any direct radiation from leaving the site. Since the survey, shielding has been added above and on all sides of those radioactive materials which would produce high radiation levels without shielding. This was done to protect Fermilab workers as well as reduce the off-site dose. The items responsible for most of the site boundary dose rate were disposed of in an approved off-site burial ground in late CY-1979. Radiation levels at the site boundary closest to the Boneyard were at background levels in CY-1981.

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.

Radioactive gas, primarily ^{11}C, was produced by interaction of secondary particles with air. Monitoring was carried out by detecting the beta particles emitted in the radioactive ^{11}C decay. A release of 1.45 kCi occurred from the labyrinth stack (Airborne Effluent Release Point in Fig. 3) in the Neutrino Area during 1981. From measurements made at the stack and calculations based on a Gaussian plume diffusion model,[14] the expected dose at the site boundary for 1981 was 0.3 mrem, which corresponds to 0.06 percent of the applicable Concentration Guide[15] (Section 5).

The Meson Area Target Box ventilation system was changed to a flow-through system using air instead of helium during the latter part of CY-1980. The air flow was in large volumes compared to the volumes of helium used in the past few years. The air was vented into the enclosure rather than being released directly to the atmosphere through a small diameter stack. These changes have resulted in reduction of tritium concentrations to levels too low to

measure by the techniques used in the past. The tritium concentration at the site boundary was negligible (as was the case in the past).[7]

A debonding oven was placed in operation in CY-1979 (near W43 in Fig. 4). Its purpose is to debond magnets by decomposing the epoxy adhesives at high temperatures. Most of these magnets are radioactive, having failed during accelerator operations. The gaseous effluent was measured during the acceptance test on June 8, 1979 conducted for the Illinois EPA and contained only ^{3}H at very low levels. The test utilized a typical 6 m (20 ft) long magnet reading 0.8 mrem/hr at 0.3 m (1 ft) from the surface and 8 mrem/hr in the bore tube where the protons traveled. The total amount of ^{3}H released from this magnet was 160 μCi at a stack concentration of 1.3×10^{-8} μCi/mℓ or about 20 percent of the Concentration Guide (Section 5) corresponding to 500 mrem per year. The stack is approximately 10 m (30 ft) high. Using the Gaussian plume diffusion model[14] with neutral wind conditions[16] gives a negligible percentage of the applicable Concentration Guide at the site boundary. Thirty magnets were debonded in CY-1981 and the total tritium release from this stack was approximately 5 mCi.

3.3 Waterborne Radioactivity

During accelerator operations, some radioactivation of the soil will occur.[17,18] 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 Fermilab 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 from 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.[17] 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 - 41 Samples

2. Fermilab Water Supplies - Approximately 70 m Deep - 4 Samples

3. Fermilab Deep Well Emergency Supply - 436 m Deep - 1 Sample

Water samples were also collected from sumps, creeks, and rivers. All surface and ground water samples were analyzed by Eberline Instrument Corp., Midwest Facilities, 245 Roosevelt Road, West Chicago, Illinois 60185, during CY-1981. Each monthly shipment included at least one sample containing accelerator-produced radionuclides in known amounts to check the accuracy of the assays. See Section 4.

3.3.1 Water Sample Collection

Water samples collected from wells not in regular use are pumped for a sufficient length of time to insure that the water standing in the pipe has been pumped out before a sample is taken. The water in the pipe could conceivably have been there since the last time a sample was taken. Normally, the pipe volume is pumped several times before sampling. Water samples from sumps, creeks and other

surface waters are normally collected by dipping a bottle well below the surface. Several of the sumps inside normally locked enclosures are sampled by remotely operated peristaltic pumps or the sump pumps themselves.

The water sampling schedule is based on the following rationale:

1. Wells 38/38*, 43, 49, & 78 are sampled quarterly because they are closest to the areas of maximum soil activation (near targets and dumps) and are in the direction the water would flow in the aquifer.

2. Wells 1, 5, 17A, 20, and 45 are sampled semiannually because they are near the accelerator.

3. The other wells are sampled annually because they are near the site boundary or serve as back-ups to the other wells or as drinking water supplies.

*38 and 39 are close to each other and sampled the same region of the aquifer. Each is sampled semiannually. See Figure 4.

4. The one deep well is sampled annually to look for long-term trends or changes in percolation down to that level.

5. The MF5, N1, N2, and PW8 sumps are sampled bimonthly because they are the closest to the areas of maximum soil activation. See Figure 3.

6. The MF4 sump and the N1 Retention Pit are sampled quarterly because the MF4 sump collects water from a region with less activity than that of the MF5 sump (outside the impervious membrane instead of inside) and the N1 Retention Pit does not have a pump in it even though it collects from a region of higher activity than the N1 sump.

7. The other sumps are sampled less frequently with the frequency based on the tritium concentration found there in the past.

8. The creeks are routinely sampled three times a year and Kress Creek is sampled monthly whenever water from the Laboratory flows over the spillway into the creek.

9. Ponds and ditches with a potential for receiving radioactive water are sampled annually.

10. The Fox River and west branch of the DuPage River which receive run-off from Fermilab are sampled annually.

11. The closed loop cooling systems which cool targets and dumps are sampled with a frequency which depends on the level of radioactivity. Operating systems having concentrations greater than 0.01 μCi/mℓ are sampled quarterly. Those having concentrations between 0.001 and 0.01 μCi/mℓ are sampled semiannually. Those between 0.00001 and 0.001 μCi/mℓ are sampled annually.

12. The resin regeneration systems are routinely sampled for analysis by an outside laboratory semiannually. Analyses are performed on site for samples from every regeneration sending radioactive effluent to the CUB tile field inside the Main Ring.

13. Several samples are collected annually to look for radioactivity leached from steel.

3.3.2 Results of Analyses

The Fermilab CY-1981 water sampling locations for detection of accelerator-produced activity are shown in Figs. 3, 4, and 5. No accelerator-produced radionuclides were reported in water samples taken from the three creeks leaving the site (Fig. 5). Five samples were obtained from Kress Creek and four each from Ferry Creek and Indian Creek. River water samples were obtained once during CY-1981 from the Fox River in Aurora and from the west branch of the DuPage River in Warrenville. Neither river is utilized as a drinking water supply. No evidence for accelerator-produced radionuclides was found.

The Village water supply (W62 in Fig. 4) is the Laboratory's only community water supply. Quarterly water samples were collected and a composite analyzed for naturally occurring as well as reactor and accelerator-produced radionuclides in CY-1980. No activity was found using very low detection limits. See Section 5. The same was true for composite samples from Fermilab's other two drinking water systems providing water to more than 25 persons a day. These (W1, with W3 as back-up, and W55 in Fig. 3) supply water to Wilson Hall (formerly called the Central Laboratory) and to the Internal Target Area

(Fig. 1). These drinking water systems received annual routine sampling in CY-1981. No accelerator-produced radionuclides were detected in the 46 samples taken from the on-site wells.

