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

FERMILAB 87/58
1104.100
UC-41

Site Environmental Report

For Calendar Year 1986

May 1, 1987

Samuel I. Baker

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

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SITE ENVIRONMENTAL REPORT FOR CALENDAR YEAR 1986

by
Samuel I. Baker
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Laboratory Work
by
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TABLE OF CONTENTS

TEXT

1986

TABLE OF CONTENTS

TABLE OF CONTENTS

Page

TABLES

1986

TABLE OF CONTENTS

Page

ILLUSTRATIONS

1986

1. Introduction

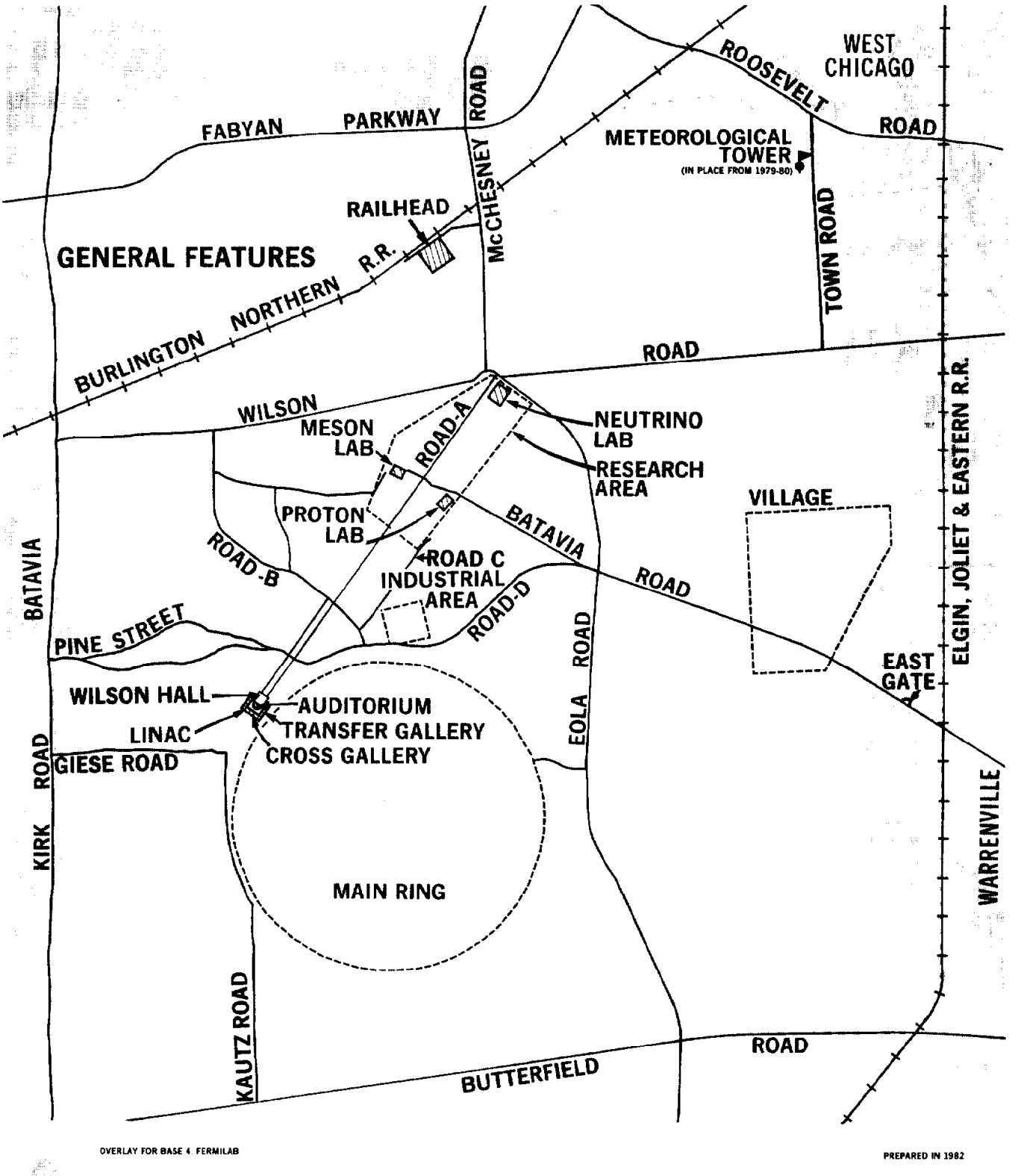
This report summarizes the environmental activities and their results at Fermi National Accelerator Laboratory (Fermilab) for Calendar Year (CY-) 1986.

The facility consists of a series of proton accelerators which became operational in 1972, producing higher energy protons than any other accelerator. As a result of accelerator improvements, the original design energy of 200 GeV (billion electron volts) was gradually raised and operation at 400 GeV was routine between 1976 and 1982 using conventional magnets. At that time a ring of superconducting magnets was added which doubled the energy while using less electrical power.

The primary purpose of the installation is fundamental research in high-energy physics. Up to the present time this research has been performed by extracting protons from the final accelerator (now the superconducting synchrotron called the Tevatron). These protons have been directed onto fixed targets. The protons are being extracted from the superconducting synchrotron and directed to fixed targets. Collisions of protons and antiprotons each having 1 TeV (1000 GeV) are planned. The antiproton source was tested in CY-1985 as well as a large detector. Head-on collisions of 800 GeV protons and antiprotons were observed. Further testing of the antiproton source was done in late CY-1986 after a long shutdown for construction of a new collision area. In addition, cancer patients are being treated using neutrons released by the interactions of 66 MeV protons from the Linac (linear accelerator), the second stage of the series of accelerators.

When the proton beam is extracted from the 2 km (1.2 mi) diameter main accelerator, the protons are delivered to three different experimental areas on-site. These are the Meson, Neutrino and Protons Labs located in the Research Area (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

Figure 1


GENERAL FEATURES
FABYAN PARKWAY
McCHESNEY ROAD
ROOSEVELT ROAD
WEST CHICAGO
METEOROLOGICAL TOWER
(IN PLACE FROM 1979-80)
RAILHEAD
BURLINGTON NORTHERN R.R.
TOWN ROAD
WILSON ROAD
MESON LAB
ROAD-A
NEUTRINO LAB
RESEARCH AREA
VILLAGE
PROTON LAB
BATAVIA ROAD
ROAD-B
ROAD C
INDUSTRIAL AREA
ROAD-D
BATAVIA ROAD
PINE STREET
EOLA ROAD
EAST GATE
ELGIN, JOLIET & EASTERN R.R.
WILSON HALL
AUDITORIUM
LINAC
TRANSFER GALLERY
CROSS GALLERY
GIESE ROAD
KIRK ROAD
MAIN RING
WARRENVILLE
KAUTZ ROAD
BUTTERFIELD ROAD
OVERLAY FOR BASE 4, FERMILAB
PREPARED IN 1982

of the accelerated protons with matter. Operation of the accelerator produces some airborne radioactivity as well as some radiation which penetrates the shielding material. Also, some radioactivation occurs in the soil and in the water used to cool beam components. A thorough evaluation has been made of the on-site discharges as well as the potential for off-site releases of radioactive and nonradioactive effluents. An extensive monitoring program is being carried out to verify that radiation exposures as well as nonradioactive releases are far below the permissible 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 increasing population concentration eastward toward Chicago (Fig. 3). Within a 3 km (2 mi) distance from the Laboratory boundaries, Batavia (pop. 13,550),[1] Warrenville (pop. 9,402),[2] and West Chicago (pop. 13,109)[2] can be found (Fig. 2). The terrain is relatively flat as a result of past glacial action.

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 (Fig. 2). The rainfall on-site during 1986 was 57.4 cm (22.6 in).[3] The land on the site is relatively flat with the highest area, elevation 244 m (800 ft) above mean sea level (MSL), near the western boundary and the lowest point, elevation 218 m (715 ft), above MSL, toward the southeast. The drainage of the groundwater 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] Also, there are many individual private wells drilled into the shallow silurian aquifer system

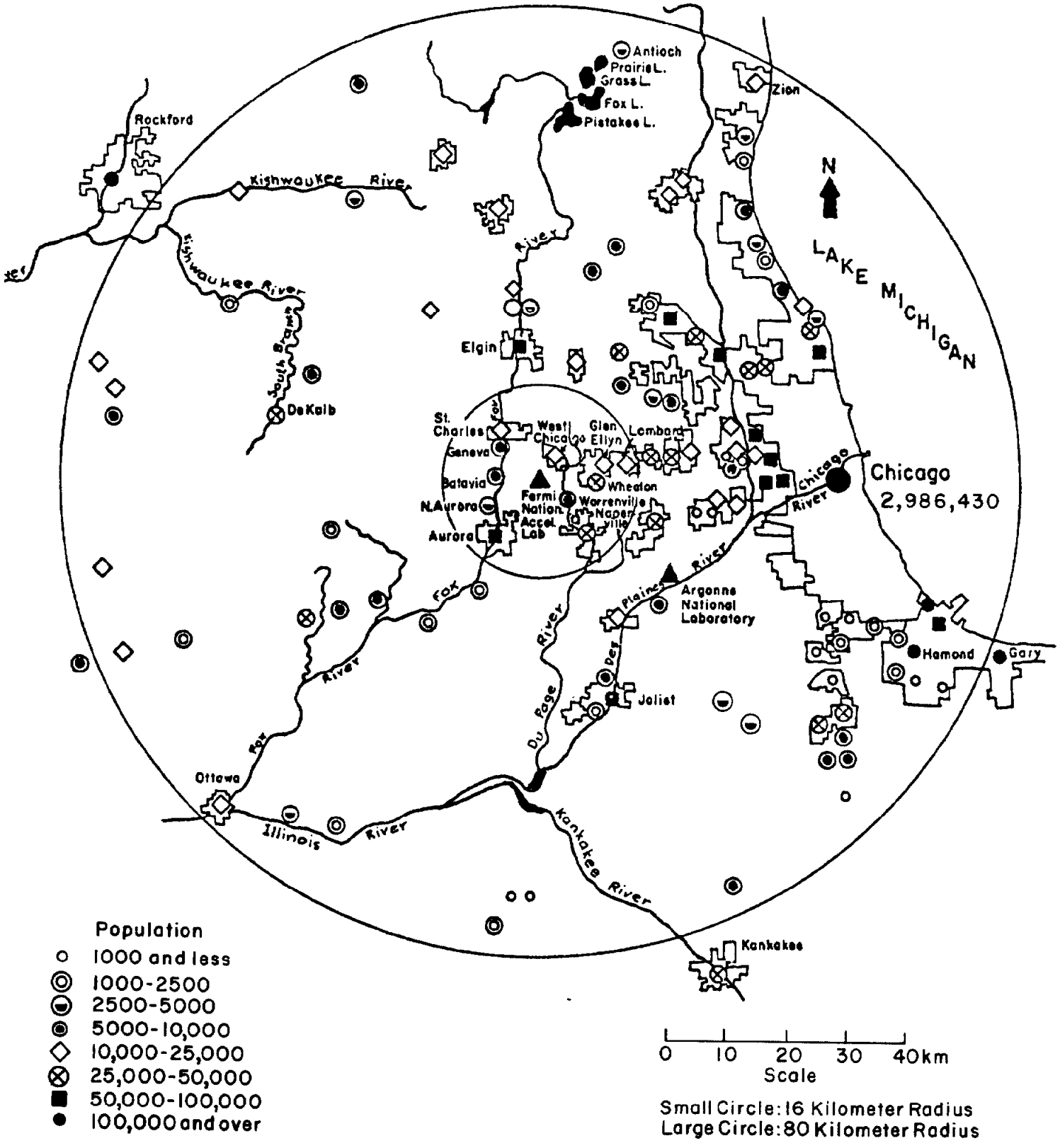
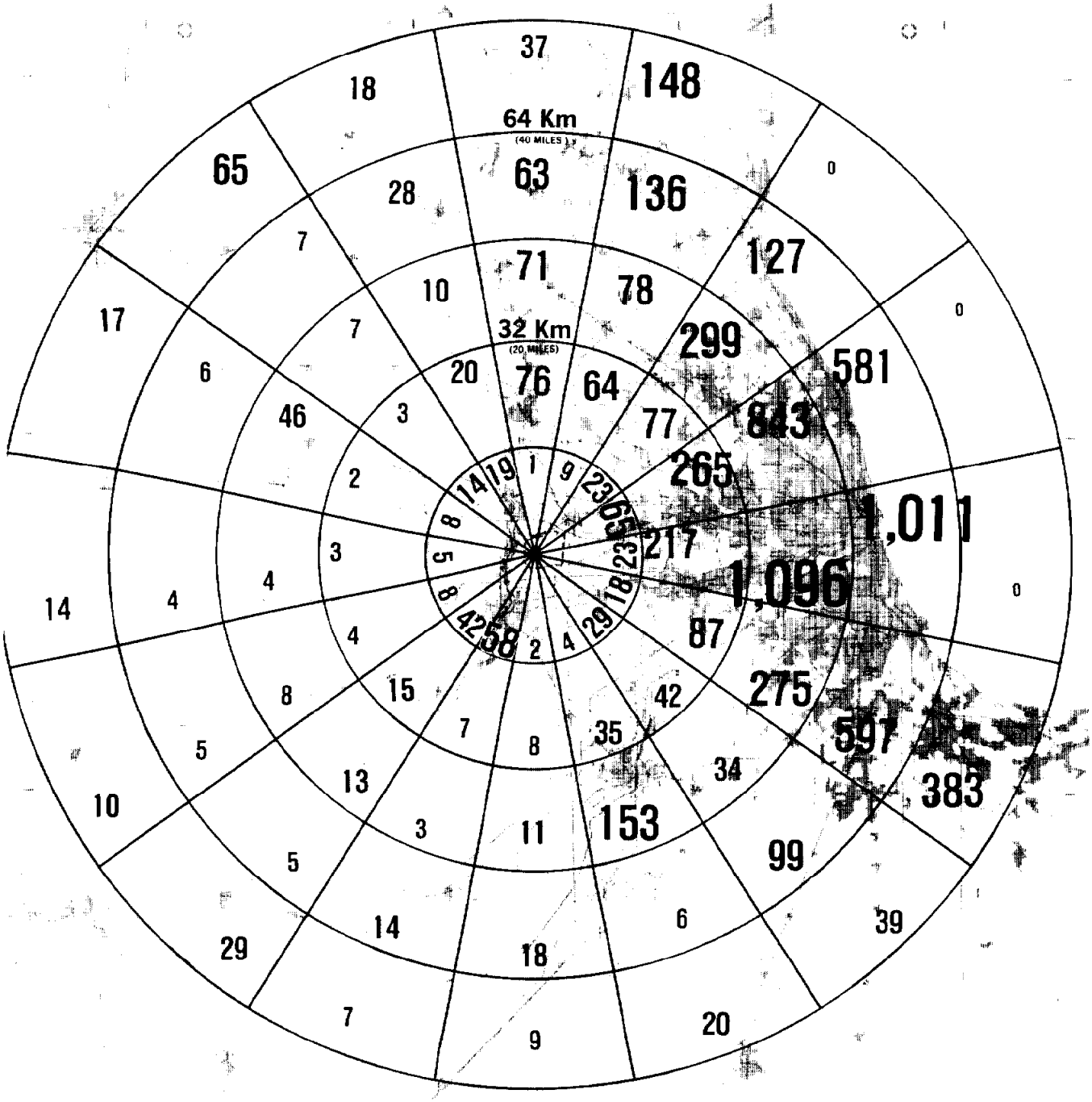


Figure 2 - Location of Fermilab and Population Concentrations within 80 km (50 mi.)

