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

FERMILAB 88/40
1104 100
UC-41

Site Environmental Report

For Calendar Year 1987

May 1, 1988

Samuel I. Baker

Operated by Universities Research Association, Inc.
Under Contract with the United States Department of Energy,
Chicago Operations Office, Batavia Area Office

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

Fermilab 88/40
1104.100
UC-41

SITE ENVIRONMENTAL REPORT FOR CALENDAR YEAR 1987

by
Samuel I. Baker
May 1, 1988

Laboratory Work and Measurements
by
R. A. Allen, R. L. Allen, S. I. Baker, S. Butala, J. H. Baldwin,
A. Elwyn, J. E. Finks III, W. S. Freeman, D. W. Grobe, C. Salsbury,
M. Thomas, and P. Yurista

Operated by Universities Research Association, Inc.
Under Contract with the United States Department of Energy,
Chicago Operations Office, Batavia Area Office

TABLE OF CONTENTS

TABLES

1987

ILLUSTRATIONS

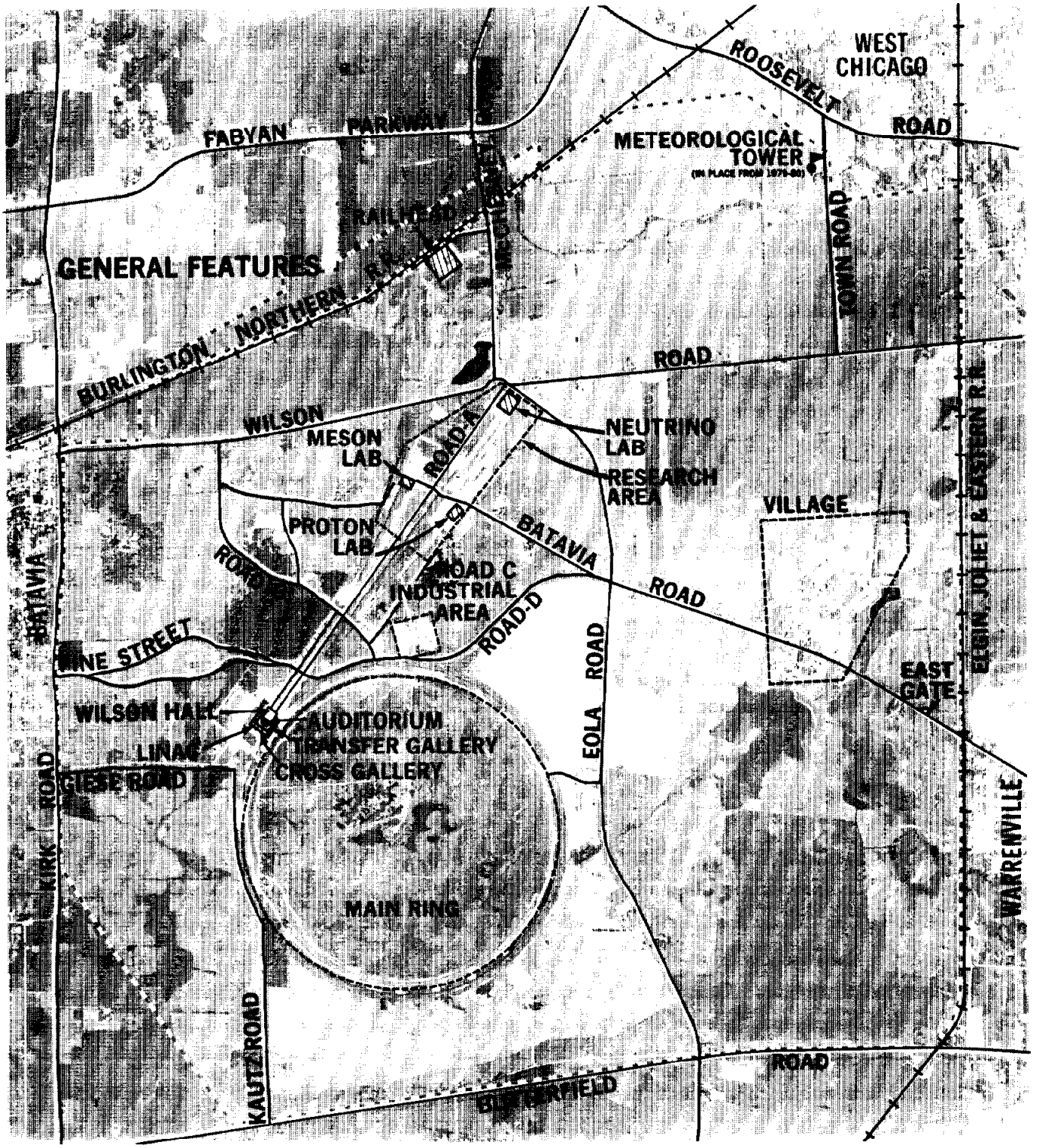
1. Introduction

This report summarizes the environmental activities and their results at Fermi National Accelerator Laboratory (Fermilab) for Calendar Year (CY-) 1987.

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. Then 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 1986 this research was performed by extracting protons from the final accelerator (now a synchrotron using superconducting magnets). These protons were directed onto fixed targets after being extracted from the superconducting synchrotron called the TEVATRON. Collisions of protons and antiprotons each having 900 GeV were used in a research program for the first time in 1987. These collisions were detected at four locations inside the TEVATRON. 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 for fixed target physics 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 Proton Labs located in the Research Area (Fig. 1). All three of these areas received proton beams for the first time in 1972. For colliding beam studies, antiprotons are produced by extracting 120 GeV protons from the ring of conventional magnets inside the main accelerator tunnel. These protons strike a fixed target and the negatively charged antiprotons are collected. Radioactivity is produced as a result of the interaction 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.