3.3.2.1 Tritium

The results for on-site tritium measurements yielding detectable levels in surface waters (Fig. 3) are given in Table 1. All other sampling points were essentially at background levels (Figs. 3 and 5). The sumps collect waters from around the footings of the buildings and enclosures. This water is considered surface water. Only aquifers are called ground waters. The total off-site release in surface waters was 655 mCi of tritium this year compared with 240 mCi last year. This increase was primarily because surface water from one sump (N1 on Fig. 3) in the experimental area which discharges most of the tritium had an average concentration approximately twice as high in 1981 as in 1980.[7] See Table 2. The release occurred at less than 0.3 percent of the Concentration Guide (Section 5) and made a negligible contribution to the potential off-site dose. Detailed reports of off-site effluent releases and on-site discharges are made via the Department of Energy Effluent and On-Site Discharge Information Systems, EG&G, Idaho, Inc., P.O. Box 1625, Idaho Falls, Idaho 83401.

TABLE 1

Tritium Detected in On-Site Water Samples

Collection Point	Number of Samples	C Max	C Max Error	C Min	C Min Error	C Mean	Percent of Standard
MF4 Sump	11	3.7×10^{-4}	$\pm 3.7 \times 10^{-5}$	6.7×10^{-6}	$\pm 7.0 \times 10^{-7}$	4.8×10^{-5}	1.6
MF5 Sump	5	8.8×10^{-4}	9.0×10^{-5}	5.4×10^{-5}	5.4×10^{-6}	3.3×10^{-4}	11.0
G6 Sump	2	1.2×10^{-5}	1.2×10^{-6}	7.6×10^{-6}	8.0×10^{-7}	9.5×10^{-6}	0.3
G7 Sump	2	8.0×10^{-6}	1.0×10^{-6}	4.0×10^{-6}	5.0×10^{-7}	6.0×10^{-6}	0.2
N1 Sump	8	4.9×10^{-4}	5.0×10^{-5}	$<7.0 \times 10^{-6}$	----	1.2×10^{-4}	4.0
N1B Sump	2	2.8×10^{-5}	3.0×10^{-6}	$<3.0 \times 10^{-6}$	----	1.6×10^{-5}	0.5
N2 Sump	6	1.4×10^{-4}	1.4×10^{-5}	3.0×10^{-5}	3.0×10^{-5}	9.1×10^{-5}	3.0
PE4 Sump	3	2.9×10^{-5}	3.0×10^{-6}	1.2×10^{-5}	1.0×10^{-6}	1.8×10^{-5}	0.6
PW1 Sump	2	4.2×10^{-6}	4.0×10^{-7}	2.8×10^{-6}	4.0×10^{-7}	3.5×10^{-6}	0.1
PCE Sump	3	1.2×10^{-4}	1.2×10^{-5}	7.0×10^{-6}	1.0×10^{-6}	4.6×10^{-5}	1.5
PCW Sump	2	6.4×10^{-6}	6.0×10^{-7}	3.0×10^{-6}	1.0×10^{-6}	4.7×10^{-6}	0.2
PW8 Sump	7	1.1×10^{-5}	6.0×10^{-7}	$<3.0 \times 10^{-6}$	----	5.6×10^{-6}	0.2
PW9 Sump	3	7.0×10^{-6}	5.0×10^{-7}	6.8×10^{-6}	5.0×10^{-7}	6.6×10^{-6}	0.2

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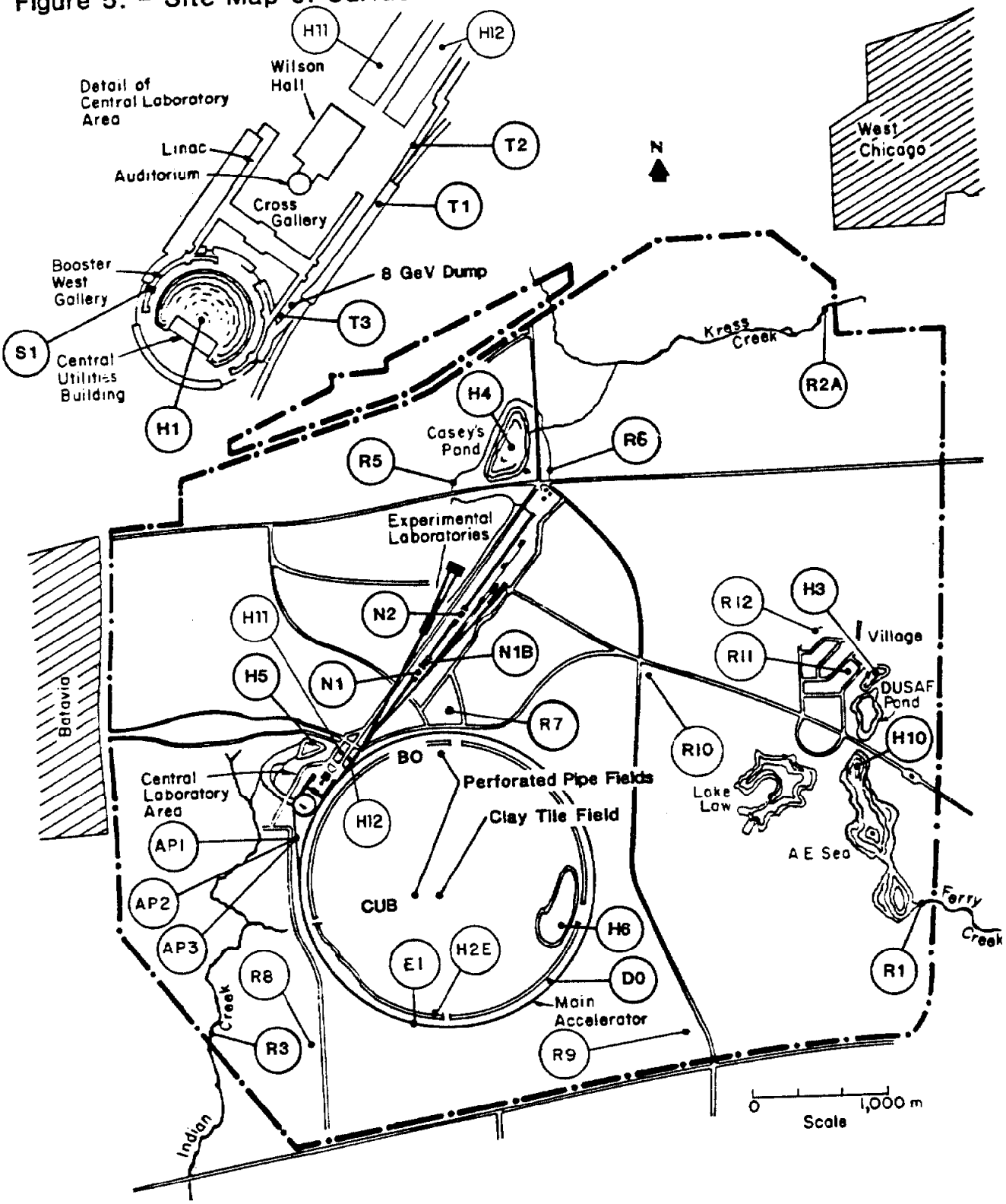
Figure 5. - Site Map of Surface Water Sampling Locations for CY-1981



Legend :

Sumps = S, T, D, E, N, and AP
Ponds = H
Ditches = R

1981

The surface water from the experimental areas flows into Casey's Pond except during wet seasons. Then, the pond fills up and barricades are placed at the two entrances to the pond to keep the water from flooding the pump room. When these barriers, called stop logs, are in place, the water bypasses the pond and leaves the site via Kress Creek. This was the case for half the year in 1981.