1986

Figure 3



NOTE: NUMBERS REPRESENT NEAREST 1000.

POPULATION DISTRIBUTION -1980
(1980 CENSUS)

OVERLAY FOR BASE 1. FERMILAB

REGIONAL AREA SURROUNDING FERMI NATIONAL ACCELERATOR LABORATORY

PREPARED IN 1982
PREPARED IN 1982
FOR DOE
EG&G

around 30 m (100 ft) below the surface.

The drinking water used on the Fermilab site comes from the shallow Silurian dolomite aquifer.[4] These wells (primarily 1, 3, and 62 in Fig. 4) collect water from 20 to 70 m (65 to 220 ft) below the surface. The surface cooling waters are used for cooling the accelerator and some experimental area facilities through heat exchangers. The surface cooling water supply is augmented as necessary by pumping water from the nearby Fox River.

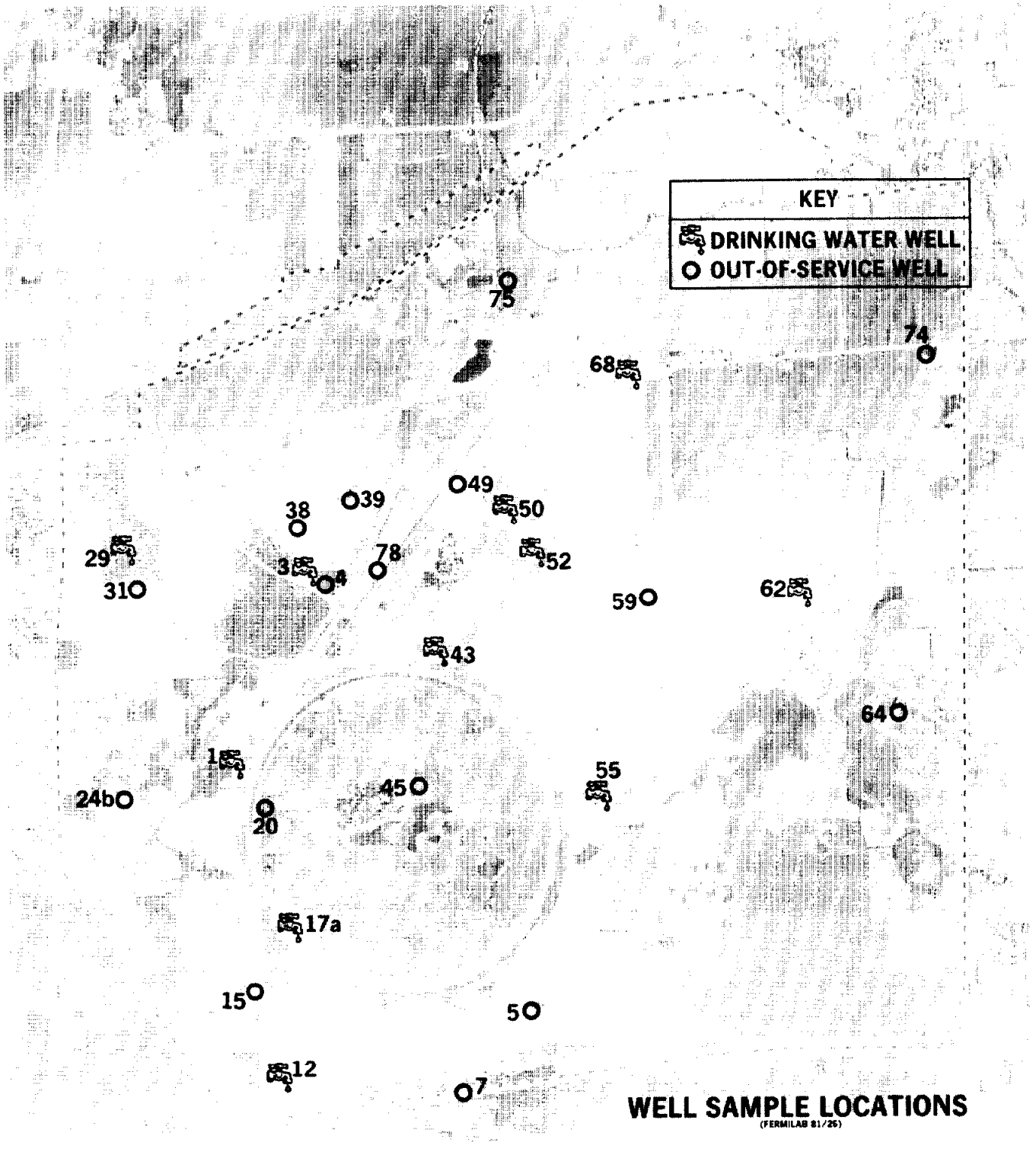
The land within the site boundary was primarily farm land before the State of Illinois acquired the site for Fermilab although the small village of Weston (population around 600 at that time) was located on the eastern side (Fig. 1). Much of the land, approximately 9.3 km^2 (2300 acres), has remained in crop production, primarily corn. About 2.0 km^2 (483 acres) has been planted in native prairie vegetation. The village of Weston has provided residences for visiting scientists as well as support facilities for the research program.

2. Summary

Fermilab began an extended shutdown of the high-energy physics research program in October, 1985 which lasted through CY-1986. A new collision and assembly hall was constructed at D0. A section of the Main Ring tunnel was removed to accommodate a new detector of proton-antiproton collisions. In addition an overpass was constructed to carry protons over the detector at B0 during acceleration in the conventional magnets from 8 GeV to 150 GeV.

In late November, 1986 the overpass had been completed at B0 and the shielding wall had been erected to separate the collision and assembly halls at D0. Testing of the antiproton source commenced on November 23 and continued into December. A total of 3.4 curies of ^{11}C were released compared to the 150 Curies of ^{11}C released from the Neutrino Area stack in CY-1985.

Figure 4


KEY
DRINKING WATER WELL
OUT-OF-SERVICE WELL
75
74
68
49
39
38
50
29
78
52
3
4
31
59
62
43
64
1
55
24b
45
20
17a
15
5
12
7
WELL SAMPLE LOCATIONS
(FERMILAB 81/25)
OVERLAY FOR BASE 4, FERMILAB
PREPARED IN 1982
FERMI NATIONAL
ACCELERATOR LABORATORY

Thus, environmental monitoring in CY-1986 was done to investigate the effect of earlier accelerator operations on the environment rather than to investigate impacts from the testing done in CY-1986.

During CY-1986 there were no abnormal occurrences which had an impact on the facility and its operation. Some oil was discovered from the abnormal occurrence in CY-1985. Approximately 190 (50 gal) of oil was collected from a sump near the Master Substation where a 100 megavolt-amp (MVA) pulsed-power transformer failed on January 24, 1985. Some oil entered the environment at that time.[5] This oil percolated down through the soil to the underdrains around an enclosure 6 m (20 ft) below ground.

The maximum potential radiation exposure at the site boundary during CY-1986 (fence line assuming 24 hr/day occupancy) was 0.0007 mrem compared to 1.5 mrem last year and 0.8 mrem the year before.

The average exposure was 3 mrem per year during the last five years of conventional magnet operation (1978-1982).

The total potential radiation exposure to the general off-site population from Fermilab operations (testing) during CY-1986 was only 0.003 person-rem compared to 1.2 person-rem in CY-1985. The primary source of potential exposure was from airborne radioactivity. The exposure was external from submersion in a cloud of gamma radiation from the radioactive decay of ^{11}C. Because of the short half-life (20 minutes) of ^{11}C the 50 year dose commitment from operations in 1986 will be the same as the exposure received in 1986.

A summary of off-site releases of radioactive effluents in CY-1986 is given in Table 1. Airborne radioactivity was released across the site boundary from the stack ventilating a Antiproton Area enclosure where the proton beam strikes a target. The total release in CY-1985 was 3.4 Ci. No tritiated water was evaporated as a means of disposal in CY-1986. The off-site release of tritium in surface water totaled approximately 83 mCi, half last year's release.

The primary source of tritium in that surface water was tritiated water discharging from an underdrain system beneath a target and dump system. The target was the primary target in the Neutrino Area. The target received most of the protons accelerated at Fermilab. After the CY-1982 operating period ended, the target was moved to a new location with a different underdrain system. Thus, the tritium released in CY-1986 was essentially from operations before CY-1983.

Table 1

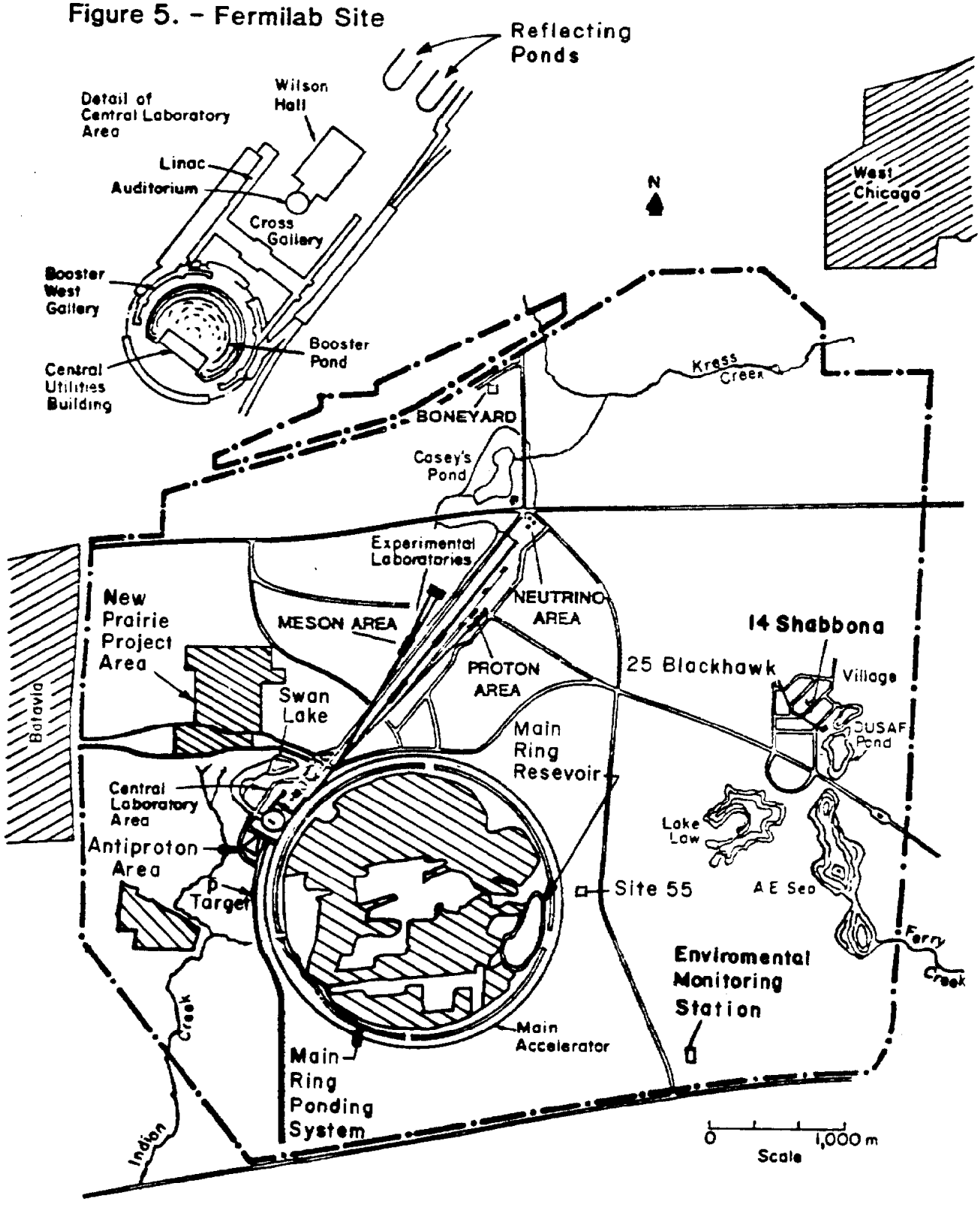
Summary of Radioactivity Released to the Off-Site Environment in CY-1986

Release Point	Radionuclide	Pathway	Release in Curies
AP0 Enclosure	^{11}C	Air	3.4
Debonding Oven	^{3}H	Air	0.003
Kress Creek Spillway	^{3}H	Water	0.083

The sewage treatment plant, a single-stage oxidation pond, in the Village (Fig. 1) exceeded permit limits for biochemical oxygen demand and suspended solids in CY-1986. Eighteen of the excursions in CY-1986 resulted from algal blooms and excessive rainfall on the 0.2 km (5 acre) pond rather than directly from improperly treated sewage. In addition, there was one report of excessive fecal coliform. There was no known adverse environmental impact on the on-site ponds downstream (Fig. 5) or off the site from these excursions. The State of Illinois Environmental Protection Agency was notified of these permit violations.

On December 22, 1986, the Laboratory completed the connection to the City of Warrenville sewage collection system and diverted sewage to that system. The Village oxidation pond will be used only as an ornamental pond. Aeration will continue and the pond will be monitored. A request has been made to terminate the National Pollution Discharge Elimination System (NPDES) permit.

Figure 5. - Fermilab Site



Prairie Restoration Project Areas

1986

The sewage from the Village will be treated in a modern treatment plant - the Springbrook Plant in Naperville, Illinois - which has ample capacity and capability.