OVERLAY FOR BASE 4, FERMILAB

PREPARED IN 1982

FERMI NATIONAL ACCELERATOR LABORATORY

DOE

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. 14,008),[1] Warrenville (pop. 9,668),[2] and West Chicago (pop. 14,246)[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 3080 million liters (814 million gallons) per day from October 1, 1986 through September 30, 1987, and the west branch of the DuPage River which passes east of the site flowing south with an average of 294 million liters (78 million gallons) per day for the same period through Warrenville (Fig. 2).[3] The rainfall on-site during 1987 was 106 cm (41.8 in).[4] 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.[5] Also, there are many individual private wells drilled into the shallow silurian aquifer system around 30 m (100 ft) below the surface.

The primary source of drinking water on the Fermilab site the shallow Silurian dolomite aquifer.[5] Wells 1 and 3 (Fig. 4) are the main wells and collect water from 20 to 70 m (65 to 220 ft) below the surface. Water for the Village (Fig. 1) was obtained from Warrenville to the east beginning in January 1987 and service from Well 62 (Fig. 4) terminated. 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,

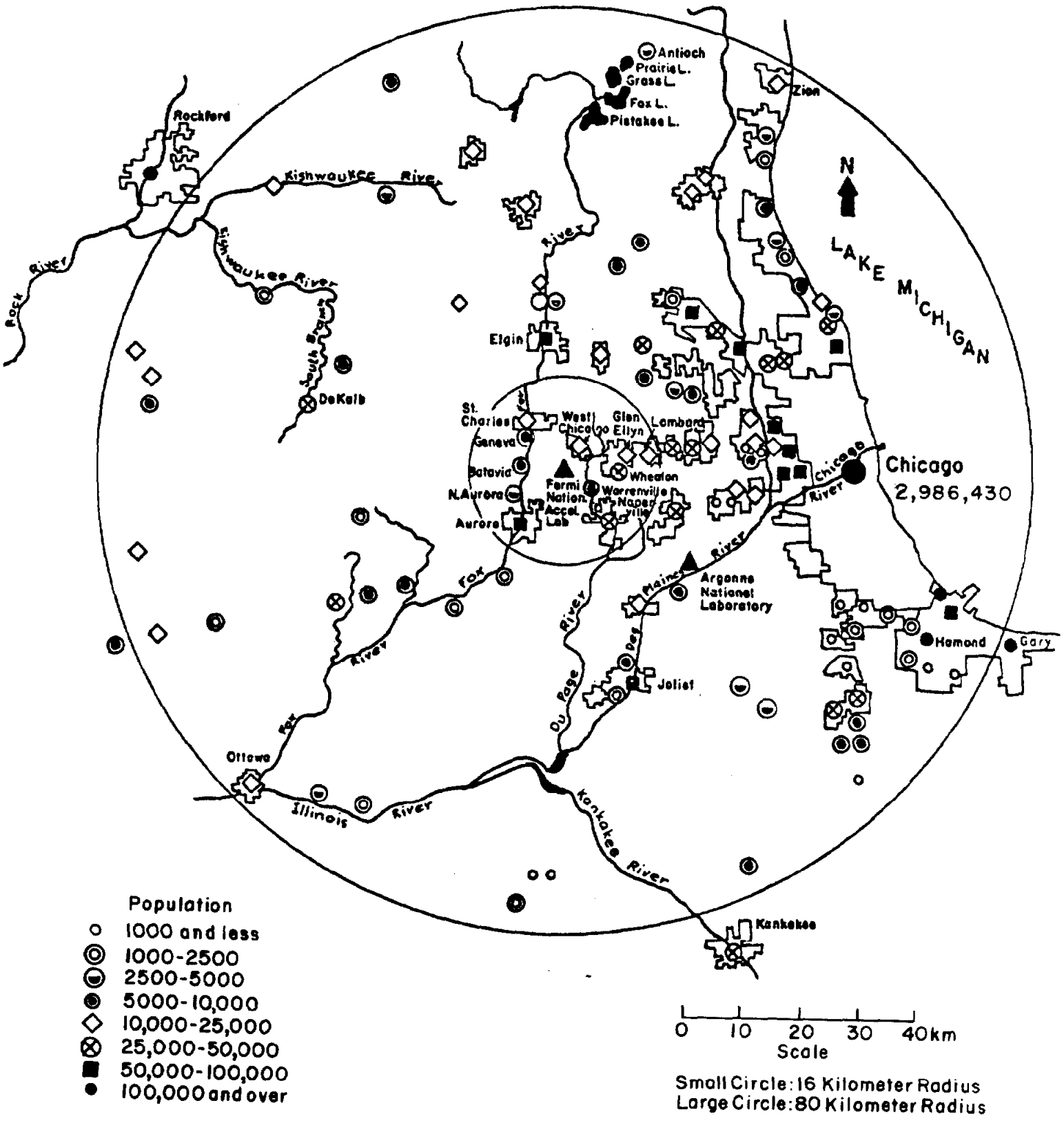
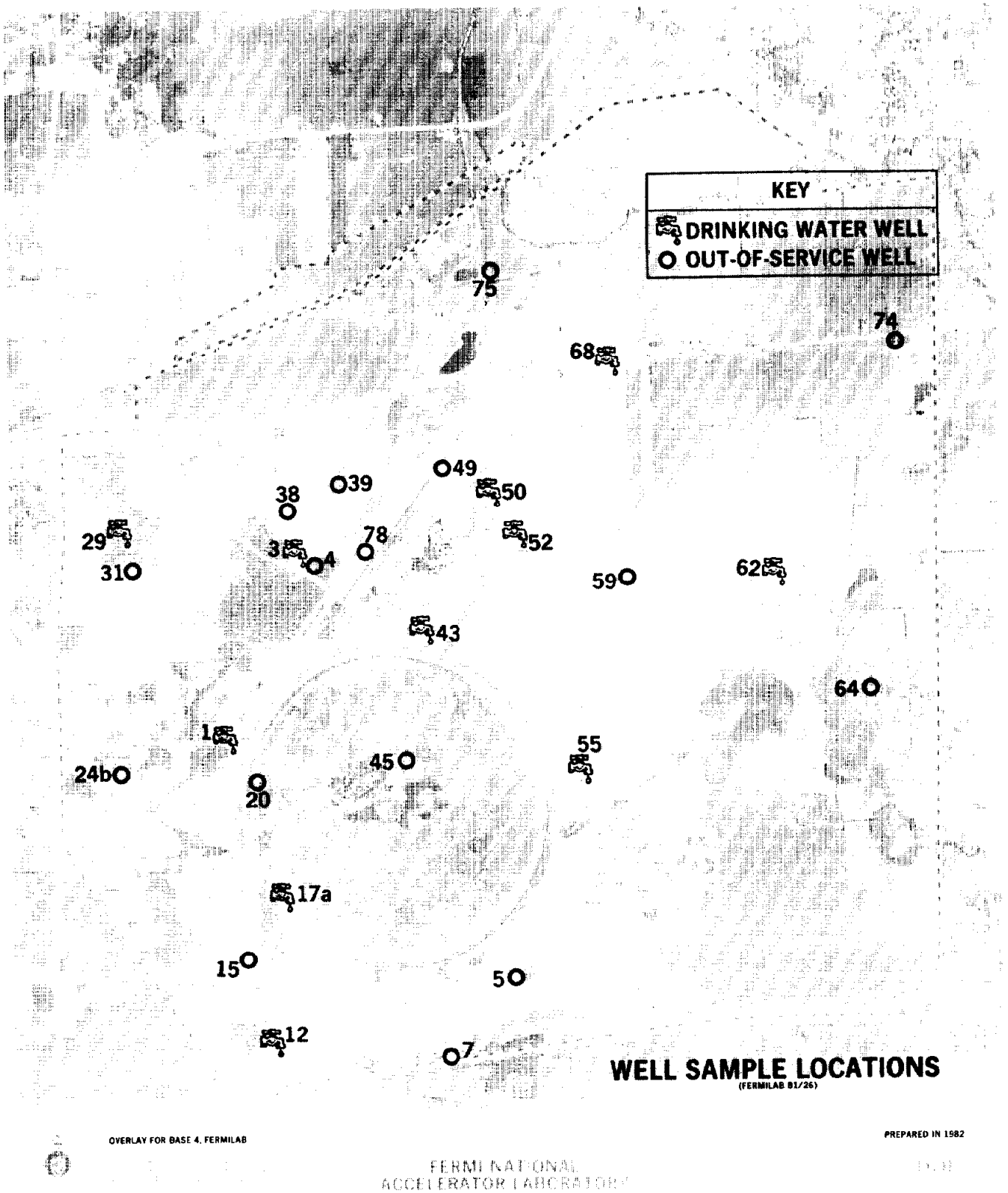