The following unplanned tritium release occurred in CY-1981:

1. Radioactive water from the retention pit in the Neutrino Area leaked out of the pit through a crack in its side wall. This water drained into the neighboring sump pit (N1 in Fig. 3). The amount of tritium released to the off-site environment is estimated to be approximately 2 mCi in CY-1981 before the retention pit was properly sealed. The source of this water is believed to be from inside the impervious membrane under the primary target.

3.3.2.2 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 in two separate systems located at the Central Utilities Building (Fig. 5). The ^{7}Be is precipitated out of the Main Ring system regeneration effluent, is allowed to decay until the residue is at a concentration below that permitted for community water systems and is disposed of as industrial process waste. The discharge from the other system, which regenerates resin from the small tanks used throughout the site, is sent to a clay tile field inside the main accelerator (Fig. 5). There it percolates into the soil about 60 cm (2 ft) below the surface. The short half-life of ^{7}Be and its strong chemical affinity with the soil ensure that the release will place no burden on the environment.

The line to the clay tile field was frozen during early CY-1981, resulting in a release of 85 mCi of ^{7}Be to the Booster Pond. This release was at concentrations well below the Concentration Guide even before dilution in the Booster Pond. See Section 5.

A silt sample taken from the Booster Pond showed no ^{7}Be or other radionuclides. See Table 2. The detection limit for ^{7}Be in silt was approximately 1 pCi/g.

A small concentration of ^{7}Be was found in the soil adjacent to the N1 Labyrinth Stack (Fig. 3) where ^{11}C is released. The concentration was (7.3 ± 1.8) pCi/g. A trace amount (0.4 ± 0.1) pCi/g of ^{22}Na was also found there. The source of ^{7}Be is the same as ^{11}C - spallation of air. The source of ^{22}Na is spallation of concrete. The fine dust from deterioration of the concrete is able to pass through the filter on the stack. The low concentrations have not warranted the installation of "absolute" filters.

TABLE 2

Silt Sampling Results for CY-1981

Location	Radionuclides	Concentration (pCi/g)
MF5 Sump Discharge Area	^{7}Be	< 1
	^{22}Na	0.3 ± 0.2
DO Sump Discharge Area	^{7}Be	< 1
	^{22}Na	< 0.1
N2 Sump Discharge Area	^{7}Be	< 1
	^{22}Na	0.9 ± 0.4
N1 Sump Discharge Area	^{7}Be	< 1
	^{22}Na	1.0 ± 0.3
	^{54}Mn	1.8 ± 0.4
	^{60}Co	0.22 ± 0.16
PW8 Sump Discharge Area	^{7}Be	< 1
	^{22}Na	< 0.1
Booster Pond	^{7}Be	< 1
	^{22}Na	< 0.1
G1 Emergency Exit Discharge Area	^{7}Be	< 1
	^{22}Na	< 0.1

3.3.3 Vegetation Sampling

An annual vegetation sampling program was initiated in CY-1978. In CY-1981 a vegetation sample was taken near the ^{11}C exhaust in the Neutrino Area (Fig. 3). A soil sample was also taken near the exhaust. See Section 3.3.2.2. Vegetation samples were taken in the vicinity of discharges from sumps collecting water in areas having the most soil activation. This soil activation resulted from direct interactions of the primary protons or the secondary particles they produce. In addition, a vegetation sample was taken next to the evaporator in the Boneyard where ^{3}H from closed loop systems is disposed of by release to the atmosphere.

The peak concentrations for vegetation sampling are based on the weight of the unprocessed sample. From previous results[7] the radionuclide ^{7}Be is expected to be present as surface contamination while ^{22}Na and ^{60}Co are most likely incorporated into the plants. Vegetation near sump discharges was analyzed for cases where accelerator-produced radionuclides were found in the silt. See Table 2. The results from the analyses of the vegetation samples are given in Table 3.

TABLE 3

Vegetation Sampling Results

Location	Radionuclides	Concentration (pCi/g)
Boneyard	^{3}H	146 ± 15
MF5 Sump Discharge Area	^{7}Be	21 ± 4
	^{22}Na	1.6 ± 0.2
N1 Sump Discharge Area	^{7}Be	68 ± 16
	^{22}Na	2.3 ± 0.4
	^{54}Mn	2.2 ± 0.4
N1 Labyrinth Stack	^{7}Be	88 ± 11
	^{22}Na	0.13 ± 0.11
	^{54}Mn	0.4 ± 0.1
	^{60}Co	< 0.2
N2 Sump Discharge Area	^{7}Be	22 ± 9
	^{22}Na	1.4 ± 0.3
	^{54}Mn	0.2 ± 0.2
T3 Sump Discharge Area (AO Ditch)	^{7}Be	7 ± 4
	^{22}Na	1.5 ± 0.2
	^{54}Mn	2.9 ± 0.3
	^{60}Co	1.4 ± 0.2

3.3.4 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[20] - 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 soil samples were taken 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.[17] The results have been presented elsewhere.[7,20]

In February 1981 water was found in the channel leading to the 8 GeV Dump again following the flooding of the pit where the end of this channel is located.[21] This channel had been welded shut, but there was an improper weld joint which leaked. The system was pumped out after checking that the radioactivity in the water was low enough. The cover was again welded and this time the channel was pressurized and is being kept pressurized to prevent recurrence.

Subsequently a routine radioactivity check of a large waste container detected radioactivity in the ditch next to it. This activity was traced to silt which was inadvertently pumped out with the radioactive water from the bottom of the 8 GeV Dump channel. The peak concentration of the principal long-lived radionuclide, ^{22}Na, was 1400 pCi/g. Since leaching of this silt had already occurred, the radioactivity in the water standing in the ditch was far below the applicable Concentration Guide. See Section 5.

3.4 Nonradioactive Pollutants

3.4.1 Airborne Effluents

A magnet debonding oven in the Industrial Building complex (W43, Fig. 4) was placed in operation in CY-1979, and was used to debond 30 magnets in CY-1981. It consists of an electrically heated oven operating at 450°C (850°F) with a propane fired afterburner operating at $\geq$760°C (1400°F) to assure complete oxidation of all combustion products.

This debonding oven was installed under a construction permit issued by the Illinois Environmental Protection Agency (IEPA). A fully documented acceptance test of emissions, including particulates, NO_x and hydrocarbons, was performed by the Almega Corporation and IEPA has granted an operating permit. The debonding process removes approximately 57 kg (125 lb) of cured bonding epoxy from each magnet.

3.4.2 Water Utilization

3.4.2.1 Domestic Water Supplies

The domestic water supply at Fermilab is essentially provided by two wells pumping from an aquifer approximately 70 m (220 ft) deep. One (W1 in Fig. 4) is located in the

Central Laboratory area and the other (W62 in Fig. 4) supplies the separate Village system. A third well (W3 in Fig. 4) pumps from the same aquifer and supplies water to the Main Site System when demand exceeds the capacity of W1.