3. Environmental Program Information

3.1 Summary of Environmental Monitoring Performed in CY-1986

Fermilab performed extensive environmental monitoring in CY-1985, while the fixed target research program was in progress, on three types of accelerator-produced radiation: penetrating, airborne, and waterborne. The penetrating radiation of concern was muons. Neutrons and gamma rays were also monitored. Gamma rays, the airborne radionuclide ^{11}C and the primary waterborne radionuclide ^{3}H (tritium) were monitored in both CY-1985 and CY-1986. The Department of Energy (DOE) regulations requiring this monitoring are found in DOE Order 5480.1A, Chapter XI. The penetrating radiation measurements were made primarily using a mobile environmental radiation laboratory (MERL), a vehicle with detection equipment. A network of 120 fixed detectors with continuous data recording was also used.

For airborne effluents a continuously operating stack monitor recorded the concentration released from the stack. For waterborne effluents a meter recorded the volume of water discharged. Monthly water samples were analyzed for tritium concentration. The fraction of the year the water left the site was determined by weekly inspections of the spillway.

The data on radioactive waterborne effluents was reported to the Department of Energy via the Effluent and On-Site Discharge Information Systems operated for the Department of Energy by EG&G, Idaho. The extremely low site boundary airborne radionuclide concentrations have been exempted from those reporting requirements.

Additional monitoring for radionuclides in sediment and vegetation on the site has been done to investigate other possible pathways to the off-site environment.

The results have been a small percentage of applicable standards in every case. In particular, the highest off-site penetration radiation level was 1.5% of the relevant standard in CY-1985 and negligible in CY-1986. The highest airborne radionuclide concentration was 0.02% of the standard and the highest waterborne concentration was less than 0.6% of the standard. See Section 5 for applicable standards.

Monitoring for chemical pollutants in drinking water systems on the site is done biennially. Wells and, in cases where distribution systems are extensive, distribution systems were sampled in CY-1985. The results indicated good water quality in all the wells sampled. The only parameters which exceeded the standard in any sample were iron, total dissolved solids, and in one well, sulfate. The iron is believed to be an indication of rust in the plumbing in those cases rather than iron in the aquifer.

Chlorine is tested every work day in the chlorinated drinking water supplies on the site. Routine monthly sampling includes fecal coliform and pH. There were two tests showing no chlorine in the Main Site Water Supply in August, 1986. All other tests were satisfactory. Coliform tests performed by Fermilab showed no colonies. Samples are sent to the State of Illinois for analysis quarterly. Coliform was reported above the limit of an average of two colonies per 100 ml in the distribution system for the Main Site water supply in June. Two additional samples were taken on consecutive days and were found to be satisfactory by the State of Illinois.

The Laboratory performs coliform tests on unchlorinated well water supplies on the site. When greater than four colonies per 100 ml are found in a sample, the well is chlorinated and subsequently retested. Wells 17a, 29, 50 and 55 (Fig. 4) were chlorinated in CY-1986.

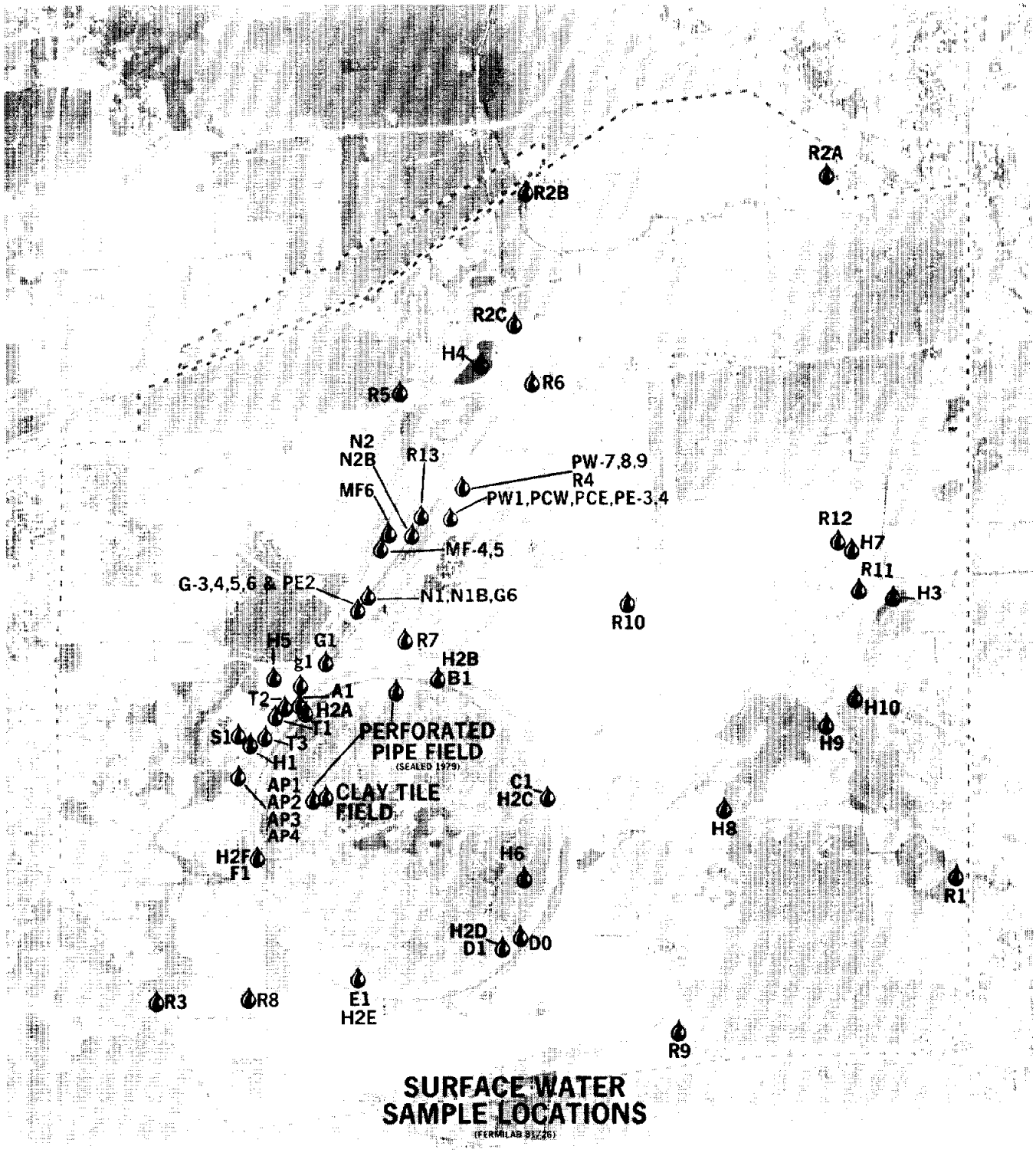
Creeks and ponds are sampled semiannually for pH, dissolved oxygen, biochemical oxygen demand, suspended solids, and fecal coliform (Figs. 5 and 6). Results met standards for waters in general use in CY-1986 except for high fecal coliform readings in Indian Creek and Kress Creek in April 1986 and Ferry Creek and Indian Creek in September 1986.

The Village sewage treatment plant effluent is sampled monthly for pH, biochemical oxygen demand, suspended solids, and fecal coliform. There were 18 permit violations in CY-1986. The flow of sewage to the Village sewage treatment plant was stopped on December 22, 1986. Sewage was sent off-site for treatment.

3.2 Environmental Program Description

Since its inception, Fermilab has endeavored to protect and enhance the environment. For over ten years a prairie restoration project has been in progress on the 1.6 km^2 (400 acre) plot inside the main accelerator ring (Main Ring in Fig. 1). In the past several years the prairie project has been expanded to include areas outside the ring (Fig. 5). The total outside is approximately 0.4 km^2 (100 acres). In another effort to enhance the environment, farm houses were moved from their original locations to a site at the south end of the Village (Fig. 1) and renovated to provide housing for scientists performing experiments at Fermilab rather than abandoned and allowed to deteriorate. Some farm wells were maintained for monitoring and others were properly sealed to prevent inadvertent contamination of the aquifer. Ponds and lakes were created to control surface run off and provide cooling water for the accelerator and experimental areas. Over 40,000 trees have been planted to improve the environment. In addition, strong emphasis has been placed on the control of chemical and radioactive materials as potential sources of environmental pollution. Adequate shielding has been provided for preventing exposure from penetrating radiation.

Figure 6


R2A
R2B
R2C
H4
R6
R5
N2
N2B
R13
PW-7,8,9
R4
MF6
PW1,PCW,PCE,PE-3,4
MF-4,5
R12
H7
R11
H3
G-3,4,5,6 & PE2
N1,N1B,G6
R10
H5
G1
R7
g1
H2B
B1
T2
A1
H2A
T1
S1
T3
PERFORATED
PIPE FIELD
(SEALED 1979)
H1
AP1
AP2
AP3
AP4
CLAY TILE
FIELD
C1
H2C
H10
H9
H8
H2F
F1
H6
R1
H2D
D1
D0
R3
R8
E1
H2E
R9
SURFACE WATER
SAMPLE LOCATIONS
(FERMILAB 81Z26)
OVERLAY FOR BASE 4, FERMILAB
PREPARED IN 1982
FERMI NATIONAL
ACCELERATOR LABORATORY
DOE

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.[6] This includes adherence to the standards given in DOE orders, in particular, DOE Order 5480.1A, chapter XI, which pertains to permissible doses due to radioactive releases, and gives guidance on maintaining exposures to as low as reasonably achievable (ALARA).[7] In addition, the environmental monitoring is supplemented by effluent monitoring following, in general, the guidance given in the Department of Energy (DOE) report A Guide for Effluent Radiological Measurements at DOE Installations.[8]

The emphasis has been placed on potential environmental exposure pathways appropriate to high-energy physics laboratories. These pathways include external exposure and internal exposure. The external exposure is from direct penetrating radiation and airborne short-lived ^{11}C. The internal exposure is from ^{3}H and ^{22}Na in water, primarily potential drinking water. There is one unique characteristic at Fermilab which requires consideration. 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 groundwater beneath these two areas is protected by membranes impervious to water and by underdrain systems to collect the water, radiological monitoring of soil and water is necessary. See Section 3.3.3.4.

Monitoring results are also reported for nonradioactive pollutants. Included as pollutants are pesticides used in weed, insect, rodent, and algae control. In addition, results are included from monitoring the performance of the sewage treatment plant (Village Oxidation Pond) on-site. Discharges of suspended solids and measurements of biological oxidation demand in effluent from this plant have frequently exceeded permit limits. See Section 3.4.4.

3.3 Environmental Radiation Monitoring

The three types of accelerator-produced radiation which receive extensive environmental monitoring are discussed below - penetrating radiation, airborne radioactivity, and waterborne radioactivity. These radiations may 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.

3.3.1 Penetrating Radiation

Operation of the accelerator at current energies and intensities results in production of some penetrating radiation (primarily muons) 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-1986 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.[9] Because the accelerator was shutdown except for some short duration testing in CY-1986 only four detectors were used primarily for environmental radiation monitoring. One was a large volume, 110 liter, ionization chamber (called a Hippo) for gamma ray and charged particle detection. It was located near the Boneyard at the Railhead (Fig. 5). Two of the remaining three detectors were large scintillation counters. They were located near the site boundary (Environmental Monitoring Station in Fig. 5). The last was a tissue-equivalent ion chamber located at 14 Shabbona in the Village (Fig. 5).

The Mobile Environmental Radiation Laboratory (MERL) was used in the past for determining the exposure levels at the site boundary and for locating the source and direction of penetrating radiation such as muons and neutrons.[10,11,12,13] 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.[14]

3.3.1.1 Muons

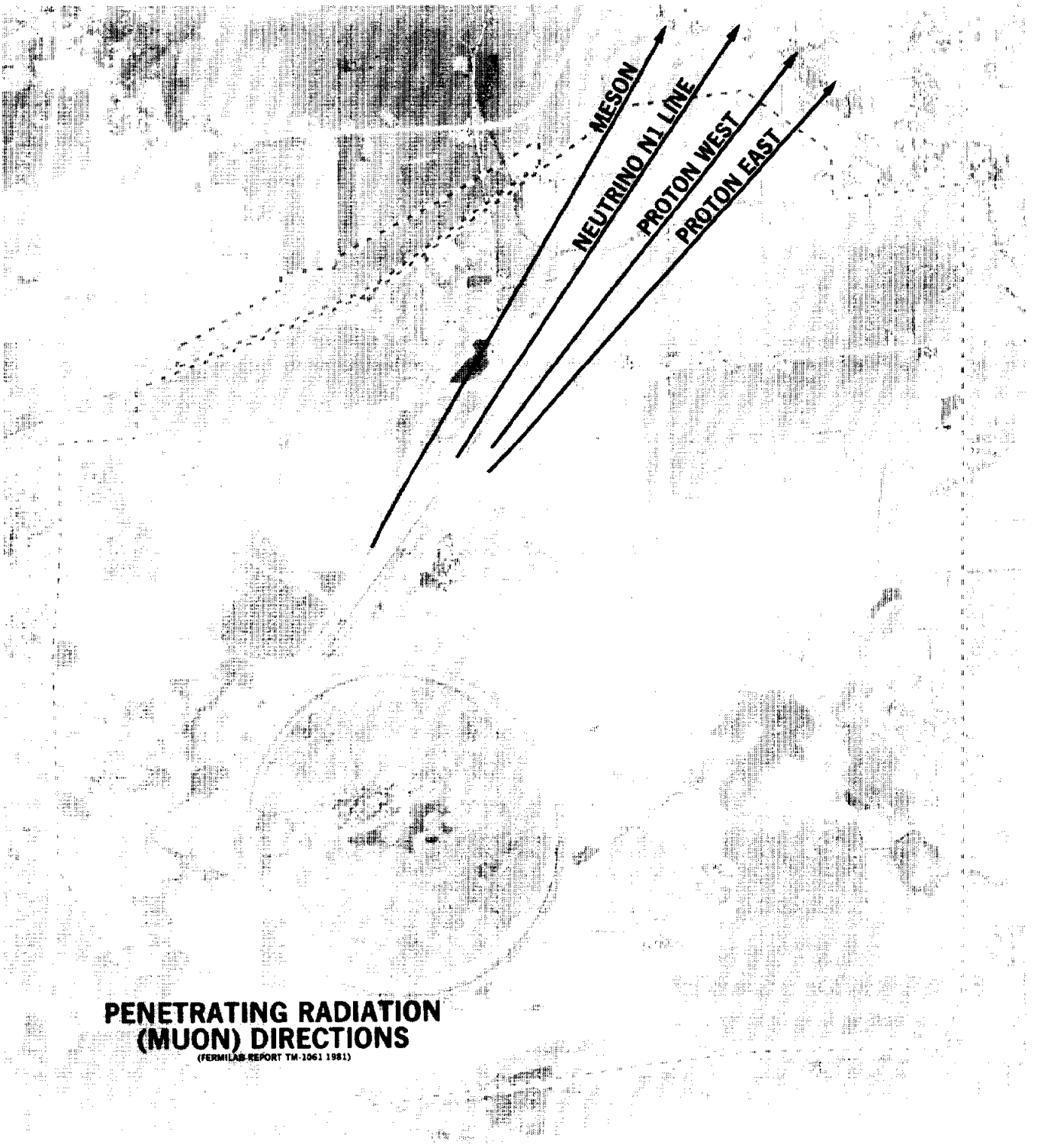
Measurements of muons from the Meson, Neutrino, and Proton Areas were made in CY-1985 while the accelerator was delivering 800 GeV protons. The directions of penetrating muons are shown in Figure 7. The muons which penetrate the earth shielding can travel far beyond the site boundary through the air before stopping. Therefore, measurements were made both on and off the site. The site boundary muon dose rates for CY-1985 were then determined from these measurements and the numbers of protons incident on the targets at 800 GeV. The maximum fence line annual dose based on 24 hour per day occupancy was 1.5 mrem for CY-1985.[5] The muon exposures were negligible in CY-1986.