Figure 2 - Location of Fermilab and Population Concentrations within 80 km (50 mi.)


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
45
24b
20
17a
15
5
12
7
WELL SAMPLE LOCATIONS
(FERMILAB 81/26)
OVERLAY FOR BASE 4, FERMILAB
PREPARED IN 1982
FERMI NATIONAL
ACCELERATOR LABORATORY

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 conducted a full year of high-energy physics research in CY-1987. The colliding beam physics program began in early January and extended into May. Protons and antiprotons each having an energy of 900 GeV were directed to collide head-on. In May the large Collider Detector Facility (CDF) detector was removed from the main accelerator tunnel. Protons were extracted at an energy of 800 GeV and delivered to fixed targets in the Meson, Neutrino, and Proton Areas from June through December.

During the colliding beams run a total of 54 curies of ^{11}C, ^{13}N, and ^{41}Ar were released from the Antiproton Source stack. This is greater than the 3.4 curies (Ci) released during the 20 days of testing in CY-1986.[6] During the fixed target program a total of 27 curies of radioactive gas, primarily ^{11}C, were released from the Neutrino Area stack.

There was a negligible exposure from penetrating radiation during the colliding beams experiments; however, muons from the new Muon Laboratory gave a maximum site boundary potential exposure equal to the highest previous annual potential exposure which occurred in 1976. This result gave a total potential radiation exposure of 13 millirem (mrem) at the site boundary during CY-1987 (fence line assuming 24 hr/day occupancy). This is compared to an average of 3.3 mrem per year for the previous years of operation.

The total potential radiation exposure to the general off-site population from Fermilab operations during CY-1987 was 5.3 person-rem, or about twice the average of 2.4 person-rem per year from previous operations. Since the exposure is from penetrating radiation, the 50 year dose commitment from operations in 1987 will be the same as the exposure received in 1987.

A summary of off-site releases of radioactive effluents in CY-1987 is given in Table 1. The total release of airborne radioactivity was 81 Ci from venting of air containing short half-life radionuclides. The off-site release of tritium (^3H) in surface

water totaled approximately 266 mCi, three times last year's release of 83 mCi.[6] The increase was primarily caused by a resumption in automatic pumping of the sump collecting radioactive water from underneath the primary target in the Neutrino Area. In addition, water left the site via the Kress Creek spillway for 38% of the year in 1987 compared with 19% the year before. The amount of rainfall was well above average in 1987, causing water to fill up Casey's Pond more frequently and overflow to Kress Creek. The primary source of tritium in water reaching Casey's Pond from drainage ditches in the Research Area 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 by 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-1987 was essentially from operations before CY-1983.