These wells have chlorination systems and our water laboratory tests for pH and fecal coliform monthly. The chlorine level in the chlorinated drinking water supplies is tested each work day. Test results conformed to Illinois standards during 1981. Our average use from these wells was approximately 190,000 ℓ/day (50,000 gal/day), down from 1980.

3.4.2.2 Industrial Water Ponding Systems

There are several water systems used for cooling magnets and for fire protection:

The Industrial Cooling Water (ICW) System consists of Casey's Pond (H4 in Fig. 5) at the end of the Neutrino Beam Line and underground mains to fire hydrants and sprinkler systems throughout the Main Site and Wilson Hall. Casey's Pond is supplied by surface drainage and can also be supplied by pumping from the Fox River. The pond, holding 68,000,000 ℓ (18,000,000 gal) is accessible to the public.

The Swan Lake/Booster Pond System (H5 in Fig. 5) is used for cooling purposes at the Central Utilities Building (C.U.B.). Water is pumped from the Booster Pond into a ditch in which it runs by way of a small West Pond into Swan Lake. The water is then returned to the Booster Pond by a return ditch. Water is also pumped from Swan Lake to N1 Service Building for cooling purposes, from which it returns by a surface ditch. This system can be supplied water from the ICW System and it overflows into Indian Creek.

The Main Ring Ponding System consists of a series of interconnecting canals completely encircling the interior of the Main Ring with a large reservoir pond at C4 (H6 in Fig. 5). This water is used in heat exchangers at the Service Buildings for cooling the Main Ring magnets. The system is generally supplied by surface drainage, although make-up water can be pumped from Casey's Pond. The system overflows into Lake Law (Fig. 5). The public is excluded from the area inside the Main Ring, and hence the Main Ring Ponding System, when the accelerator is in operation. The water in these systems normally meets the quality requirements of water in general use in Illinois (Section 5). There was an exception to this during spraying of the Main Ring Ponding System with copper sulfate. See Section 3.4.5.

3.4.2.3 Other Lakes and Ponds

Surface drainage from the eastern portion of the site flows into Lake Law, DUSAF Pond and the AE Sea (Fig. 5). The chlorinated effluent from the Village sewage treatment plant oxidation pond (H3 in Fig. 5) also flows into DUSAF Pond. These lakes and ponds are accessible to the public, and they are the head waters of Ferry Creek.

3.4.2.4 Tests for Pollutants

Semi-annual tests are made of water samples taken where the three creeks leave the site (Fig. 5), as well as from Casey's Pond and the Fox River. Results for 1981 are found in Table 4. Tests for fecal coliform bacteria are made monthly in our water laboratory.

3.4.3 Sewage Treatment

An authorization permit to discharge under the National Pollutant Discharge Elimination System (NPDES) has been obtained for the Village Oxidation Pond (H3 in Fig. 5).[22] Monthly testing results for 1981 are in Table 5.

TABLE 4

Site Wide Water Quality Report for CY-1981

	pH		DO mg/ℓ		BOD5 mg/ℓ		Susp. Solids mg/ℓ		Fecal Coliform mg/ℓ	
	April	Oct.	April	Oct.	April	Oct.	April	Oct.	April	Oct.
Ferry Creek	8.2	*	8.2	*	7.3	*	36	*	0	*
Kress Creek	8.5	7.6	8.0	9.7	4.3	4.9	15	14	114	104
Indian Creek	7.9	7.5	9.1	8.5	.4	3.5	13	46	90	404
Casey's Pond	8.0	7.8	8.4	9.6	0	1.5	57	13	12	26
Fox River	8.5	8.2	9.0	11.4	5.3	5.1	60	36	254	464
General Standards[22]	6.5 - 9.0		Not less than 5.0 at any time		**		**		Mean of 200	

*Inaccessible

**There are standards for effluent from treatment works or waste water sources, but no general standards.

TABLE 5

Village Sewage Treatment Plant

Monthly Averages Report for CY-1981

Parameter	Permit Limit	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
pH		8.1	8.6	8.7	7.8	8.6	8.1	7.9	8.0	7.25	No Release	7.8	7.8
BOD5 mg/ℓ		8.8	8.1	8.2	14.8*	13.8*	8.2	7.7	13.4*	1.8	No Release	6.6	2.4
Suspended Solids mg/ℓ		9.5	47 *	39*	27 *	40*	15*	15.5*	11.5	26.5*	No Release	9	12
Fecal Col. #/100 mℓ		0	0	0	0	0	0	0	Not Sampled **	0	No Release	Not Sampled **	0

* Violation Report Filed
** Retention test in progress when coliform measurements were being made

The Main Site sewer system was hooked into the City of Batavia system June 26, 1979 and has been delivering sewage to the Batavia sewage treatment plant since that time.

The NPDES permit[22] for the Village sewer system was renewed by IEPA in 1979 and the limits for 30 days average BOD5 and suspended solids were reduced from 30 mg/ℓ and 37 mg/ℓ to 10 mg/ℓ and 12 mg/ℓ, respectively. Subject to the limits of the new permit, the Village system exceeded the limits for suspended solids seven times in CY-1981, in spite of treatments with Aquazine to control algae. The high levels early in the year were the result of a television scan and sewer flushing and joint sealing operation. The purpose of this operation was to reduce infiltration of rain water run-off into the sewer system. A 60% reduction resulted. In October 1981, the effluent release was halted for the entire month. The increase in retention time helped reduce the level of suspended solids. See Table 5.

3.4.4 Chemical Treatment of Water Systems

Chemical treatment of our various water systems is required each year to control the growth of algae and aquatic weeds. Only EPA registered agents are administered by trained personnel following the manufacturer's directions.

3.4.4.1 Dalapon

Dalapon was used to treat drainage ditches for control of cattail (*Typha sp.*) growth. Applications were made to ditches in the external experimental areas and along the Main Ring Road inside the main accelerator. A total 329 kg (725 lb) was applied to an estimated 34 km (21 mi) of drainage ditches.

3.4.4.2 Diquat

Diquat was used to treat the Main Ring cooling ponds for control of duckweed (*Lemna minor sp.*). A total of 27 kg (60 lb) was applied to 175,000 ℓ (46,000,000 gal) of water in the ponding system.

3.4.4.3 Chlorine

In addition to the routine chlorination of the domestic water systems, the swimming pool and the Village Oxidation Pond, a chlorination system for the Swan Lake cooling pond system has proved successful in helping to eliminate the need for chromate treatment of the cooling towers. Chlorine is added to the cooling water for a period of 30 minutes four times a day at a rate which results in a chlorine concentration of 0.5 ppm as the cooling water leaves the equipment.

3.4.4.4 Aquazine

As previously mentioned, it was necessary to treat the Village Oxidation Pond to control algae growth and reduce suspended solids. The pond was treated a total of five times in CY-1981, following the manufacturer's application instructions. The quantity of Aquazine used four of the five times was 68 kg (150 lbs). The fifth time the quantity was 102 kg (225 lbs).

Aquazine was also used to treat other ponding systems. See Table 6.