Since muons do not interact strongly with matter, they are more penetrating than protons of the same energy. Thus, more shielding is required. Since they deposit less energy, they are not as damaging to human tissue. The muon is basically a heavy electron and hence has the same capability for damage (the same quality factor of 1) as electrons or gamma rays. Just as electrons and positrons have negative and positive charges, muons can be positive and negative but not neutral in charge.

3.3.1.2 Neutrons

Neutrons penetrated the shielding in the most easterly of the external experimental areas (Proton East line in Fig. 5) in the Proton Area in CY-

Figure 7


MESON
NEUTRINO N1 LINE
PROTON WEST
PROTON EAST
PENETRATING RADIATION
(MUON) DIRECTIONS
(FERMILAB REPORT TM-1061 1981)
OVERLAY FOR BASE 4, FERMILAB
PREPARED IN 1982
FERMI NATIONAL
ACCELERATOR LABORATORY

1982.[13,16] However, in CY-1983 additional shielding was added to this area resulting in negligible site boundary dose rates from neutrons since that time.

3.3.1.3 Gamma Rays

The primary radioactive waste storage area on-site - the Boneyard - is also the primary source of off-site gamma radiation. Activated accelerator components and shielding, primarily iron and concrete, are stored at the Boneyard for future disposal or reuse following radioactive decay. As shown in Fig. 5, the Boneyard, which is a secure 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. Shielding has been provided 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. Radiation levels at the site boundary closest to the Boneyard were at background levels in CY-1986.

3.3.2 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. During CY-1986 the primary target in the Neutrino Area was not in operation. A new target in the Antiproton Area ($\bar{p}$ target in Fig. 5) was tested during November and December, 1986. These targets are sources of radioactive gas, primarily ^{11}C, which is produced by interaction of secondary particles from these targets with air. The concentration at the Antiproton Area stack was recorded using a continuous air monitor which detected the positron from the

decay of 20 min half-life ^{11}C. The site boundary concentration was calculated using the computer program AIRDOSE-EPA[17,18] (a gaussian plume diffusion model) with neutral wind conditions and average wind speed. In November and December, 1986 the average wind speed at O'Hare International Airport, Chicago, Illinois, was 4.7 m/sec (10.4 mi/hr).[19] Fermilab is about 43 km (27 mi) from the airport and the terrain between them is relatively flat. The site boundary ^{11}C dose for CY-1986 was 0.0007 mrem. See Section 3.3.3.3 for vegetation sampling results near Neutrino Area airborne release points. Radionuclides are still present from earlier operations there.

A debonding oven was placed in operation in CY-1979 in the Industrial Area (Fig. 1). Its purpose is to debond magnets by decomposing the epoxy adhesives at high temperatures. Most of these magnets are radioactive and have 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 tests were primarily performed to measure nonradioactive emissions. 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 seven percent of the Concentration Guide (Section 5) corresponding to 100 mrem per year. The stack is approximately 10 m (30 ft) high. Using the computer program AIRDOSE-EPA gives a negligible percentage of the applicable Concentration Guide at the site boundary.

The number of radioactive magnets debonded in CY-1986 was 19 corresponding to a total release of 3 mCi of ^{3}H into the air. The radioactivity in the magnets was similar to that in the 1979 test, thus the 1979 data are still valid. Two magnets had radiation levels of 2 mrem/hr at 0.3 m (1 ft). Those releases were determined by multiplying 160 μCi by 2/0.8, the ratio of dose rates. In CY-1986 the wind conditions were similar to those in past years.

A water evaporator was placed in operation in CY-1981 at the Boneyard (Fig. 4) to dispose of tritiated water collected from closed loop cooling systems. No tritiated water was evaporated in CY-1986.

3.3.3 Waterborne Radioactivity

During accelerator operations, some radioactivation of the soil will occur.[20,21] Leaching of these radionuclides into the groundwater provides a possible mechanism for transport of Fermilab-produced radionuclides into the surface run-off waters and aquifer. Hence, a broad program of groundwater 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.[20] 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 resins. These ion exchange resins are used to remove impurities from water in closed loop systems.

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

The wells routinely sampled are shown in Figure 4. Water samples were also collected from sumps, creeks, and rivers. All surface and groundwater samples collected were analyzed by Teledyne Isotopes, Inc., 1500 Frontage Road, Northbrook, Illinois 60062. 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 on quality assurance.

3.3.3.1 Water Sample Collection

To obtain water samples from wells not in regular use, the wells 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. Also, in CY-1984 meters were added to record the operating time of sump pumps which pumped radioactive water.

The water sampling schedule is based on the following rationale:

1. Wells 38/39*, 43, 49, and 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 is expected to flow in the aquifer.

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

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

3. The remaining wells are sampled annually because they are near the site boundary or serve as backups to more frequently sampled wells or as drinking water supplies.

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

5. Sumps closest to the areas of maximum soil activation are pumped frequently. The number of samples per year is dependent on the concentration seen in the water. In CY-1986 N1 and N2 sumps were each sampled eight times. The MF5 sump was sampled bimonthly, and the MF4 sump was sampled five times and the PW8 sump was sampled quarterly. Radioactivity was seen for the first time in a sump near the NM2 enclosure. This sump, designated NM2, was sampled twice. The NM2 sump is near N1 in Fig. 6. The enclosure containing this sump has received very few protons to date. The enclosure is adjacent to the target location which received most of the protons in the past. During CY-1986 the N1 sump which pumps out the water from under that target was not pumping automatically. Since the NM2 sump is lower, it is believed that radioactive water flowed down to it from the vicinity of the target.

6. The N1 retention pit and the retention pit nearby in the south addition to the Neutrino Target Hall designated NØ1RP, are sampled quarterly. Discharge does not occur automatically from them. The water from these pits is monitored and disposed of properly by solidification and burial as radioactive waste, if necessary.

7. The other sumps are sampled less often 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. Ferry was sampled three times and Indian and Kress Creek were sampled four times in CY-1986.

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 (500% of the Derived Concentration Guide in Section 4). Those having concentrations between 0.001 and 0.01 μCi/ml are sampled annually. The total number of closed loop samples is approximately 20 per year.

12. The ion exchange resin regeneration systems are routinely sampled for analysis on-site. Semiannually one of these samples is sent to an outside laboratory for analysis as part of the quality assurance program. The regeneration systems remove radionuclides such as ^{7}Be, ^{54}Mn, and ^{60}Co as well as calcium and other nonradioactive impurities from the resins which function to keep conductivity of closed loop water systems low. Analyses are performed on-site for samples from every regeneration sending radioactive effluent to the Central Utilities Building (CUB) tile field inside the Main Ring. The line to the tile field was frozen in CY-1986 until January 31, 1986. During that time there were two regenerations. The discharge from these was sent to the Booster Pond. Samples were taken and results of the analyses are given in Section 3.3.3.2.2. The line was also frozen for a few days beginning on December 12, 1986. The radioactivity from these regenerations was collected along with the sodium chloride in a settling tank and was not released.

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

3.3.3.2 Results of Analyses

All current Fermilab water sampling locations for detection of accelerator-produced activity are shown in Figs. 4 and 6 except for several new ones in the Neutrino Area (near N1 in Fig. 6). Not all locations need to be sampled every year. See Section 3.3.3.1 above. No accelerator-produced radionuclides were reported in 3 water samples taken from Ferry Creek (R2A in Fig. 6) and 4 samples each from Indian Creek and Kress Creek. No accelerator-produced radionuclides have ever been detected in the water from the creeks and rivers. Thus, the results are not included in Table 2. All water samples with detected activity are reported in Table 2 with the exception of the sample containing radium and thorium from the deep well. River water samples were obtained once during CY-1986 from the Fox River in Aurora and from the west branch of the DuPage River in Warrenville (Fig. 2). Neither river is utilized as a drinking water supply.

The Village water supply (62 in Fig. 4) was the Laboratory's only community water supply in CY-1986. EPA regulations require analysis of community water supply samples every four years for radionuclides.[22] Quarterly water samples were collected and a composite analyzed for naturally occurring as well as accelerator-produced radionuclides in CY-1985. No activity was found.[5] See Section 4.

3.3.3.2.1 Tritium

The results for on-site tritium measurements yielding detectable levels in surface waters (Fig. 6) are given in Table 2. All other sampling points were at background levels. The sumps collect waters from around the footings of the buildings and enclosures. This water is considered surface water. Only aquifers are called groundwaters. The total off-site release in surface waters was 83 mCi of tritium this year, half the 165 mCi released last year. The reduction was primarily caused by a sump pump problem with the N1 sump.

TABLE 2

Tritium Detected in On-Site Water Samples

Tritium Concentration C (μCi/mℓ)*

Collection Point	Number of Samples Collected	C Max	C Max Error	C Min	C Min Error	C Mean	Percentage of Relevant Standard
C1 Sump	1	4.0×10^{-6}	1.4×10^{-6}	4.0×10^{-6}	1.4×10^{-6}	4.0×10^{-6}	0.2
D1 Sump	4	$<3.0 \times 10^{-6}$	---	$<3.0 \times 10^{-6}$	---	3.0×10^{-6}	0.15
G4 Sump	2	7.4×10^{-5}	1.9×10^{-6}	5.8×10^{-5}	1.7×10^{-6}	6.6×10^{-5}	3.3
G5 Sump	2	6.5×10^{-6}	9.0×10^{-7}	$<3.0 \times 10^{-6}$	---	4.8×10^{-6}	0.24
G7 Sump	3	1.8×10^{-5}	1.0×10^{-6}	$<3.0 \times 10^{-6}$	---	9.4×10^{-6}	0.47
MF4 Sump	5	1.8×10^{-5}	1.1×10^{-6}	2.8×10^{-6}	7.0×10^{-7}	6.7×10^{-6}	0.33
MF5 Sump	6	1.2×10^{-4}	3.0×10^{-6}	6.1×10^{-5}	2.1×10^{-6}	8.9×10^{-5}	4.45
N1 Sump**	8	3.2×10^{-4}	4.2×10^{-6}	1.4×10^{-4}	2.0×10^{-6}	2.1×10^{-4}	10.5
N2 Sump**	8	4.9×10^{-4}	5.0×10^{-6}	9.8×10^{-5}	2.6×10^{-6}	3.2×10^{-4}	16.0
N2B Sump	1	2.5×10^{-6}	1.5×10^{-6}	2.5×10^{-6}	1.5×10^{-6}	2.5×10^{-6}	0.125
G3 Sump	1	3.9×10^{-6}	8.0×10^{-7}	3.9×10^{-6}	8.0×10^{-7}	3.9×10^{-6}	0.2
NM2 Sump	2	6.4×10^{-5}	1.8×10^{-6}	2.6×10^{-5}	1.2×10^{-6}	4.5×10^{-5}	2.3
PW7 Sump	2	3.1×10^{-6}	9.0×10^{-7}	2.5×10^{-6}	7.0×10^{-7}	2.8×10^{-6}	0.1
PW8 Sump ***	4	7.3×10^{-4}	4.1×10^{-6}	2.5×10^{-6}	7.0×10^{-7}	2.3×10^{-4}	11.5
PW9 Sump	4	1.9×10^{-4}	2.3×10^{-6}	3.8×10^{-6}	8.0×10^{-7}	6.2×10^{-5}	3.0

*C Max is the highest concentration detected in any sample from that location and C Min is the lowest. C Mean is the average for all samples from one location.

**The high concentrations in these sumps are assumed to be due to the accumulation during the period of time that the sumps were not pumping automatically. This period of time was about 75% of the year. The sumps were pumped only a few times manually during the year.

***The high concentration in this sump sample was the result of a leak into the sump totaling less than .5 mCi of tritium.

Less water was pumped out. The off-site release occurred at less than 0.2 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.