Table 1

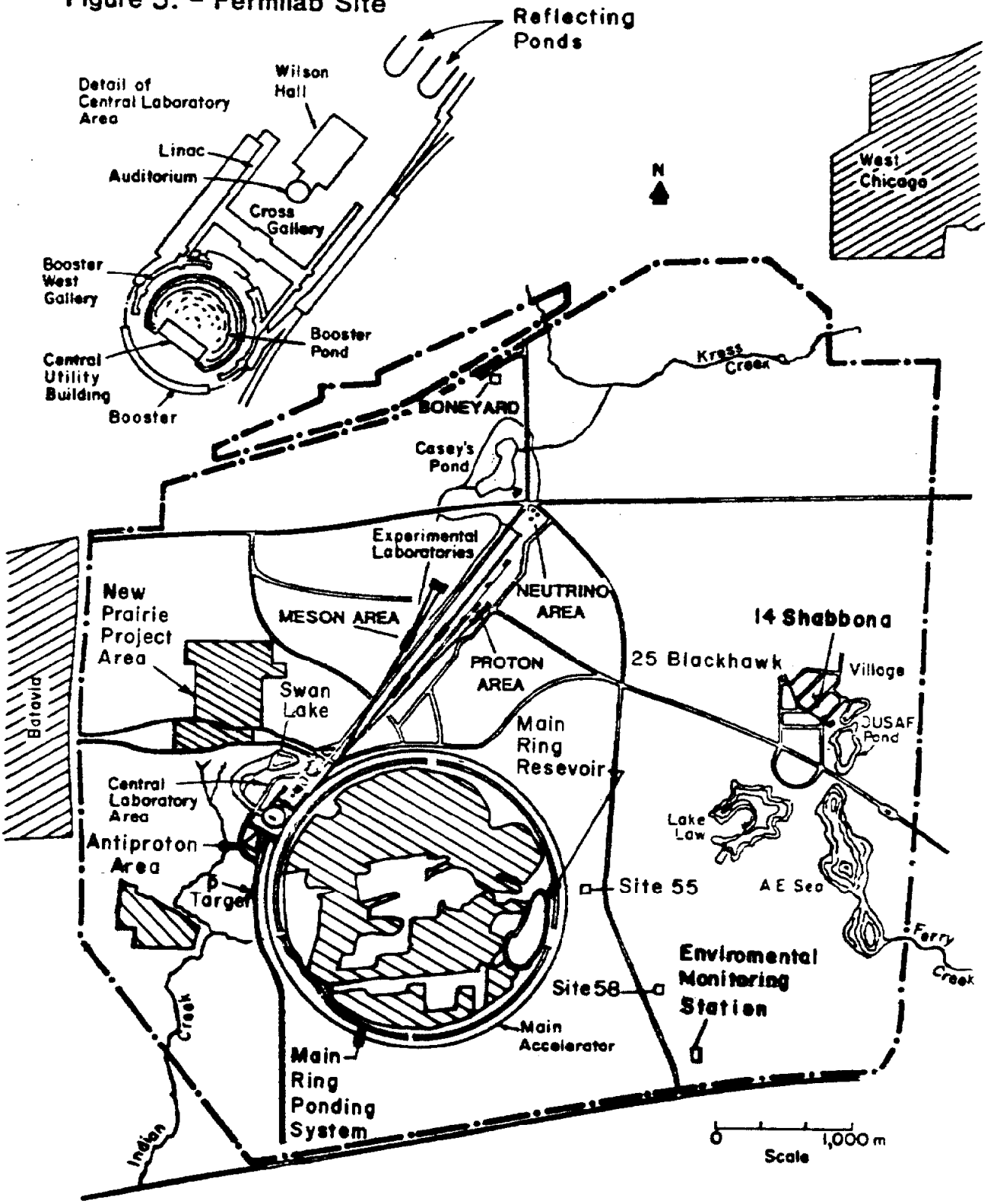
Summary of Radioactivity Released to the Off-Site Environment in CY-1987

Release Point	Radionuclide	Pathway	Release in Curies
NO1 Enclosure	^{11}C, ^{13}N	Air	27
APO Enclosure	^{11}C, ^{13}N, ^{41}Ar	Air	54
Debonding Oven	^{3}H	Air	0.002
Kress Creek Spillway	^{3}H	Water	0.266

During CY-1987 there was one abnormal occurrence which had an impact on the facility and its operation. There was a fire in an experimental hall in the Research Area (Fig. 1) on October 3. An electromagnetic calorimeter, a large detector consisting of alternating thin plates of lead and plastic scintillator, was ignited from a burning cable which was electrically short-circuited. Some lead was released to the environment immediately next to the building, but levels were below regulatory limits. Sprinklers kept the fire from spreading and the experiment resumed in nine weeks.

In order to comply with an October 1988 date for polychlorinated biphenyl (PCB) control, Fermilab has removed large PCB capacitors from the Booster accelerator tunnel (Fig. 5) and from the Capacitor Tree adjacent to the Master Substation (northwest corner of intersection of Roads A and B in Fig. 1). The total number removed was 1596.

Figure 5. – Fermilab Site



Prairie Restoration Project Areas

3. Environmental Program Information

3.1 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.

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.[7] 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).[8] 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.[9]

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, ^{13}N, and ^{41}Ar. 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 done to ensure that no radioactivity reaches drinking water supplies. See Section 4.4.4. Monitoring results are also reported for nonradioactive pollutants. Included as pollutants are pesticides used in weed, insect, rodent, and algae control.