TABLE 6

Use of Aquazine in CY-1981

Location and Designation in Figure 5		Amount Applied (kg)	Amount Applied (lbs)
Village Oxidation Pond	(H3)	374	825
Reflecting Ponds	(H11 and H12)	11	25
Swan Lake	(H5)	111	245
Booster Pond	(H1)	18	40
Casey's Pond Ditch	(R5)	27	60

3.4.5 Heavy Metals and Other Toxic Materials

The continued success of the Swan Lake cooling pond system again made it possible to eliminate the use of chromates in 1981. Although it was necessary to use the cooling towers during the warm summer months, it was not necessary to treat the towers with chromate compounds. The chlorinated Swan Lake cooling pond water was passed through the cooling system and a biodispersant, Nalco 7348, was added which lifted deposits from the metal surfaces so they could be oxidized by the chlorine. The rate of application was 3.6 kg (8 lbs) per day with a peak concentration of 20 mg/ℓ. Nalco 7348 is a polyglycol manufactured by Nalco Chemical Company, 2901 Butterfield Road, Oak Brook, Illinois 60521.

A soil boring was made in the CUB perforated pipe field (Fig. 5), and a soil sample collected between 117 cm (3.5 ft) and 147 cm (4.5 ft) below the surface. This sample was analyzed for hexavalent chromium by Environmental Research Group, Inc., 7303 West 90th Street, Bridgeview, Illinois 60455. None was detected at a detection limit of 0.1 mg/kg. Since the perforated tile is at a higher elevation than the soil sampled, this is an indication that there is no uniform downward movement of chromate toward the aquifer.

The Main Ring cooling ponds were sprayed with 380 kg (840 lbs) of copper sulfate to control algae. This total was applied to 175,000,000 ℓ (46,000,000 gal) of water in the ponding system. This yielded a copper concentration of 1 mg/ℓ, the maximum permitted for discharge. A water sample taken in the pond subsequently yielded a concentration of 0.77 mg/ℓ. These waters are not for general use. The concentration of copper in the mud from the bottom of a pond into which the copper sulfate solution was sprayed showed a variation of concentration. See Table 7. The peak concentration was 109 mg/kg compared to 18 mg/kg in a pond (near W38 in Fig. 5) at Site 38 which had not been sprayed with copper sulfate. All of the samples except the one with 36 mg/kg copper concentration were analyzed by Aqualab, Inc., Route 20 at Valley Lane, Streamwood, Illinois 60103.

The remaining sample was analyzed by Environmental Research Group, Inc.

Analyses were made of oil from 108 additional transformers on site in CY-1981 whose PCB content had not been measured. Fifty-nine were found to contain PCB concentrations greater than 50 mg/ℓ (ppm). The highest concentration reported was 54,173 mg/ℓ (ppm). Most of the samples were collected by the Nardi Electric Company, Inc., 3506 67th Street, Kenosha, Wisconsin 53142 and the analyses performed by T & R Service, Box 197, Coleman, South Dakota 57017.

There were no ethylene glycol spills in CY-1981.

Sampling of silt and run-off water was done in CY-1981 for fields treated with pesticides. The locations sampled were R8, R9, R10, R11, and R12 in Fig. 5. Analyses were made for eight pesticides including 2,4D. Not one of these was detected. The detection limit for 2,4D was 10 ppm and the detection limit for the other pesticides was 100 ppm. The analyses were performed by Gabriel and Associates, 1814 North Marshfield, Chicago, Illinois 60622.

TABLE 7

Copper Concentrations in the A1 Pond Mud

Distance from Dam West Side		Concentration of Copper	Distance from Dam East Side		Concentration of Copper
m	ft	(mg/kg)	m	ft	(mg/kg)
1	3	22 and 36*	1	3	109
15	50	31	15	50	16 and 58**
30	100	96	30	100	15
61	200	20	61	200	29

* Different samples analyzed by different laboratories
**Different samples analyzed by the same laboratory

3.5 Environmental Impact

3.5.1 Assessments of Potential Radiation Dose to the Public

Fermi National Accelerator Laboratory is located in the densely populated Chicago Area. There are about eight million people living within 80 km (50 mi) of the site.[23] There are 328,910 people within 16 km (10 mi) of the center of the main accelerator based on the 1980 census results compared to 265,677 counted in the 1970 census. The detailed distribution of population as a function of distance and direction from Fermilab is given in Table 8.[23]

The dose rate at the site boundary from Fermilab operations was primarily from neutrons leaving the Proton East underground enclosure. The distribution of neutrons was assumed to be isotropic while measurements of muons showed they went in one direction (toward the northeast).

TABLE 8

Incremental Population Data in Vicinity of Fermilab, 1980

DISTANCE, KILOMETERS FROM CENTER OF MAIN RING	LATITUDE = 41.832					LONGITUDE = 88.251			
	0-8	8-16	16-32	32-48	48-64	64-80	80-97	97-113	113-128
DISTANCE, MILES	0-5	5-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80
DIRECTION									
N	450	2388	77247	75658	63188	37183	30696	28459	149892
NNE	2492	5564	68274	76075	120930	145415	100858	173092	87495
NE	8486	11583	78701	292724	139718	0	0	0	0
ENE	2767	55274	263526	840460	551913	0	0	0	0
E	4013	21721	218631	1107254	924752	0	0	33317	56442
ESE	3832	20558	92242	268040	597113	379986	196888	78056	17600
SE	2484	27848	37956	34405	106938	38944	24651	11963	10027
SSE	405	2330	44203	148699	7962	21154	70503	10828	13195
S	2071	2980	8604	10301	17011	11089	6640	4354	11967
SSW	10039	44835	8635	3492	17420	6373	25217	24588	10469
SW	6889	36071	13598	15566	5317	30917	36362	13671	13226
WSW	7829	2698	5578	6322	4509	10930	8474	11704	12175
W	1496	1807	2941	5339	5111	13693	8445	28768	49103
WNW	6890	877	3018	42762	6723	21231	40449	13891	37012
NW	7044	7959	3297	7974	7358	65288	157549	71682	28229
NNW	4073	13157	22722	10674	29830	17952	29399	24276	58430
TOTAL	71260	257650	949171	2945745	2605793	800155	736131	528649	555262
CUMULATIVE TOTAL	71260	328910	1278081	4223826	6829619	7629774	8365905	8894554	9449816

1781

The radiation exposure to the general population from operation of Fermilab in CY-1981 was about 11 person-rem. Approximately 1.5 person-rem was from airborne radioactivity (^{11}C). The exposures are given in Table 9. This is to be compared with a total of approximately one million person-rem to the population within 80 km (50 mi) from natural background radioactivity.[23,24] Radiation from diagnostic x-rays, medical treatments, and other artificial sources accounted for about 500,000 person-rem in CY-1981.[24]

TABLE 9

Summary of Population Exposures for CY-1981
Within an 80 km (50 mi) Radius of Fermilab

Source	Contribution to Population Exposures (person-rem)
Penetrating Radiation from the Proton Area	9.6
Airborne Radioactivity from Neutrino Area	1.5
TOTAL	11.1

Gamma rays from the Boneyard and from Lab 7 made negligible contributions this year.[7,21]

The maximum fence line dose rates at the site boundary were comparable for muons and neutrons. Similarly since the dose rates vary inversely with the square of the distance and the sources are approximately 1600 m (1 mi) from the site boundary, the dose to the maximum individual is approximately the same as the fence line dose. However, since the neutrons are assumed to be distributed isotropically and the muons are known to all travel in approximately the same direction, the dose commitment is much higher for neutrons than for muons. The exposure was 9.2 person-rem from neutrons and only 0.4 person-rem from muons. This neutron exposure is an upper limit since there will be absorption of high energy neutrons in air with an absorption length less than the distance to the site boundary.[25]

The exposure from muons and neutrons 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 mi) from the site using the inverse square of the distance and summing over the appropriate numbers of individuals. For muons the dose was received by individuals living only in a portion of the northeast sector. See Table 8. For neutrons the dose was received by everyone.