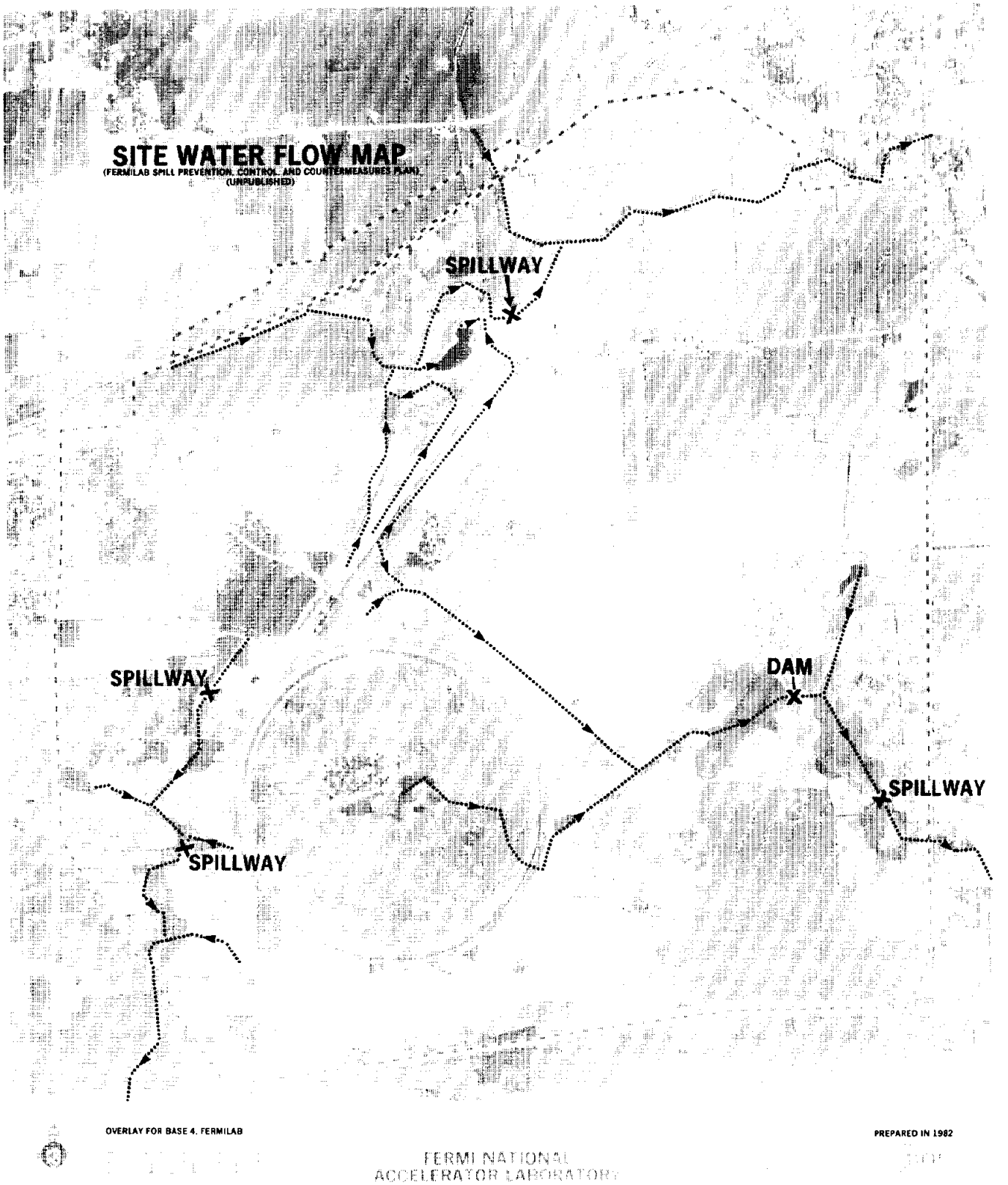
The surface water from the experimental areas (Fig. 5) flows into Casey's Pond except during wet seasons. Then, the pond fills up (68 million l or 18 million gal capacity) and barricades are placed at the two entrances to the pond to keep the water from flooding the pump room. When these barriers, called stop logs, are in place, the water bypasses the pond and leaves the site via Kress Creek (Figs. 5 and 8). This was the case for approximately 19% of the year in CY-1986. There were no discharges of radioactivity totaling greater than 1 mCi from a closed loop water system leak in CY-1986.

3.3.3.2.2 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 effluent from these two systems is sent to a clay tile field inside the main accelerator (Fig. 7). 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 total amount of ^{7}Be discharged to the tile field in CY-1986 was five millicuries. This quantity is less than the total of 25 millicuries discharged in CY-1985 because a settling tank was used throughout most of CY-1986. The salts, essentially NaCl, were allowed to precipitate and take almost all of the

Figure 8



1986

radioactivity out of solution. The solution was drained off the top and sent to the CUB tile field after pH adjustment to ensure it was not a hazardous waste.

During January, 1986, the tile field was frozen and ^{7}Be was discharged into the Booster Pond (Fig. 5). The total amount of ^{7}Be discharged was 0.2 millicurie at an average concentration of 1.0×10^{-5} $\mu Ci/ml$ or 0.5% of the applicable concentration guide. The tile field was frozen for a few days starting on December 12, 1986. The solution was sent to the Booster Pond during that period, but the quantity of ^{7}Be released was negligible.

3.3.3.2.3 Other Radionuclides

Tests were also made for radium and thorium in our deep well (4 in Fig. 4) to look for any long-term changes in percolation rates to deep-lying aquifers. The results were consistent showing no changes, as has been the case in the past.

3.3.3.3 Sediment and Vegetation Sampling

Sediment and vegetation samples were taken near discharge points for radioactive effluents. The results for sediment samples are given in Table 3. The vegetation results are given in Table 4. The samples were taken of the top centimeter of sediment in the ditches. Dry weights were obtained by weighing the samples after baking in an oven for at least 24 hours at 115°C.

The presence of ^{137}Cs (Table 3) indicates fallout from previous atmospheric nuclear testing. The ^{60}Co should be from fallout or accelerator-produced. The ^{7}Be could be from cosmic ray production or accelerator-produced. The radionuclides ^{22}Na and ^{54}Mn are only accelerator-produced.

Table 3

CY-1986 Sediment Sampling Results

Location	Concentration (pCi/g dry weight)				
	^{7}Be	^{22}Na	^{54}Mn	^{60}Co	^{137}Cs
Ferry Creek	--	--	--	--	0.88±0.08
Indian Creek	--	--	--	--	0.08±0.02
Kress Creek	2.0±1.2	--	--	--	0.15±0.02
MF5 Sump	--	0.29±0.05	0.56±0.06	0.28±0.03	0.07±0.02
N1 Sump	2.6±0.9	0.33±0.03	0.12±0.02	0.39±0.03	0.08±0.02
N2 Sump	1.9±1.2	0.08±0.03	0.07±0.03	--	0.10±0.02
PW8 Sump	3.3±1.6	--	0.17±0.04	--	--
T3 Sump	3.1±1.4	0.59±0.05	--	--	0.07±0.02
CUB Tile Field	--	0.06±0.03	0.07±0.03	0.17±0.02	0.38±0.04

An annual vegetation sampling program was initiated in CY-1978. Vegetation samples were taken near the ^{11}C exhausts in the Neutrino Area (N1 in Fig. 7) in addition to vegetation samples in areas with waterborne radioactivity. See Table 4.

Table 4

CY-1986 Vegetation Sampling Results

Location	Concentration (pCi/g dry weight) (pCi/ml of soil moisture for ^{3}H)				
	^{3}H	^{7}Be	^{22}Na	^{54}Mn	^{60}Co
Ferry Creek		5±3	--	--	--
Indian Creek		12±4	0.24±0.11	--	--
Kress Creek		21±8	--	--	--
MF5 Sump		13±8	14±1	1.2±0.2	--
N1 Sump		6±4	2.3±0.2	--	0.17±0.09
N2 Sump		17±3	--	--	--
PW8 Sump		33±7	0.15±0.12	--	--
T3 Sump		12±2	--	--	--
N1 Labyrinth Stack	64±6	17±4	--	--	--
N1 Muon Line Stack	192±19	14±3	--	--	--
N1 Spur Stack	59±6	23±5	--	--	--
CUB Tile Field		25±5	--	--	--

The peak concentrations for vegetation sampling are based on the dry weight of the sample except for ^{3}H which is measured in the water extracted. The results from the analyses of the vegetation samples indicated small concentrations of radionuclides similar to those seen in the past.[16] In other samples based on previous results[25] the radionuclide ^{7}Be is expected to be present as surface contamination - from air while other radionuclides are most likely incorporated into the plants. The vegetation contained small quantities of accelerator-produced radionuclides. The amounts of radioactivity are so low that consumption of the vegetation by animals in the human food chain would be permissible. The concentrations of ^{7}Be are unlikely to be accelerator-produced because of the short half-life and long accelerator shutdown. The ^{3}H concentrations are taken adjacent to the low (1 to 3 m or 3 to 10 ft) stacks. Thus, some ^{3}H is being emitted from the stacks, but it is masked by the much higher concentrations of ^{11}C ($> 10^{6}$ times higher by calculation). Concentrations near the stack should be the highest since the stacks have covers and emit air centrifugally.

3.3.3.4 Soil Activation

Because the percolation rates for water in Fermilab soils are calculated to be very low - less than 1 m (3 ft) per year[26] - analyses of well waters do not provide the early warning desired for detection of accelerator-produced radioactivity in the groundwater. 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 because the major long-lived ones leachable from Fermilab soils were ^{3}H and ^{22}Na, quantitative measurements were made only on those.[19]

In CY-1984 a hole was drilled at 45° to sample the soil below the lowest underdrains beneath the Neutrino Area primary target tube.[27] The target in this 2 m (6 ft) diameter tube has received most of the protons accelerated at Fermilab. The purpose of the hole was to look for radionuclides, primarily ^{3}H

and ^{22}Na, which might have been leached and escaped from the water collection system. No evidence was found for large quantities of radionuclides migrating downward toward the aquifer.[27]

In CY-1983 a new target and dump system was put into operation to abort any errant protons inside the Main Ring tunnel. The well shielded dump was placed just outside the tunnel (near C1 in Fig. 6). It was provided with a sampling underdrain which normally is not pumped.[5] The drains adjacent to the Main Ring tunnel lead to sump pits equipped with pumps, hence water in the region around the tunnel and above the underdrains is normally kept free of standing water. The region below the Main Ring drains is not.

The abort dump itself is sealed watertight. Drains inside have remained dry. The part of the dump below the Main Ring tunnel drains sits in water, permitting leaching of tritium produced in the sand and gravel surrounding the dump. Water samples from the underdrain beneath the dump contain tritium and ^{22}Na. The concentrations are below the DOE Concentration Guides for release to surface waters (Section 5). We have begun a program of pumping approximately 2000 liters (approximately 500 gallons) of water from the sampling underdrain periodically to keep the concentration low.

3.4 Environmental Monitoring for Nonradioactive Pollutants

3.4.1 Domestic Water Supplies

The primary drinking water supply at Fermilab in CY-1986 was provided by two wells pumping from an aquifer approximately 70 m (220 ft) deep. One (1 in Fig. 4) is located in the Central Laboratory Area and the other (62 in Fig. 4) supplies the separate Village system. A third well (3 in Fig. 4) pumps from the same aquifer and supplies water to the Main Site System when demand exceeds the capacity of the Central Laboratory well (1 in Fig. 4).

These wells have chlorination systems and our water laboratory conducts tests for pH and fecal coliform monthly. No fecal coliform was found and pH conformed to Illinois standards during 1986. The chlorine level in the chlorinated drinking water supplies is tested each work day. Test results conformed to standards except for two days in August when no chlorine was detected in the Main Site system. Samples of the Main Site (Central Laboratory Area) and Village Supplies are independently analyzed by the Illinois Environmental Protection Agency quarterly for total coliform per 100 ml. Coliform was reported above the permissible average of two colonies per 100 ml in the distribution system for the Main Site water supply in June. As soon as the report was received, additional samples were taken on two consecutive days and found to be satisfactory. Our average use from the Central Laboratory well and its backup well (1 and 3 in Fig. 4) was approximately 264,000 l/day (70,000 gal/day) during 1986 a decrease of 36% from 1985.[5] The average use from the Village well (62 in Fig. 4) was 140,000 l/day (37,000 gal/day) during CY-1986 a decrease of 21% from 1985.

Wells are monitored biennially to determine compliance with State of Illinois regulations for nonradioactive pollutants such as heavy metals.[28] Eleven potable water wells (Fig. 4), two wells (20 and 45 in Fig. 4) near the CUB tile field (Fig. 5), and one well near the Industrial Area (43 in Fig. 4) were sampled directly from the wells in CY-1985.[5] Also, samples were taken from the water taps of the distribution system of three of the 14. The water from all wells except the one in the industrial area was analyzed for nine metals including chromium, iron, lead, mercury, and zinc. Most of the samples were also analyzed for sodium. Total dissolved solids, chloride, fluoride, sulfate, and nitrate plus nitrite were also measured as well as pH and cyanide. Water from the chlorinated systems was analyzed for trihalomethanes: chloroform, dichlorobromomethane, dibromochloromethane and bromoform. Water from the industrial area well and other wells in areas where solvents are used were analyzed for ammonium, trichloroethane, trichloroethylene, and total organic carbon. Also, a few wells were sampled for benzene and gasoline. The analyses were performed by Aqualab, Inc., 850 W. Bartlett Road, Bartlett, Illinois 60103.

Fermilab's community drinking water supply, the Village well #62, met all drinking water standards (Section 5). Several other wells were above the standard for iron. This is probably from the plumbing. One well, #3, was above the standards for manganese and total dissolved solids as well as iron. However, all these wells including the community water supply are exempt from the standards for iron and manganese. These standards only apply to community water supplies serving larger populations.[28]

The water laboratory performs coliform tests on unchlorinated well water systems on the site. When coliform levels exceed four colonies per 100 ml, the well is chlorinated and retested. Wells 17a, 29, 50 and 55 (Fig. 4) were chlorinated in CY-1986.

Well #29 has a sulfate problem and ion exchange resins are used to treat the water. Several other wells are just above the standard for total dissolved solids. Well #50, which had high coliform levels in CY-1986, has a high total organic carbon value compared to other wells. This might indicate organic infiltration. This well is behind a former farm house. Thus, there were many potential sources of organic pollutants.

3.4.2 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 (Fig. 5) at the end of the Neutrino Beam Line and underground mains to fire hydrants and sprinkler systems throughout the Central Laboratory Area and Experimental Areas. Casey's Pond is supplied by surface drainage and can be supplied by pumping from the Fox River. The pond holds 68,000,000 ℓ (18,000,000 gal).

The Swan Lake/Booster Pond System (Fig. 5) is used for cooling purposes at the Central Utilities Building (CUB). 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 NS1 Service Building (N1 in Fig. 7) 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 (Figs. 5 and 8).

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 inside the Main Ring Ponding System (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 (Figs. 5 and 8).

The water in these systems normally meets the quality requirements of water in general use in Illinois (Section 5).

3.4.3 Other Lakes and Ponds

Surface drainage from the eastern portion of the site flows into Lake Law, DUSAF Pond and the AE Sea (Figs. 5 and 8). The chlorinated effluent from the Village sewage treatment plant oxidation pond (just north of DUSAF Pond) also flows into DUSAF Pond. These lakes and ponds are accessible to the public, and they are the head waters of Ferry Creek.