3.2 Summary of Environmental Monitoring Performed in CY-1987

Fermilab performed extensive environmental monitoring in CY-1987, while the colliding beam and fixed target research programs were in progress, on three types of accelerator-produced radiation: penetrating, airborne, and waterborne. The largest source of penetrating radiation 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. 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 continuously operating stack monitors recorded the concentration released from the two stacks emitting essentially all of the radioactivity. 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.

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 during the full year of operations in CY-1987 were much less than the applicable standards in every case. In particular, the highest off-site penetration radiation level was 1.5% of the relevant standard in CY-1985, negligible in CY-1986, and 13% in CY-1987. Operation of the new Muon Laboratory in 1987 produced a cone of muons which resulted in the higher radiation level over a narrow portion of the site boundary. Airborne radionuclide concentrations and waterborne concentrations were below detection limits. See Section 7 for applicable standards.

Monitoring for chemical pollutants in drinking water systems on the site is done periodically. 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.

On January 28, 1987, the source of drinking water for the Village (Fig. 5) was switched from the Village well (62 in Fig. 4) to the Warrenville community water supply. Chlorine concentrations continued to be tested every workday by Fermilab in the Village as well as in the Main Site supply (1 and 3 in Fig. 4). Routine monthly sampling included fecal coliform and pH. Quarterly samples for fecal coliform were sent to the Illinois Environmental Protection Agency (IEPA) for analysis.

There were two tests showing no chlorine in the Village water distribution system. There were 25 tests showing no chlorine in the Main Site system. All other tests were satisfactory. Most of the zero readings in the Main Site system came in June 1987 while Well #1 was shutdown for servicing. The pump was rebuilt, some column pipe replaced, and the standard technique of acidizing to open up silted channels in the bedrock was used. Well #3 served as the supply well during this period. Fermilab was late in sending samples to IEPA twice in 1987. There was also a sample contaminated with atypical bacteria from a faucet with an aerator in the Village. No samples from either supply system contained fecal coliform. Appropriate notices were posted. There was no adverse impact from any of the above noncompliance.

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. No fecal coliform was found in these unchlorinated supplies and none were chlorinated in CY-1987.

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-1987 except for high fecal coliform readings in Kress Creek in April 1987 and Indian Creek in October 1987.

3.3 Environmental Permits

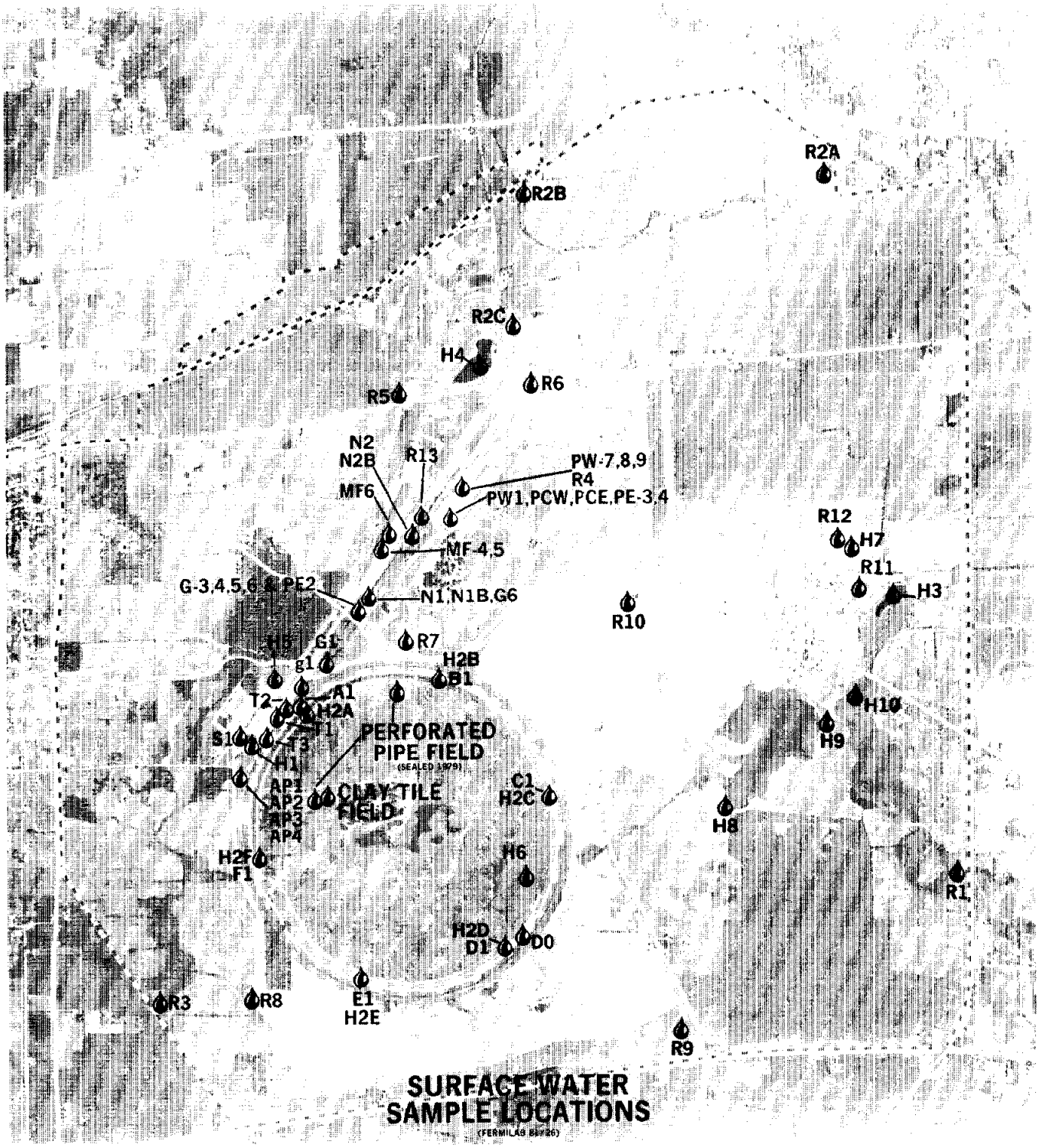
The NPDES permit (IL0025941) was terminated on May 12, 1987, following the connection to the Warrenville sewage collection system in December 1986.[6]