The exposure from airborne releases was calculated starting with the 0.3 mrem per year dose rate at the site boundary obtained using the Gaussian plume diffusion model[14,16] and determining dose versus distances out to 80 km (50 mi) from the site including ^{11}C decay. The site boundary dose rate was calculated for a given one of the 16 sectors for which population data was available from the 1980 census. The source term used was the concentration and rate of flow from the Neutrino Area Labyrinth Stack. The average wind speed for the months when the releases occurred was used rather than the detailed speeds and directions at a set of given times. The contributions from adjacent sectors were added since the distances to the site boundaries were large enough to result in diffusion across sector boundaries. Most of the exposure occurred within 16 km (10 mi) from the site.

Several of the closed loop cooling systems are reaching levels where potential off-site releases, from these loops, would be detectable but not hazardous. No releases occurred from these closed loop systems in CY-1981. Some releases of radioactive water occurred from sumps collecting water from under areas where protons interacted. About half of this volume of water left the site while Casey's Pond (H4 in Fig. 4), 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 negligible.

3.5.2 Assessment of Nonradioactive Pollutant Releases

Although it was necessary to chemical treat some waters to control the growth of algae and weeds during CY-1981, efforts were made to keep these treatments as low as possible in order to protect wildlife and fish, i.e., well within guidelines established by the State of Illinois. However, there was evidence that a build-up of copper occurred in the bottom of a section of the A1 Pond, a part of the Main Ring ponding system. Peak concentrations of copper in the sediment exceeded 100 mg/kg (parts per million). Three of a dozen young Trumpeter swans (Olor buccinator) died a few days after being released near this pond. Concentrations of copper in excess of 100 mg/kg were found in these birds.[27] Other older swans placed earlier in the area were not affected. The pond was sprayed with copper sulfate for algae control about a week before the swans were released. A fish taken from the Main Ring ponding system contained copper in a concentration of only

0.62 mg/kg. Since this fish was taken from a different part of the ponding system, and there was no evidence of any other environmental impact, the problem appears to be associated with spraying into one section of the ponding system. No deleterious effects on on-site waters were expected or observed (based on sampling of the waters leaving the site). The Swan Lake Ponding System (Section 3.4.2.2) has been successful in eliminating the need for chromate treatment and subsequent disposal.

There was no significant environmental impact resulting from the operation of the magnet debonding oven (Section 3.4.1). There were no other activities during CY-1981 which created problems with respect to nonradioactive airborne effluents. Heating is accomplished by use of natural gas, liquefied propane gas, or electricity. The bulk of the heating is supplied by natural gas fired boilers located in the Central Utilities Building. The effluents from these boilers are analyzed annually to maintain proper combustion efficiency. Small spills of hazardous materials continued to occur from time to time, but these were cleaned up and no significant environmental impact has resulted.

3.5.3 Potential Impact of Other Toxic Substances

3.5.3.1 Pesticides

In addition to the water treatments mentioned in Section 3.4.4, the following EPA registered herbicides, insecticides and rodenticides were applied by trained personnel following the manufacturer's instructions:

PRAMITOL 25E, in 20% solution, was sprayed on approximately 3,500 m^2 (one acre) to control weed growth at electrical substations in three locations. A total of 57 ℓ (15 gal) was applied during 1981.

No 2,4D was applied in CY-1981.

Corn was planted on 9.22 km^2 (2,278 acres) by licensees who applied pesticides and fertilizers. Application of these pesticides (herbicides and one soil insecticide) was supervised by Fermilab. The soil insecticide (Dyfonate 20G) was applied to 2.97 km^2 (733 acres) at the rate of 3.2 kg/4,047 m^2 (7 lbs/acre). See Table 10.

TABLE 10

Pesticides Applied by Corn Plot Licensees

Plot Size (km^2)	Plot Size (acres)	Pesticide	Total Applied in CY-1981 (kg or ℓ)	Total Applied in CY-1981 (lbs or gal)
6.25	1545	Atrazine	1401 kg	3090 lbs
6.25	1545	Lasso	4386 ℓ	1159 gal
2.97	733	Aatrex 80W	1994 kg	4396 lbs
2.97	733	Dyfonate 20G	2661 kg	5866 lbs

Sampling was done in CY-1981 for residues of Atrazine, Aatrex 80W, Dyfonate 20G, and Lasso (used in previous years) mentioned above. No evidence was found for any environmental impact.

For mosquito control, an ultra low volume application of CYTHION Premium Grade Malathion was performed at 16 different times. Approximately 7.6 ℓ (2 gal) of CYTHION were used in each application and the following areas were covered: Village and Sauk Circle just south of the Village (Fig. 4), Sites 29, 38, and 43 (W29, W38, and W43 in Fig. 4), the Meson, Proton and Neutrino experimental areas (Fig. 1), and the Industrial Areas (near W43 in Fig. 4).

EATON's AC Formula 50, a rodenticide, was placed in pan-type feeders inside approximately 40 outdoor electrical substations to reduce rodent nesting in this high voltage equipment. Approximately 4.5 kg (10 lbs) was used in CY-1981.

The services of a contract exterminator, licensed by the State of Illinois and using EPA registered pesticides, was retained during 1981 for the control of miscellaneous pests found in kitchens, laboratories and living areas throughout the site.

3.5.3.2 Polychlorinated Biphenyls

An inventory of polychlorinated biphenyls (PCBs) is maintained, and a Status Report as of January 1, 1981 listed 80 PCB transformers and 4,569 large capacitors in use or storage for future use. These PCB items have been labeled as required.

There are five of ten askarel-filled transformers in service without secondary containment (curbing) and one failed askarel-filled transformer without curbing. In addition, 62 Main Ring Pulse Power Supply transformers contain from 1% - 9% PCBs and are classified as PCB transformers. None of these have containment curbing. One

askarel-filled transformer failed during CY-1981, and the protective fuse worked properly. Thus, no loss of fluid occurred. The transformer was safely transported to the Hazardous Waste Storage Area at Site 55 (near the Internal Target Area in Fig. 1).

It is apparent that the removal and disposal of PCBs from transformers site wide is a signficant problem and its solution will be costly.

Environmental Research Group, Inc. reported a PCB concentration of 44 mg/kg in a routine sample of fish collected from the Booster Pond (H1 in Fig 5). The maximum permissible concentration of PCBs in fish is 5 mg/kg. Fishing is not permitted in the Booster Pond; however, it is possible for fish from the Booster Pond to enter Swan Lake (H5 in Fig. 5) where fishing is permitted. No PCB concentrations in excess of 1 mg/kg were found in fish from Swan Lake, shell fish from the Booster Pond, or silt samples from the Booster Pond and an adjacent catch basin leading to the Booster Pond from the Booster accelerator. Thus, there is no evidence to date to support this one report of PCBs in fish.