Semiannual tests are made of water samples taken where the three creeks leave the site (R1, R2A, and R3 in Fig. 6), as well as from Casey's Pond and the Fox River. Results of the tests for pH, dissolved oxygen, five-day biochemical oxygen demand, (BOD5), suspended solids, and fecal coliform for 1986 are found in Table 5. Tests for fecal coliform bacteria are made monthly in our water laboratory. Levels above 200 were found in all three

TABLE 5

Site Wide Water Quality Report for CY-1986

	pH		DO mg/ℓ		BOD5 mg/ℓ		Susp. Solids mg/ℓ		Fecal Coliform mg/ℓ	
	April	Sept.	April	Sept	April	Sept	April	Sept	April	Sept
Ferry Creek	8.4	8.4	9.8	8.2	5.8	6.8	26	84	0	772
Kress Creek	8.2	8.2	12.1	8.6	3.6	1.3	24	14	304	138
Indian Creek	8.2	8.7	12.6	8.4	2.8	1.9	18	47	320	304
Casey's Pond	8.5	8.5	10.2	8.3	2.4	1.8	19	14	22	30
Fox River	8.8	8.5	11.5	8.9	6.1	4.8	53	79	160	536
General Standards[28]	6.9 - 9.0		Not less than 5.0 at any time		*		*		Mean of 200	

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

creeks in CY-1986. The explanations for the high readings have not been found. Fecal coliform bacteria are found in recent deposits of fecal material from warm-blooded animals. They serve as an indicator for pathogens which can multiply under similar conditions. Thus, the Laboratory will continue to check the levels, search for the sources of nutrients, and look for any impacts.

3.4.4 Sewage Treatment

An authorization permit to discharge under the National Pollutant Discharge Elimination System (NPDES) was obtained for the Village Oxidation Pond (just north of DUSAF Pond in Fig. 5) in 1979.[29] Monthly testing results for 1986 are in Table 6. On December 22, 1986, the Village sewage collection system was connected to the City of Warrenville system and has been delivering sewage to the Naperville Springbrook Treatment Plant via that system since then. The Naperville plant is a modern sewage treatment system with ample capacity.

The Main Site sewer system was connected to 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 for the Village sewer system renewed in 1985 has limits for 30 days average BOD5 and suspended solids of 10 mg/l and 12 mg/l, respectively. The Village system exceeded the limit for suspended solids eight times in CY-1986, in spite of treatment with Aquazine to control algae. The limit for BOD5 was exceeded ten times. See Table 6. These results are reported to the Illinois Environmental Protection Agency monthly. Fermilab has requested termination of the NPDES permit and plans to maintain the Village Oxidation Pond as an ornamental pond in the future.

3.4.5 Chemical Treatment of Water Systems

Some chemical treatment of our various water systems is required each year to control the growth of algae and aquatic weeds. Only EPA registered

TABLE 6

Village Sewage Treatment Plant

Monthly Averages Report for CY-1986

Parameter	Permit Limit	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
pH	6-9	8.1	8.2	8.6	8.2	8.9	8.2	8.4	8.5	8.3	7.7	7.8	7.8
B0D5 mg/ℓ	10	12*	18*	17*	17*	22*	32*	19*	17*	18*	10	9	14*
Suspended Solids mg/ℓ	12	12	12	20*	20*	45*	58*	2	28*	9	15*	16*	16*
Fecal Col. #/100 mℓ	400	0	0	0	0	0	28	0	0	0	0	0	0

*Violation Report Filed

agents are administered by trained personnel licensed by the State of Illinois and following the manufacturer's directions.

3.4.5.1 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. Only one piece of equipment within the plant is chlorinated at a time. Consequently the concentration of chlorine entering the Swan Lake system is significantly reduced from 0.5 ppm.

3.4.5.2 Aquazine

The Village Oxidation Pond was treated three times in CY-1986 in an attempt to control algae growth and reduce suspended solids. The total quantity of Aquazine used was 272 kg (600 lbs). Aquazine was also used to treat the Main Ring Ponding System, the Swan Lake/Booster Pond System, and the reflecting ponds by Wilson Hall in CY-1986 (Fig. 5). Approximately 540 kg (1200 lbs) of Aquazine was applied to the Main Ring Ponding System, 142 kg (314 lbs) was applied to the Swan Lake/Booster Pond System, and 21 kg (46 lbs) was applied to the reflecting ponds.

3.4.5.3 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 1986. 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. Another Nalco product, Nalco 7387, was applied continuously to maintain less than 1 mg/l with a peak total phosphorus concentration of 1.3 mg/l. The rate of application was the same per day as for Nalco 7348. Nalco 7387 is an organophosphorus compound which prevents scale information. It does not have the toxic properties of organic phosphorus esters found in some restricted-use pesticides.[30]

Trace amounts of heavy metals and copious quantities of sodium chloride have been discharged into the CUB Tile Field (clay tile field in Fig. 6) inside the Main Ring in the past. Copper is the primary heavy metal. It is an impurity removed by the ion exchange resins used to keep the conductivity of closed loop water systems low. These mixed-bed resins are regenerated using hydrochloric acid and sodium hydroxide. When the two chemicals combine after traversing the resins, salt is formed. Trace amounts of ^{7}Be are also removed (Section 3.3.3.2.2). A settling tank was used beginning in CY-1986 to remove salt and ^{7}Be from the effluent from resin regeneration. The salt is being stored to allow ^{7}Be levels to decrease by radioactive decay.

3.5 Environmental Permits

As mentioned in Section 3.4.4 Fermilab has a NPDES permit (IL0025941) for discharge of sewage from the Village Oxidation Pond. This permit expires September 1, 1990; however, a request has been made to terminate this permit now that off-site treatment is being done. The State of Illinois Environmental Protection Agency (IEPA) was notified of all permit violations in CY-1986. The noncompliance has had negligible environmental impact on the on-site ponds (Fig. 5) or off the site.

The magnet debonding oven (Section 3.3.2) has an Illinois Environmental Protection Agency permit (I.D. No. 089801AAD D/0-1) which expires May 7, 1989. There have been no cases of noncompliance.

Fermilab has an interim permit (USEPA I. D. No. IL6890030046) to operate a hazardous waste storage facility. This permit was issued by the U. S. Environmental Protection Agency and will expire November 1, 1988. The facility is in compliance with regulations. Regulated chemical wastes are stored in the facility. Examples are hazardous wastes, polychlorinated biphenyls (PCBs), and used oil. Only wastes generated by Fermilab are stored at the facility for proper disposal elsewhere in the future.

Emco Wheaton coaxial vapor recovery systems have been installed on all gasoline dispensing equipment at Fermilab under a permit (Identification Number 089801-AAD) issued by the Illinois Environmental Protection Agency. The permit expires on February 13, 1991. There have been no compliance problems with the systems.

3.6 Assessments and Impact Statements

No formal environmental assessments and no environmental impact statements were prepared in either draft or final form during the year at Fermilab. However, there is an on-going program in place to routinely evaluate new projects and modifications to existing operations and facilities to determine if there is a significant potential for impact. Also, see Section 3.9 for the evaluation of operations conducted in CY-1986.

3.7 Summary of Significant Environmental Activities

In the early 1970's Fermilab began a prairie restoration project on the approximately 1.6 km^2 (400 acre) plot inside the main accelerator (Fig. 4). Three State of Illinois endangered species of prairie plants (Cypripedium candidum, Iliamna remota, and Petalosteum foliosum) and one State threatened plant (Filipendula rubra) have been introduced into the plot. In CY-1986 a prairie sedge which is endangered in Illinois (Carex atherodes) was found in a wet area of the plot. This plant is believed to have been there all the time, but was not able to compete well until burning and restoration had improved conditions.

In CY-1984 some Fermilab land (0.11 km^2 or 28 acres) outside this plot was plowed and seeded with prairie plants. Since then additional prairie planting has been done (Fig. 5), resulting in a total of approximately 0.4 km (100 acres) outside the main accelerator.

There are very few remnants of the original prairie left. In CY-1986 a small remnant was found along the Burlington Northern Railroad tracks near the northern site boundary. Since the soil is similar to the restored prairie, there is interest in comparing the two.

The Fermilab restoration is one of the largest prairie sites in the country. The harvesting of seeds is done by volunteers and the environmental aspects receive the attention of a prairie committee consisting of laboratory personnel and outside university representatives. Fermilab conducts routine burning of the prairie restoration areas with assistance from the prairie committee and volunteers.

An archaeologist was hired in CY-1986 to update the status of Fermilab's American Indian sites. The work done in 1970-71 by A. Early was validated, and a new site was found. This brings the total number of sites to 25. The sites are basically hunting camps occupied for relatively short periods of time rather than villages. Most of the land was prairie and marsh adjacent to a forest on the west side of the Laboratory. The forest stretched to the Fox River when the Indians camped here. Some sites were occupied 3000 years ago.

Although the discharge from the Photography Sump into Swan Lake (Fig. 5) met the State of Illinois Water Pollution Standards (Section 5), the Laboratory terminated the discharge on September 26, 1986. The effluent from photographic processing is now being sent to the City of Batavia Sewage Treatment Plant with their permission.

On January 24, 1985, a large transformer failed, cracking its case and spilling a small fraction of its oil on the transformer pad. Most of the oil spilled was contained on the transformer pad and pumped into drums for later disposal by incineration. A small quantity (less than 380 ℓ or 100 gal) entered the gravel containment area surrounding the transformer pad. Subsequently when the water was released from the containment area, a thin film of oil was seen in the ditch adjacent to the Master Substation (near 4 in Fig. 4). In CY-1986 a thin film of oil was found in different ditch south of the Master Substation. This oil was traced to the outlet of a sump in an underground enclosure about 7.5 m (25 ft) east of the transformer pad. The sump collects water near the footings of the enclosure about 6 m (20 ft) below the ground surface. In CY-1986 about 190 ℓ (50 gal) of oil was collected.

In 1986 the State of Illinois Geological Survey drilled an angle hole 150 m (500 ft) deep at Site 75 (Fig. 4) and a vertical hole approximately 300 m (1000 ft) deep at Site 5 (Fig. 4). The information from these boring holes will be used in preparing the State's proposal for the Superconducting Super Collider.

As part of a Laboratory program to reduce the volume of polychlorinated biphenyls (PCBs), two of the last three askarel-filled transformers (60-70% PCB) were replaced in CY-1986. The fluid was drained and disposed of by incineration. The casings were flushed and buried in an approved PCB disposal facility off the site.

In addition, approximately half of the 862 large PCB capacitors were removed from the Booster in 1986. The nonradioactive ones were incinerated. Radioactive PCB capacitors are being held until they become exempt quantities by radioactive decay. Then they will be disposed of by incineration.

3.8 Summary of Hydrogeology

The Fermilab site has thick glacial till consisting primarily of low permeability clay.[31] This clay forms a barrier to the downward percolation of any water containing radioactivity. Beneath the clay the first layer of rock is a dolomite of Silurian age.[4] Its fractured upper 3 m (10 ft) carries sufficient water for individual farm needs. The water level contours for this aquifer are shown in Fig. 9. Note that the water from the Experimental Areas flows toward Well 1, the primary on-site drinking water supply (Fig. 4). Groundwater leaves the site and flows southwest toward the Fox River and southeast toward the West Branch of the DuPage River.

Beneath the silurian dolomite are older formations laid down by sedimentation during the Cambrian and Ordovician periods when the region was under sea water. These consist of dolomite and sandstone with perhaps some shale. The sandstone aquifer at approximately 300 m (1000 ft) below the surface provides sufficient volumes of water for local municipal water supplies.

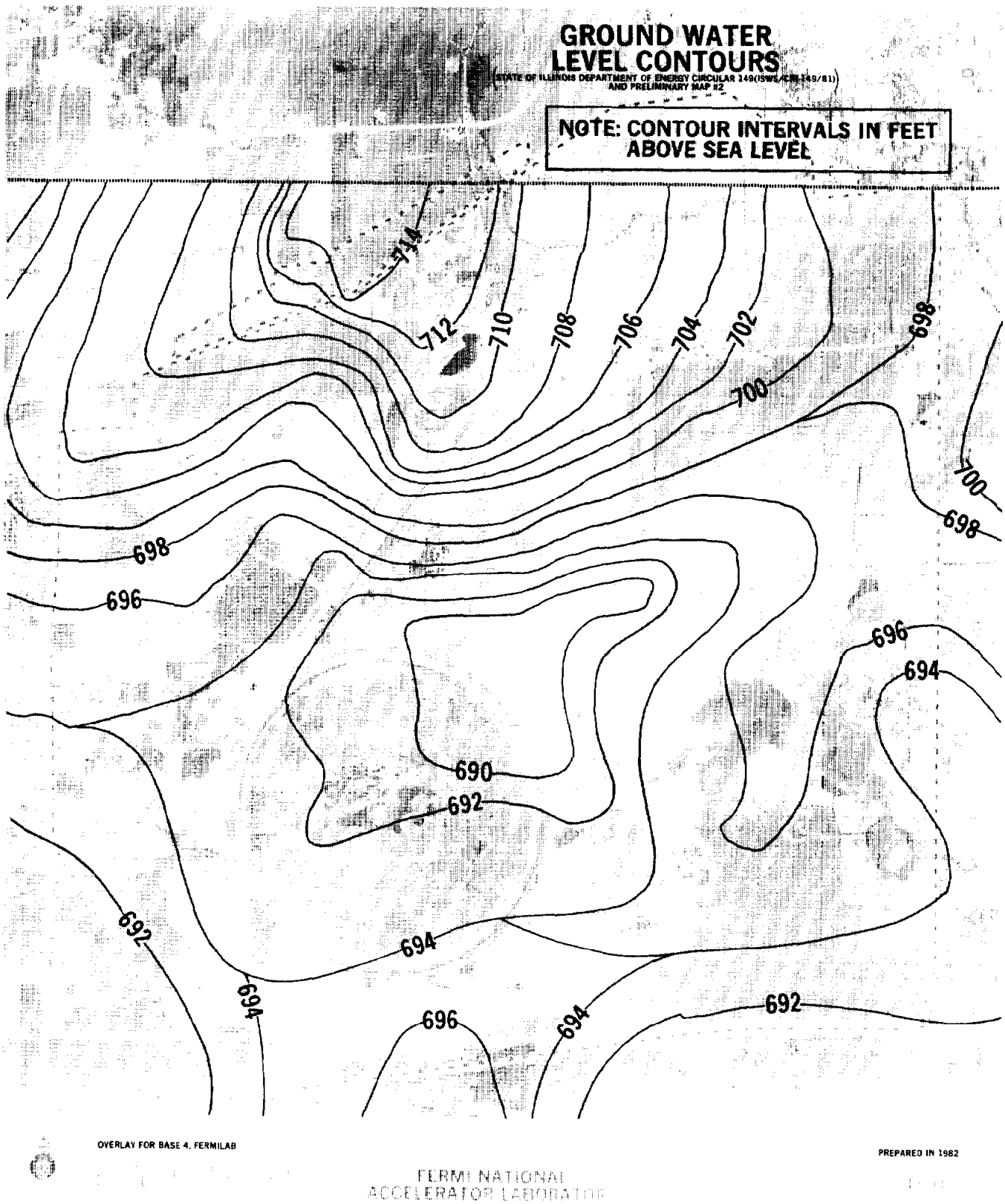
The spillways should be noted as shown on the map of surface water drainage (Fig. 8). In the event of an accidental spill, backup efforts will be concentrated at those points to stop the flow of any hazardous substance if it cannot be contained closer to the discharge point.