The magnet debonding oven (Section 3.3.2) has an Illinois Environmental Protection Agency permit (I.D. No. 089801AAD, Application No. 79070012) 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 No. 089801-AAD, Application No. 86020057) issued by the Illinois Environmental Protection Agency (IEPA). The permit expires on February 13, 1991. There have been no compliance problems with the systems.

Permit applications were sent to IEPA in CY-1987 for three natural gas boilers at Central Utility Building (Fig. 5), two natural gas boilers at the Wide Band Lab


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
R7
H2B
B1
H5
G1
g1
A1
T2
H2A
T1
PERFORATED
PIPE FIELD
(SEALED 1979)
S1
T3
H1
AP1
AP2
AP3
AP4
CLAY TILE
FIELD
C1
H2C
H10
H9
H8
H6
H2F
F1
R1
H2D
D1
D0
E1
H2E
R3
R8
R9
SURFACE WATER
SAMPLE LOCATIONS
(FERMILAB 84126)
OVERLAY FOR BASE 4, FERMILAB
PREPARED IN 1982
FERMI NATIONAL
ACCELERATOR LABORATORY

in the Proton Area (Fig. 5), and one propane gas boiler at Industrial Building #2 in the Industrial Area (Fig. 1). In addition, applications were sent for a grit blast operation at Industrial Building #2 and a vapor degreaser at Industrial Building #3 in the Industrial Area. Other boilers did not need permits.

IEPA determined that no permits were needed for diazo blueprint copiers, cold vapor degreasers, or small glove box grit blasters which did not vent outside the buildings. Also, a high efficiency particulate filter system to prevent lithium emission in case of an accident did not need a permit because there are no emissions during normal operations.

3.4 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 6 for the evaluation of operations conducted in CY-1987.

3.5 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). 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. In CY-1987 part of the prairie along the tracks was inadvertently covered with soil from the cleaning of a ditch on the other side of the tracks. Personnel from the Burlington Northern uncovered that part of the prairie at Fermilab's request, and the remnant is recovering well.

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. In CY-1987 mechanical harvesting yielded about 4000 kg (9000 lbs) of uncleaned prairie seeds, the largest harvest to date. 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. Archaeological sites being impacted by agriculture were evaluated in CY-1987. No significant findings resulted, but two sites need additional study.

On January 24, 1985, the large transformer T82A 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 760 l or 200 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 CY-1987 about 208 l (55 gal) more 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 was used in preparing the State's proposal for the Superconducting Super Collider. In addition,

several hundred shallow holes (2 to 10 m or 6 to 35 ft deep) were drilled in 1987. Seismic studies were made to locate bedrock using shock waves generated by compressed air released underwater in the holes.

As part of a Laboratory program to reduce the volume of polychlorinated biphenyls (PCBs), most (about 400) of the remaining large PCB capacitors were removed from the Booster in 1987. Some are radioactive and are being held until they become exempt quantities by radioactive decay. Then they will be disposed of by incineration as are the nonradioactive ones. All the capacitors (over 700) in the Capacitor Tree by the Master Substation (northwest corner of the intersection of Roads A and B in Fig. 1) were removed in 1987.

The U. S. Department of Energy Environmental Survey for Fermi National Accelerator Laboratory was conducted from September 14 to September 25, 1987. The purpose of this effort was to identify, via baseline surveys, existing environmental problems and areas of environmental risk at Fermilab. This survey was part of a larger effort to rank the findings on a DOE-wide basis and establish priorities for addressing the environmental problems found.

The Survey team consisted of two members from the DOE Headquarters in Washington, D.C., and seven independent specialists with expertise in dealing with different types of environmental problems. Findings, in general, were placed in four categories based on risk. Fermilab had no findings in the two highest risk categories (Category I and II). There were five findings in the category requiring lengthy investigation (Category III) and nine in the catch-all category (Category IV) which does not necessarily involve environmental risk.

The Survey team found that discharges of chromates from 1974 to 1976 to the old CUB perforated pipe field may be a source of soil and groundwater contamination. They found no evidence of contamination, but felt that more sampling was needed. Similarly, the Survey team felt more effort was needed in searching for the missing oil from the T82A transformer oil spill. In fact, during the Survey approximately 475 l (125 gal) of oil was found in the vault under the Capacitor Tree. This oil had flowed down an open cable duct on the transformer pad the night the spill occurred.