3.5.3.3 Hazardous Wastes

Significant progress was made during 1981 with respect to identification, collection and disposal of hazardous waste in an environmentally acceptable manner. Responsibility for this program was assigned to the Safety Section in CY-1979 and a hazardous waste handling and storage facility was developed at Site 55 (near W55 in Fig. 4). This facility is roofed and fenced, has hardstand and a concrete containment area. An additional facility with concrete containment area for PCBs was developed at Site 3 where the Environmental Monitoring Station is located (Fig. 4). This facility is for inside storage of hazardous materials which are for future use.

Over the years it has been the practice to deposit excess materials such as lumber, concrete, building materials and earth on the Meson Area shielding hill. To assure that none of these materials are hazardous to the environment and none will contribute to the contamination of surface or ground waters, a program to control such deposition was developed during 1979. Rules have been promulgated and responsibility for access and control has been assigned to the Roads and Grounds group. The Safety Section monitors this program.

4. Quality Assurance in CY-1981

Water samples were analyzed by Eberline, Midwest Facility, 245 Roosevelt Road, West Chicago, Illinois 60185, for radioactivity. In addition, such samples were counted at the Fermilab Nuclear Counting Laboratory. Tritium and ^{45}Ca analyses were done only by Eberline since Fermilab does not have the necessary liquid scintillation counting system. Each monthly shipment to Eberline included at least one sample prepared at Fermilab containing known amounts of several of the accelerator-produced radionuclides. Tritium was included every month.

4.1 Analytical Procedures at Eberline

The procedures used by Eberline Instrument Corporation follow. Most of the chemical procedures were taken either directly or with minor modifications from procedures manuals prepared by government agencies.

Once the samples reach Eberline Instrument Corporation's Midwest Facilities, West Chicago, Illinois 60185, they are subjected to the appropriate one of the following analyses:

Type 1a: Test for ^{3}H (tritium), ^{7}Be, ^{22}Na, ^{45}Ca, ^{54}Mn, and ^{60}Co at surface water sensitivities. See Section 5.

Type 2a: Test for all of the above at ground water sensitivity plus total radium (the sum of ^{223}Ra, ^{224}Ra, and ^{226}Ra) and total thorium (the sum of ^{228}Th and ^{232}Th).

Type 3a: Chemical separation of ^{45}Ca before its determination; otherwise the same as Type 1a.

Type 4a: ^{3}H only, at surface water sensitivity.

Type 5a: Chemical separation of ^{45}Ca and analysis for ^{45}Ca only, using surface water sensitivity.

Type 6a: The same as Type 1a except at ground water sensitivity.

Type 7a: The same as Type 4a except at ground water sensitivity following distillation.

Type 8a: Test for gross alpha, gross beta, ^{3}H, ^{131}I, and ^{134}Cs at ground water sensitivity. This

analysis is performed on Fermilab's one community water system and on other drinking water systems on site which supply water to more than 25 people during the work day.

Type 9a: Test for Sr-90 only, at ground water sensitivity.

Separate analyses of two aliquots from the same sample bottle is indicated by changing the letter "a" to the letter "b" on the Type designation.

4.1.1 Gamma-Ray Spectroscopy

For gamma-ray pulse height analysis for Fermi National Accelerator Laboratory samples, the sample is homogeneously mixed and a 500 milliliter aliquot is transferred to a 550 mℓ marinelli beaker for a direct count.

The gamma-ray detectors used in the determinations are a Harshaw Chemical Company, 6801 Cochran Road, Solon, Ohio 44139, Princeton Gamma-Tech, Inc., 1200 State Road, Princeton, New Jersey 08540, and Canberra Industries, 45 Gracey Avenue, Meriden, Connecticut 06450, 54 mm diameter by 37 mm deep lithium drifted germanium crystals of

17 and 18% efficiencies relative to a 7.6 cm diameter by 7.6 cm deep thallium-activated sodium iodide crystal. The resolution, full width at half maximum, for the peak corresponding to the 662 keV gamma ray from ^{137}Cs is 2 keV. A Nuclear Data, Inc. (Golf and Meacham Roads, Schaumburg, Illinois 60172) ND600 8192 channel analyzer is used to accumulate the pulse height information. Counting efficiencies are checked once per working day at different energy levels: 0.12, 0.66, 1.17 and 1.33 MeV, using a calibrated mixed source (source containing several radionuclides). Count rates at each peak must be comparable to historical data, and must be within 1 keV of former energy calibration (or a correction is made) in order for the unit to be considered calibrated for counting. The analyzer has a capacity for recalibrating channel numbers to correspond to given energies.

Radionuclide standards are now purchased from Amersham, Searle, 2636 S. Clearbrook Drive, Arlington Heights, Illinois 60005. Efficiencies have been determined for various geometrical configurations based on multiple counts of replicate standards.

4.1.2 Alpha Counting

Proportional counters are used for determining the presence of thorium and radium by alpha-particle detection. Either an Eberline Instrument Corporation SAC-4 or a 0.5 mg gold coated window Beckman Instruments, Inc. (3900 River Road, Schiller Park, Illinois 60176) 5.7 cm (2.25") diameter proportional counter is used. Backgrounds are determined per sample run routine and sample counting time count. Operating plateaus are determined weekly and counting efficiencies once daily using ^{239}Pu sources. Counting efficiencies are expected to fall within 3 percent of the expected values as determined from historical data. Deviations greater than this will require the instrument to be removed from use and returned when the problem is rectified. For the proportional counters, curves of counting efficiency versus precipitate weight on counting planchets have been constructed based on multiple counts of replicate standards of each point on the curves. This method of calibration serves to correct for such things as backscatter as well as air, window and sample absorption.

The radium in water is concentrated and separated from sample solids by coprecipitation with barium and lead as the sulfates. The precipitate is treated with concentrated HNO_3 a few times to dissolve the lead and dissolved the

precipitate with ethylene diaminetetraacetic acid (EDTA) and NaOH. The completely dissolved radium is sealed in a glass tube and stored for a period of several days to four weeks for ingrowth of radon.

The glass tube is connected to an evacuated system, and the radon gas is removed from the liquid by passing radon free nitrogen gas, dried with a desicant and collected in a counting cell for the counting.

The procedure for ^{228}Ra involves precipitating radium isotopes on $BaSO_4$, dissolving the precipitate using the EDTA complexing agent. Strontium and yttrium carriers are added to scavenge the ^{228}Ac and the radium is reprecipitated on $BaSO_4$, by lowering the pH with acetic acid. After dissolving with EDTA, then adding yttrium carrier, the sample is stored for 36 hours to allow ^{228}Ac to approach equilibrium with ^{228}Ra. The radium is then again precipitated on $BaSO_4$ by lowering the pH with acetic acid, and the supernate containing ^{228}Ac is scavenged with lead and the yttrium and yttrium oxalate is precipitated. ^{228}Ac is counted in a low background beta counter for 50 minutes.

Fermilab samples for thorium analysis are sent to Eberline Southwest Facilities, P. O., Box 3874, Albuquerque, New Mexico 87190. The sample is first evaporated to near dryness and dissolved with 8N HNO_3. Then, the aqueous solution is extracted by 30% aliquat 336* and back-extracted by 10N HCl. After electroplating for four hours at 210 ma, the sample is counted in alpha spectrometer for activity determination.