3.9 Evaluation of Environmental Impacts

3.9.1 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 (Fig. 3).[32] There are 326,645 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.[33] The detailed distribution of population as a function of distance and direction from Fermilab is given in

Figure 9


GROUND WATER
LEVEL CONTOURS
(STATE OF ILLINOIS DEPARTMENT OF ENERGY CIRCULAR 149(ISWS/CIR-149/81))
AND PRELIMINARY MAP #2
NOTE: CONTOUR INTERVALS IN FEET
ABOVE SEA LEVEL
714
712
710
708
706
704
702
700
698
700
698
698
696
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692
OVERLAY FOR BASE 4, FERMILAB
PREPARED IN 1982
FERMI NATIONAL
ACCELERATOR LABORATORY

Table 7.[31] The population distribution close to Fermilab is shown in Figure 10. The estimated increase in population from 1980 to 1985 is 9% within 16 km (10 mi) of Fermilab based on county and local city population estimates.[1,2]

The dose rate at the site boundary in CY-1986 from Fermilab operations was from airborne radioactivity (^{11}C). The total dose to the individual is 0.0007 mrem for CY-1986. The point where that exposure occurred is along the western site boundary. This is approximately 0.001 percent of the background radiation dose.[34]

The radiation exposure to the general population from operation of Fermilab in CY-1986 was 0.003 person-rem. This exposure was from airborne radioactivity. 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.[33,34] Based on typical United States radiation exposures from diagnostic x-rays, medical treatments, and other artificial sources an additional 500,000 person-rem would be expected for the population in the Chicago area with 80 km (50 mi) of Fermilab in CY-1986.[34] The exposure to airborne radioactivity was determined using the computer program AIRDOSE-EPA.[17] This program or an equivalent method approved by the U. S. Environmental Protection Agency, is required for dose determination.[35]

The magnet debonding oven was used to debond 19 radioactive magnets in CY-1986. The resulting ^{3}H release from the debonding oven stack had negligible impact.

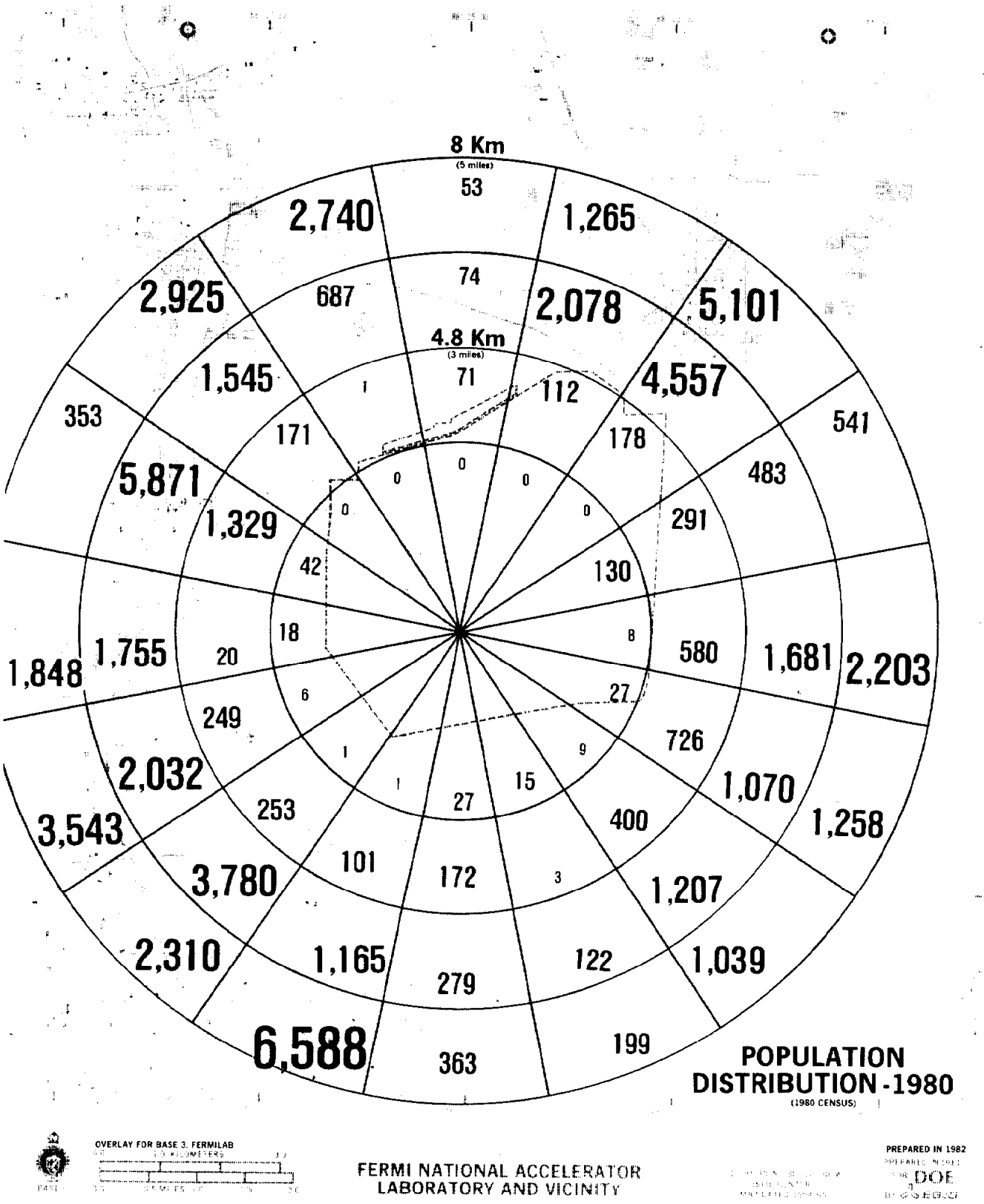
TABLE 7

Incremental Population Data in Vicinity of Fermilab, 1980

DISTANCE, KILOMETERS FROM CENTER OF MAIN RING	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	198	1110	77247	75658	63188	37183	30696	28459	149892
NNE	3455	5821	68274	76075	120930	145415	100858	173092	87495
NE	9836	12718	78701	292724	139718	0	0	0	0
ENE	1445	63784	263526	840460	551913	0	0	0	0
E	4472	18423	218631	1107254	924752	0	0	33317	56442
ESE	3081	15075	92242	268040	597113	379986	196888	78056	17600
SE	2655	25167	37956	34405	106938	38944	24651	11963	10027
SSE	339	3262	44203	148699	7962	21154	70503	10828	13195
S	841	1336	8604	10301	17011	11089	6640	4354	11967
SSW	7055	49656	8635	3492	17420	6373	25217	24588	10469
SW	6344	35851	13598	15566	5317	30917	36362	13671	13226
WSW	5030	2205	5578	6322	4509	10930	8474	11704	12175
W	3641	971	2941	5339	5111	13693	8445	28768	49103
WNW	7595	851	3018	42762	6723	21231	40449	13891	37012
NW	4641	9607	3297	7974	7358	65288	157549	71682	28229
NNW	3428	15152	22722	10674	29830	17952	29399	24276	58430
TOTAL	65656	260989	949171	2945745	2605793	800155	736131	528649	555262
CUMULATIVE TOTAL	65656	326645	1275816	4221561	6827354	7627509	8363640	8892289	9447551

LATITUDE = 41.832 LONGITUDE = 88.251

Figure 10



1986

Table 8

Summary of Population Exposures for CY-1986
Within an 80 km (50 mi) Radius of Fermilab

Source	Contributions to Population Exposures (person-rem)
Airborne Radioactivity from the Antiproton Area	0.003

Several of the closed loop cooling systems were drained during the extended shutdown in CY-1982-3. These were at levels where potential off-site releases, from these loops, would be detectable but not hazardous. The tritiated water was evaporated.[36] Some releases of radioactive water occurred from sumps collecting water from under areas where protons interacted. About 19% of this volume of water left the site while Casey's Pond (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 prolonged exposure to the general population. 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.

The D0 abort system was replaced by a new abort system at C0 in CY-1983, featuring a well-shielded dump (at C1 in Fig. 6). Therefore, no additional soil activation is expected near D0 in the future. The soil was sampled near D0 in CY-1983.[36] Based on those sampling results, no environmental impact is expected from the D0 abort system. The soil activation associated with the new system at C0 should be much lower than at D0. Some ^{3}H and ^{22}Na have been detected in the underdrain beneath the new abort dump. The amount of radioactivity is consistent with the amount expected from design calculations. See Section 3.3.3.4.

A 45^{o} hole was drilled and the soil was sampled beneath the primary target in the Neutrino Area in CY-1984. No evidence was found for movement of radionuclides toward the aquifer (Section 3.3.3.4).

3.9.2 Assessment of Nonradioactive Pollutant Releases

Although it was necessary to chemically treat some waters with aquazine to control the growth of algae and weeds during CY-1986, efforts were made to keep these treatments as low as possible in order to protect wildlife and fish. Minimum amounts were used and the aquazine is biodegradable. No environmental impact was expected. There is a program to look for persistent chemicals in the Fermilab environment periodically.

There were no activities during CY-1986 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. These boilers are adjusted annually to maintain proper combustion efficiency.

3.9.3 Potential Impact of Other Toxic Substances

3.9.3.1 Pesticides

In addition to the water treatments mentioned in Section 3.6.3, the following EPA registered herbicides, insecticides and rodenticides were applied by trained personnel following the manufacturer's instructions:

For broad leaf noxious weed control of the bison pasture 2,4-D Amine was applied to 32 hectares (80 acres) in 1986.

Chipco Turf Kleen, containing 16.1% 2,4-D and 16.2% 2-(2-methyl-4 chlorophenoxy) proponic acid, was applied to turf areas around Wilson Hall, the east reflecting pond and Swan Lake (Fig. 5) to control broad lead weeds. Approximately 15 ℓ (4 gal) was applied to 1.2 hectares (3 acres) in CY-1986.

Roundup, containing 40% isopropylamine salt of N-(phosphonomethyl) glycine, was applied around bases of all trees and sign posts in the Village, around bases of trees along Road-D (Fig. 1), and around all sign posts along all Fermilab roads. Approximately one liter in 240 ℓ (one quart in 60 gallons) was applied per 0.4 hectare (acre). The total applied was approximately 30 ℓ (8 gal).

Corn was planted by licensees in CY-1986 on 9.3 km^2 (2306 acres). Licensees are persons who pay the Laboratory for use of a portion of the land on the site for agricultural purposes. Herbicides were applied as follows:

6800 ℓ (1800 gal) Lasso-atrazine herbicide, containing 27.2% alachlor [2-chloro-2'6'-diethyl-N-(Methoxymethyl)acetanilide] and 15.5% atrazine [2-chloro-4-(ethylamino)-6-(isopropylamino)s-triazine], applied to 5.8 km^2 (1437 acres).

9400 kg (20700 lbs) Counter insecticide, containing 15% terbufos (S-{[(1,1-dimethylethyl)thio] methyl}0, 0-diethyl phosphorodithioate) applied to 9.3 km^2 (2306 acres).

8300 ℓ (2200 gal) Bicep-6L herbicide, containing 27.4% atrazine, 1.5% atrazine related compounds, and 36.1% metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl)acetamide], applied to 3.5 km^2 (869 acres)

Spike 80-W, EPA Registration No. 1471-97, was applied to control weeds around storage areas, parking lots, and hardstand (crushed limestone) areas at electrical substations, Experimental Areas service buildings, and the Bubble Chamber yard. Approximately 56 kg (123 lb) was applied to 0.14 km^2 (41 acres) during CY-1986.

For mosquito control, an ultra low volume application of CYTHION Premium Grade Malathion was performed at 18 different times. Approximately 11 ℓ (2.8 gal) of CYTHION were used in each application and the following areas were covered: Village and Sauk Circle just south of the Village (Fig. 1), Sites 29, 38, and 58 (29, 38, and south of 55 in Fig. 4), and the Meson, Proton and Neutrino experimental areas (Fig. 5).

Contrac Rat and Mouse Bait, EPA #12455-36, a rodenticide, was placed in pan-type feeders inside approximately 40 outdoor electrical substations to reduce rodent nesting in this high voltage equipment. Approximately 11.3 kg (25 lbs) was used in CY-1986.

Approximately 100 trees on the site were treated with Dipel, containing bacillus thuringiensis, for killing eastern tent caterpillars (Malacosoma sp.). Approximately 2.3 kg (5 pounds) was applied diluted in 3785 ℓ (1000 gal) of water.

The services of a contract exterminator, licensed by the State of Illinois and using EPA registered pesticides, was retained during CY-1986 for the control of miscellaneous pests found in kitchens, laboratories and living areas throughout the site.

3.9.3.2 Polychlorinated Biphenyls

An inventory of polychlorinated biphenyls (PCBs) is maintained. PCB inspections are performed and reports made to the U. S. Environmental Protection Agency as called for in the regulations.[36] The PCB Status Report as of January 1, 1986, listed 53 PCB transformers in use, in storage for use, or in storage for disposal. These PCB items have been labeled as required. These totals differ from last year's totals because two askarel-filled (60-70% PCBs) transformers and several oil-filled transformers were properly disposed of.[5] The fluid from draining and flushing the transformers was incinerated in an off-site EPA-approved incinerator. The casings were buried in off-site EPA-approved disposal facilities. One of the askarel-filled transformers had a

rusted casing. A PCB stain was found on the concrete pad when the transformer was moved. The surface of the pad was decontaminated and a note placed in the Decontamination and Decommissioning File for future action. PCB could have penetrated into the concrete. The soil around the pad was removed. Thus, the environmental impact was negligible.

The inventory of large PCB capacitors in use, in storage for use or in storage for disposal was reduced from 2017 to 1860 in CY-1986. The capacitors were disposed of by incineration in an off-site EPA-approved incinerator. Efforts are being made to obtain non-PCB substitutes for those in storage for future use.