Some PCB spills occurred during removal of the capacitors from the Capacitor Tree and some PCB contamination remains from earlier leaks. Cleanup work was already in progress at the time of the Survey. The team listed that contamination in their findings. The total amount of PCB spilled is estimated to be below the reportable quantity of 4.54 kg (10 lbs).[10]

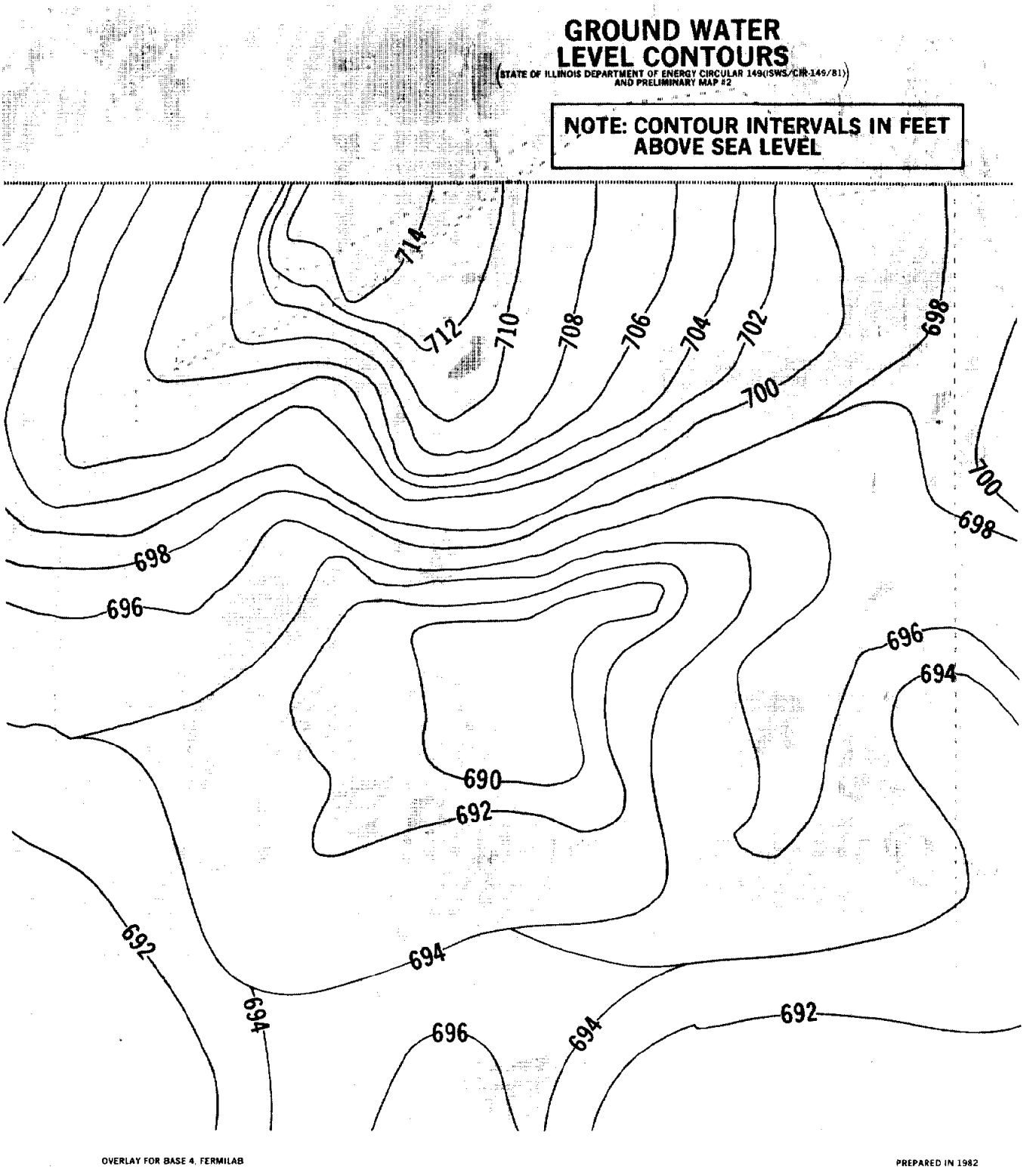
Soil radioactivation has occurred and continues to occur near the NØ1 and MØ1 target areas and the NW4 beam dump as a result of fixed target experiments. The team was not satisfied with the characterization of the soils beneath the underdrains. They felt that the groundwater monitoring system in these areas as well as in the old CUB perforated pipe area and oil spill area needed improvement.

Fermilab has developed an implementation plan to address these deficiencies as well as the remaining ones (Category IV). Work began on the search for chromates in CY-1987. Geophysical explorations for chromate (and chloride) ions included an electromagnetic induction survey and vertical electric soundings (resistivity measurements) in the vicinity of the old CUB perforated pipe field. There was evidence of movement of ions toward the southeast. Soil corings will be made and the samples analyzed for chromate in CY-1988. Work continued on cleanup of the PCB contamination of the Capacitor Tree itself and soils samples were taken.

3.6 Summary of Hydrogeology

The Fermilab site has thick glacial till consisting primarily of low permeability clay.[11] 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.[5] 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. 7. Note that the water from the Research Area 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.


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
696
694
692
690
OVERLAY FOR BASE 4, FERMILAB
PREPARED IN 1982

The spillways should be noted as shown on the map of surface water drainage (Fig. 10). 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.

4. Environmental Radiological Program Information

4.1 Environmental Radiation Monitoring

Three types of accelerator-produced radiation monitored - penetrating radiation, airborne radioactivity, and waterborne radioactivity. These radiations usually 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.

4.2 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 is routinely performed both on and off the site.