4.1.3 Liquid Scintillation Counting

Concentrations of tritium and ^{45}Ca are determined by intimate mixing of the samples with liquid scintillator. Liquid scintillation counting is done using the Beckman Instruments, Inc. LS-100 system. Optimum operating settings are determined prior to use for each radionuclide to be analyzed, using the appropriate source, i.e., ^{3}H and ^{45}Ca for Fermilab samples. Ten percent of all samples counted contain no activity and thus establish background levels.

*30% solution of Tricatylylmethyl-ammonia chloride in toluene, manufactured by General Mills, Kankakee, Illinois 60901

Ten percent of all samples counted contain known amounts of activity for calibration of the system. Every unknown is internally "spiked" after the original count, with a calibrated source, and recounted to accurately determine the quenching effect, or else duplicate samples are counted, one of which is spiked. Backgrounds are about 22 counts per minute. Counting efficiencies are expected to fall within four percent of the expected values as determined by historical data. Deviations outside expected limits result in removal of the instrument from service until the problem is corrected.

Tritium in water is measured by a direct count of the sample in the liquid scintillation counter. One, three, seven, or ten milliliters of sample specified, (depending on the type of analysis hence on the tritium concentration) is pipetted into a counting vial and scintillator cocktail ("handifluor" from Mallinckrodt, Inc. P.O. Box 5840, St. Louis, Missouri 63134 or "lustagel" from Packard Instrument Co., Inc. 2200 Warrenville Road, Downers Grove, Illinois 60515) chemical added to a total volume of 22 mℓ. Duplicate samples are run for Fermilab and one is spiked with a known amount of tritium. This procedure allows both the determination of quenching and counting efficiency; the latter is approximately 55 percent for 1 mℓ of sample in 25 mℓ of scintillation "cocktail."

Calcium-45 in water samples from Fermilab can also be measured by the above procedure. A known amount of ^{45}Ca is substituted for tritium in the spiked cocktail. However, the determination of ^{45}Ca, which has a very low maximum permissible concentration compared with tritium (Section 4), is difficult to make in the presence of higher concentrations of tritium and other accelerator-produced isotopes such as ^{22}Na. When there are interfering nuclides, a ^{45}Ca separation must be done and is described below.

To an aliquot of sample a known amount of calcium is added along with aluminum carrier. This procedure involves a carbonate precipitation of calcium. The precipitate is dissolved in hydrochloric acid, transferred to a liquid scintillation vial, and diluted with deionized water to a final volume of 3 mℓ. A 19 mℓ volume of scintillator cocktail is added and the sample counted.

4.2 EML Samples

Fermilab and Eberline also analyzed samples received from the DOE Environmental Measurements Laboratory (EML) as part of a quality assurance program. The results obtained are shown in Table 11.[29] The agreement between EML, Fermilab, and Eberline results was within the precision specified by Fermilab for Eberline analyses. See Table 12.

TABLE 11

Comparison of Water Analyses

Sample Date	Radio-nuclide	Environmental Measurements Laboratory Results ($\mu Ci/m\ell$) ($\times 10^{-6}$)	Percentage of Concentration Guide for Surface Waters (%)	Fermilab Results ($\mu Ci/m\ell$) ($\times 10^{-6}$)	Eberline Results ($\mu Ci/m\ell$) ($\times 10^{-6}$)	Mean Value for all Participants in Quality Assurance Program ($\mu Ci/m\ell$) ($\times 10^{-6}$)	Percentage of Participants Outside Ratio Range 0.8-1.2
04/81	^{3}H	19.7	2		24.6	24.2	20
04/81	^{60}Co	1.29	13	1.24	1.33	1.24	24
10/81	^{3}H	15.6	2		15.3	16.7	25
10/81	^{54}Mn	1.35	4	1.85	1.2	1.35	12

TABLE 12

Specifications For The Analyses Of
Accelerator-Produced Radionuclides In Water

Radionuclide	CONCENTRATION GUIDE FOR POPULATION			SPECIFIED SENSITIVITY AND PRECISION*	
	Individual (μCi/mℓ)	Suitable Sample (μCi/mℓ)	Community Water System	Surface Water (μCi/mℓ)	Ground Water (μCi/mℓ)
^{3}H	3×10^{-3}	1×10^{-3}	2×10^{-5}	3×10^{-6}	1×10^{-6}
^{7}Be	2×10^{-3}	6.7×10^{-4}	1.3×10^{-5}	5×10^{-7}	5×10^{-7}
^{22}Na	3×10^{-5}	1×10^{-5}	2×10^{-7}	3×10^{-7}	2×10^{-8}
^{45}Ca	9×10^{-6}	3×10^{-6}	6×10^{-8}	3×10^{-7}	6×10^{-9}
^{54}Mn	1×10^{-4}	3.3×10^{-5}	6.7×10^{-7}	1×10^{-7}	7×10^{-8}
^{60}Co	3×10^{-5}	1×10^{-5}	2×10^{-7}	1×10^{-7}	2×10^{-8}

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

4.3 Other Quality Assurance Samples

Quality assurance samples were sent for PCB analyses to Environmental Research Group, Inc., Bridgeview, Illinois 60455 and to Associated Analysts, 11515 W. North Avenue, Milwaukee, Wisconsin 53226. The PCB concentration provided by United States Environmental Protection Agency were 54 and 498 parts per million (ppm). Environmental Research Group, Inc. reported 18 ppm for the lower concentration sample. Associated Analysts reported 150 ppm for the higher concentration sample. These results are about 70% lower than the given concentrations.

5. References

The appropriate Radiation Protection Standard for penetrating radiation applied to individuals in uncontrolled areas was taken from the DOE Order 5480.1, Chapter XI. The annual dose for whole body exposure is 0.5 rem when applied to a suitable sample of the exposed population.

The Concentration Guides used in the analyses of the surface water samples for radioactivity were taken from the DOE Order 5480.1, Chapter XI, 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 12. 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, 2×10^{-8} μCi/mℓ, was taken from the calculations by Yamaguchi.[15]

The Concentration Guide used in the analyses of ground water samples for tritium were taken from the U. S. Environmental Protection Agency regulations for community drinking water systems. The maximum contamination level permitted for tritium is 2×10^{-5} μCi/mℓ and corresponds to an annual exposure of 4 mrem if one uses the supply as one's sole drinking water source. Note that this is 50 times more stringent than the DOE regulation for a suitable sample of the general population which corresponds to 170 mrem/year. The Concentration Guide for the other radionuclides in Fermilab's analyses of ground water samples have been determined by dividing the surface water concentrations for a suitable population sample by 50 (Table 9). The specified sensitivity and precision of the analyses have been reduced to well below these Concentration Guides.

The Air and 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 for general water quality is 0.05 mg/ℓ. The Standards for total copper at the discharge point and for general water quality are 1.0 and 0.02 mg/ℓ respectively, and for zinc are both 1.0 mg/ℓ for surface water and for well water. The Air Quality Standards limit the release for

SO_2 and 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.

The appropriate regulations for PCBs and hazardous wastes are found in the U. S. Code of Federal Regulations 40 CFR 761 and 40 CFR 260-265, respectively.

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