3.9.3.3 Hazardous Wastes

Significant progress was made during 1986 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 (Fig. 5). This facility is roofed and fenced, and has a hardstand and three concrete containment areas. An additional facility with concrete containment area for PCBs was developed at Site 3 where the Environmental Monitoring Station is located (Fig. 5). This facility is for inside storage of hazardous materials which are for future use. In CY-1982 a PCB storage building was constructed at Site 55 which is much farther from the site boundary than Site 3. Off-site impact from a potential airborne release of PCBs was greatly reduced when most of the PCB items were removed from Site 3. In CY-1984 a heated chemical waste storage building was added at Site 55. This facility was completed in 1985 and has a hood and a indoor shower and eye wash. It also has indoor containment areas to segregate acids and bases. Typical wastes are solvents, oils, laboratory chemicals, asbestos, acids, and bases.

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 (north of the Meson Lab, Fig. 1) to scatter muons and provide some additional shielding. To assure that none of these materials are hazardous to the environment and none will contribute to the contamination of surface or groundwaters, 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. In 1982 burial of wood, paper and other wood products on the hill was halted.

3.9.3.4 Heavy Metals

Copper sulfate is no longer used to treat the ponding systems. Copper solution from the etching of printed circuit boards was disposed of as hazardous waste or recycled. Chromate treatment of the cooling towers has been replaced by biodegradable treatments. Only trace amounts of copper were released in the CUB Tile Field. The copper came from the regeneration of resins used on copper closed loop water systems. Thus, the environmental impact from heavy metals released in CY-1986 should be negligible.

3.9.3.5 Chlorides

The potential environmental impact of release of chlorides from the resin regeneration process into the CUB clay tile field (Fig. 6) has been evaluated. The process uses sodium hydroxide and hydrochloric acid, yielding sodium chloride (salt) and water. Assuming the salt released in one year (before CY-1986) all ends up in the nearest drinking water well (W1 in Fig. 4) and is diluted in the water normally pumped from the well for one year, the concentration would be less than 25% of the applicable limit of 250 mg/l. See Section 5. Thus, the environmental impact should be minimal. A similar result was found for the impact from salt applied to Fermilab roads in the winter. Disposal of salt in the CUB Tile Field was halted in CY-1986.

4. Quality Assurance in CY-1986

4.1 Quality Control

Water samples collected in CY-1986 were analyzed by Teledyne Isotopes, Inc., 1500 Frontage Road, Northbrook, Illinois 60062. In addition, such samples were counted at the Fermilab Nuclear Counting Laboratory. Tritium and ^{45}Ca analyses were done only by Teledyne Isotopes, Inc. since Fermilab does not have the necessary liquid scintillation counting system. Each shipment to Teledyne included at least one sample prepared at Fermilab containing known amounts of several of the accelerator-produced radionuclides. Known concentrations of tritium were included in every shipment.

4.1.1 Analytical Procedures at Teledyne

Teledyne Isotopes, Inc. analyzes water samples using essentially the same procedures as described previously.[38] Liquid scintillation counting is done using a Beckman Instruments, Inc., LS-230 refrigerated system. A 1 ml aliquot of the sample is placed in 10 or 15 ml of the scintillator "Instagel," manufactured by Packard Instrument Co., Inc., 2200 Warrenville Rd., Downers Grove, Illinois 60515.

The samples were 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 Table 9.

Type 2a: Test for all of the above at groundwater 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.

TABLE 9

Specifications for the analyses of
Accelerator-Produced Radionuclides in Water

Radionuclide	CONCENTRATION GUIDE FOR POPULATION (μCi/mℓ) Prolonged Period of Exposure	Community Water System	SPECIFIED SENSITIVITY AND PRECISION* (μCi/m ℓ) Surface Water	Ground Water
^{3}H	2×10^{-3}	2×10^{-5}	3×10^{-6}	1×10^{-6}
^{7}Be	1×10^{-3}	4×10^{-5}	5×10^{-7}	5×10^{-7}
^{22}Na	1×10^{-5}	4×10^{-7}	3×10^{-7}	2×10^{-8}
^{45}Ca	5×10^{-5}	2×10^{-6}	3×10^{-7}	6×10^{-9}
^{54}Mn	5×10^{-5}	2×10^{-6}	1×10^{-7}	7×10^{-8}
^{60}Co	5×10^{-6}	2×10^{-7}	1×10^{-7}	2×10^{-8}

* The precision and sensitivity are stated for the 95% confidence level (approximately two standard deviations). 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.

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 groundwater sensitivity.

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

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

The specifications for the above analyses are given in Table 9.

4.1.2 Quality Assurance Samples

During CY-1986 Fermilab participated in the DOE Environmental Measurements Laboratory (EML) quality assurance program.[39] Results are given in Table 10. Also, Fermilab sent quality assurance samples monthly to Teledyne Isotopes, Inc., who analyzed Fermilab water samples independently. There were problems with the vendor's performance for samples sent by Fermilab. Some results were reported for the wrong samples initially. See Tables 11 and 12.

Table 10

Quality Assurance Results for Fermilab

Sample Date	Radionuclide	Percentage of Concentration Guide for Surface Waters* (%)	Prepared Concentration	Ratio of Fermilab Result to Prepared Concentration
6/86	^{7}Be	+	1.98×10^{-3} μCi	1.06
	^{54}Mn	+	2.38×10^{-4} μCi	1.08
	^{60}Co	+	2.10×10^{-4} μCi	1.10
	^{54}Mn	4.9	2.47×10^{-6} μCi/ml	1.07
	^{60}Co	47.6	2.38×10^{-6} μCi/ml	1.03

*Prolonged Exposure (Table 9)
+Air Filter

4.2 Additional Quality Assurance Efforts

The scope of the environmental protection program at Fermilab has broadened over the years. The Laboratory has doubled in personnel from the number employed when the first proton beam was extracted from the main accelerator in 1972. Regulations have changed. Much more emphasis is now being placed on control of hazardous wastes and other nonradioactive pollutants.

As the inventory of radionuclides with potential for release to the environment has grown, the environmental monitoring program has expanded. More remote pathways have been explored and additional sampling points have been added. Special investigations have been made to measure concentrations and to detect any unexpected movement of radionuclides. These investigations would provide any necessary early warnings, giving time to take action before an off-site problem occurs. No such warnings have resulted to date.

Table 11

Quality Assurance Results for Teledyne

First Half of CY-1986

Sample Number	Radionuclide	Percentage of Concentration Guide for On-Site Surface Waters (%)	Prepared Concentration (μCi/ml)	Ratio of Teledyne Result to Prepared Concentration*	
				Sample 1	Sample 2
8601	^{3}H	0.17	3.4×10^{-6}	1.3	1.2
8602	^{3}H	0.14	2.7×10^{-6}	1.3	1.3
	^{7}Be	0.10	1.0×10^{-6}	1.0	1.1
	^{22}Na	1.5	1.5×10^{-7}	1.3	1.3
	^{45}Ca	1.8	8.8×10^{-7}	0.57	0.57
	^{54}Mn	3.0	1.5×10^{-6}	1.3	1.4
	^{60}Co	6.6	3.3×10^{-6}	1.2	1.4
8603	^{3}H	0.14	2.7×10^{-6}	1.2	1.2
	^{22}Na	0.14	1.4×10^{-6}	1.3	
		0.13	1.3×10^{-6}+		1.2
	^{45}Ca	2.0	1.0×10^{-6}	0.51	0.51
	^{54}Mn	2.8	1.4×10^{-6}	1.1	1.1
	^{60}Co	6.2	3.1×10^{-6}	1.2	1.1
8604	^{3}H	.07	1.3×10^{-6}	3.3	1.6
8605	^{3}H	5.0	1.0×10^{-4}	1.0	0.99
8606	^{3}H	0.17	3.3×10^{-6}	0.91**	0.94
	^{7}Be	0.84	8.4×10^{-6}	1.0	1.1
	^{22}Na	40	4.0×10^{-6}	1.1	1.1
	^{45}Ca	5.6	2.8×10^{-6}	0.43	0.53
	^{60}Co	62	3.1×10^{-6}	1.2	1.2

*Prepared sample was split for a second analysis.
**Vendor reported results as less than the required sensitivity <3.0 pCi/ml.
+Difference in concentration reflects additional decay before analysis date.

Table 12

Quality Assurance Results for Teledyne

Second Half of CY-1986

Sample Number	Radionuclide	Percentage of Concentration Guide for On-Site Surface Waters (%)	Prepared Concentration (μCi/ml)	Ratio of Teledyne Result to Prepared Concentration*	
				Sample 1	Sample 2
8607	^{3}H	20	3.9×10^{-4}	0.98	0.97
	^{7}Be	5.1	5.1×10^{-5}	1.1	1.1
	^{22}Na	110	1.1×10^{-5}	1.2	1.2
	^{54}Mn	52	2.6×10^{-5}	1.0	1.1
	^{60}Co	19	9.3×10^{-6}	1.3	1.3
8608	^{7}Be	0.44	4.4×10^{-6}	1.0	
		0.42	4.2×10^{-6}+		1.2
	^{22}Na	13	1.3×10^{-6}	1.2	1.1
	^{60}Co	15	7.6×10^{-6}	1.2	1.1
8609	^{3}H	1.7	3.3×10^{-5}	2.0	2.0
8610	^{3}H	0.33	6.5×10^{-6}	1.1	1.1
	^{45}Ca	2.0	1.0×10^{-6}	0.48	0.48
	^{60}Co	6.0	3.0×10^{-6}	1.1	1.2
8611	^{3}H	1.6	3.2×10^{-5}	2.0	N/A

*Prepared sample was split for a second analysis.
+Difference in concentration reflects additional decay before analysis date.

Fermilab has number of closed water systems which build up inventories of radionuclides, primarily tritium. These are sampled periodically to provide information useful for spill control. The precautions taken are imposed based upon the potential environmental impact. Once the concentration exceeds that which can be released according to DOE regulations (Section 5), then a spill plan is written and becomes part of the Laboratory's Spill Prevention, Control, and Countermeasures Plan (SPCC Plan).

When spills occur from closed loop cooling systems, sump pumps are shut off in the vicinity and samples taken to determine whether or not the water in the sump pits can be released. One of the lessons learned from spills is that a leak of water into a vacuum system in a radiation area can result in much higher tritium concentrations in the water pumped out than expected. The water vapor removes tritium from components. Other radionuclides are not removed, so a gamma ray survey meter does not detect the problem.

The Laboratory has strengthened its environmental review program. All new projects requiring project directives and/or affecting land management on the site receive an comprehensive environmental review. The review program includes considerations, such as threatened and endangered species, cultural resources, wetlands, and floodplains, specifically addressed in the National Environmental Policy Act (NEPA).

Groundwater protection from organic chemicals has become a concern in recent years. Testing for several of these has been added to our sampling and analysis program. In addition, the Laboratory has strengthened its waste collection and auditing programs. Hazardous waste generators on the site are now required by regulation[40] to have a waste reduction program. The Laboratory documents these efforts in an annual report to the State of Illinois. This report also gives the quantities and types of hazardous waste generated, stored on-site, and disposed of off the site. The Laboratory does not have an on-site hazardous waste disposal facility.

All radioactive water disposed of in CY-1986 from Fermilab was solidified and sent to a Department of Energy burial facility at Richland, Washington. Some low-level radioactive scrap metal which normally has been declared waste and shipped off-site for burial was used in the construction of shielding blocks. These blocks are being used for reducing the exposure from higher level radioactive materials at the Boneyard (Fig. 5). The composition and radioactivity inside these blocks has been recorded in the Decontamination and Decommissioning File.

In 1986 the Laboratory added a formal chain-of-custody procedure for environmental samples. Signatures are required when samples change hands on the Fermilab site. The documentation accompanies the particular sample.

5. References

The appropriate Radiation Protection Standard for penetrating radiation applied to individuals in uncontrolled areas was taken from the DOE Order 5480.1A, Chapter XI.[6] The annual dose for whole body exposure is 500 mrem when applied to occasional exposures such as might occur during an accident. The appropriate standard for a prolonged period of exposure of the general population is 100 mrem/yr. Exposures to the public from routine Fermilab operations must meet the regulations corresponding to prolonged periods.

The Concentration Guides used in the analyses of the surface water samples for radioactivity were taken from the draft revision to DOE Order 5480.1, Chapter XI, (replacing Table II, Column 2). Derived Concentration Guides (DCG) - Concentrations of Radionuclides in Water and Air that could be Continuously Consumed or Inhaled, Respectively, and Not Exceed an Effective Dose Equivalent of 100 mrem/year. The specifications are given in Table 9. These Derived Concentrations Guides are based on guidance given in International Commission on Radiological Protection (ICRP) Publications 23, 26, and 30, Pergamon Press, New York. For tritium the Derived Concentration Guide is 2×10^{-7} μCi/ml. For ^{11}C the Derived Concentration Guide, for prolonged exposures, is 2×10^{-8} μCi/ml because submersion dose must be included for ^{11}C. The exposure limit for the off-site population is 25 mrem/year per person rather than 100 mrem/year for prolonged exposure to airborne radioactivity. This regulation is imposed by the United States Environmental Protection Agency (EPA) and is found in the U. S. Code of Federal Regulations 40 CFR 61.

The Concentration Guide used in the analyses of groundwater samples for tritium was taken from the U. S. Environmental Protection Agency regulations for community drinking water systems.[22] 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 25 times more stringent than the DOE regulation for a prolonged period of exposure of the general population, which is 100 mrem/year. The proposed EPA regulation based on ICRP-30 lists 9×10^{-5} μCi/ml for ^{3}H. The Concentration Guides for the other radionuclides in Fermilab's analyses of groundwater samples have been determined by dividing the Derived Concentration Guides (DCG) in the draft revision to DOE Order 5484.1 by 25 (Table 9). These agree with the proposed EPA regulations. The specified sensitivity and precision of the analyses have been reduced to well below these Concentration Guides (to at most 10% of the Guide).

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.[29] The waters on-site were considered to be in the "general use" category. The value for total hexavalent chromium for general water quality of 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, for silver are 0.1 and 0.005 mg/l respectively, and for cyanide are 0.025 mg/l for both. The maximum contaminant level for chloride in water for general use is 500 mg/l and the level of total dissolved solids is 1000 mg/l. In public drinking water the standards for chloride and total dissolved solids are 250 mg/l and 500 mg/l, respectively.[41] The Air Quality Standards limit the release for oxides of nitrogen to 136 g (0.3 lbs) per 252 million calories (per million btu's) of actual heat input in any one hour. Release of sulfur doxide shall not exceed 2000 ppm.[29]

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. The concentration limit is 2 ppm for human consumption of fish.[42]

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1986

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1986

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