A network of detectors was used to monitor penetrating radiation. At the end of CY-1987 there were approximately 120 detectors deployed around the site with the primary purpose of controlling on-site radiation. The majority of these detectors were connected to a data logger which automatically recorded the radiation levels for subsequent examination.[12] In CY-1987 only three 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). Another was a large scintillation counter. It was 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 CY-1987 for determining the exposure levels at the site boundary and for locating the source and direction of penetrating radiation such as muons and neutrons.[13,14,15,16] The

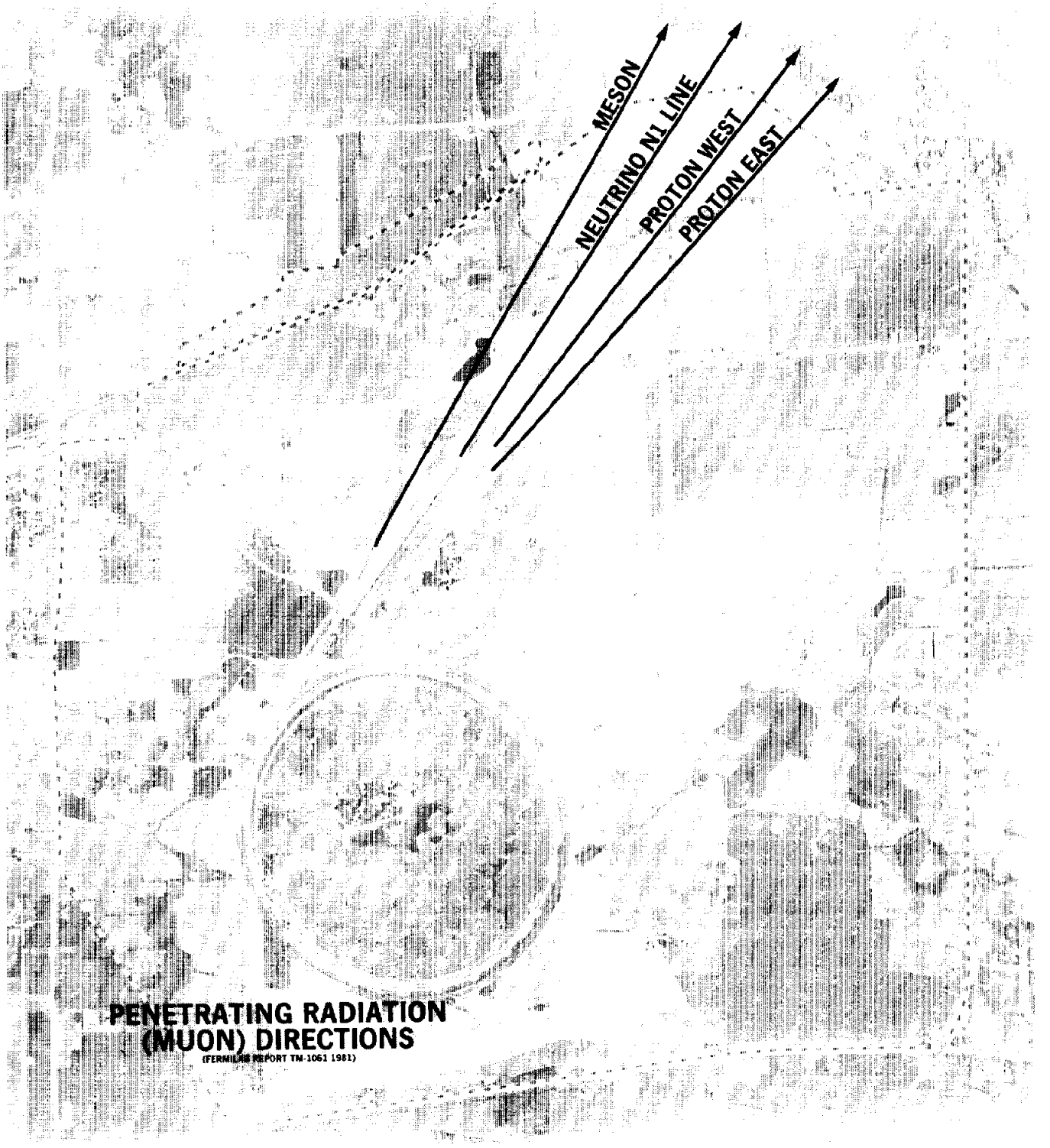
MERL is a four-wheel-drive vehicle equipped with two 20 cm x 20 cm (8 in x 8 in) scintillation counters, one approximately 15 cm (6 in) behind the other, for muon detection. It also has a DePangher "long counter" for neutron detection.[17]

4.2.1 Muons

Measurements of muons from the Meson, Neutrino, and Proton Areas were made in CY-1987 while the accelerator was delivering 800 GeV protons.[18] The directions of the penetrating muons are essentially those shown in Fig. 8. A new beam line between the Neutrino N1 Line and the Proton West Line in Fig. 8 was placed in operation in CY-1987. This line produced a beam of muons for studying their interactions with matter. The line was located 3.7 m (12 ft) below the surface at the Muon Laboratory just north of Wilson Road (just north of the Neutrino Lab in Fig. 1).

The muons which penetrate the earth shielding can travel beyond the site boundary through the air before stopping. Therefore, measurements were made both on and off the site. Muons travel farther than protons because they do not interact strongly with matter. Muons are the cosmic rays of natural background radiation. The muon is basically a heavy electron and hence has the same biological effect (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. This gives one the possibility of deflecting a beam of muons downward to reduce the number which go off-site at ground level. This was done in November 1987 with the muon beam at the Muon Laboratory. The results are shown in Fig. 9. It is clear that future exposures will be greatly reduced (about 15 times less) as a result of the installation of the deflecting magnet.

The site boundary dose rates for CY-1987 were determined from the numbers of protons incident on the targets and the muon dose rates per incident proton obtained by measurements using the MERL (Section 4.2 above). The maximum fence line annual dose based on 24 hour per day occupancy was 13 mrem for CY-1987. Almost all of this muon exposure came from operation of the Muon Laboratory without muon deflection. Muons were also measured from the Meson Area and Proton Area.


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

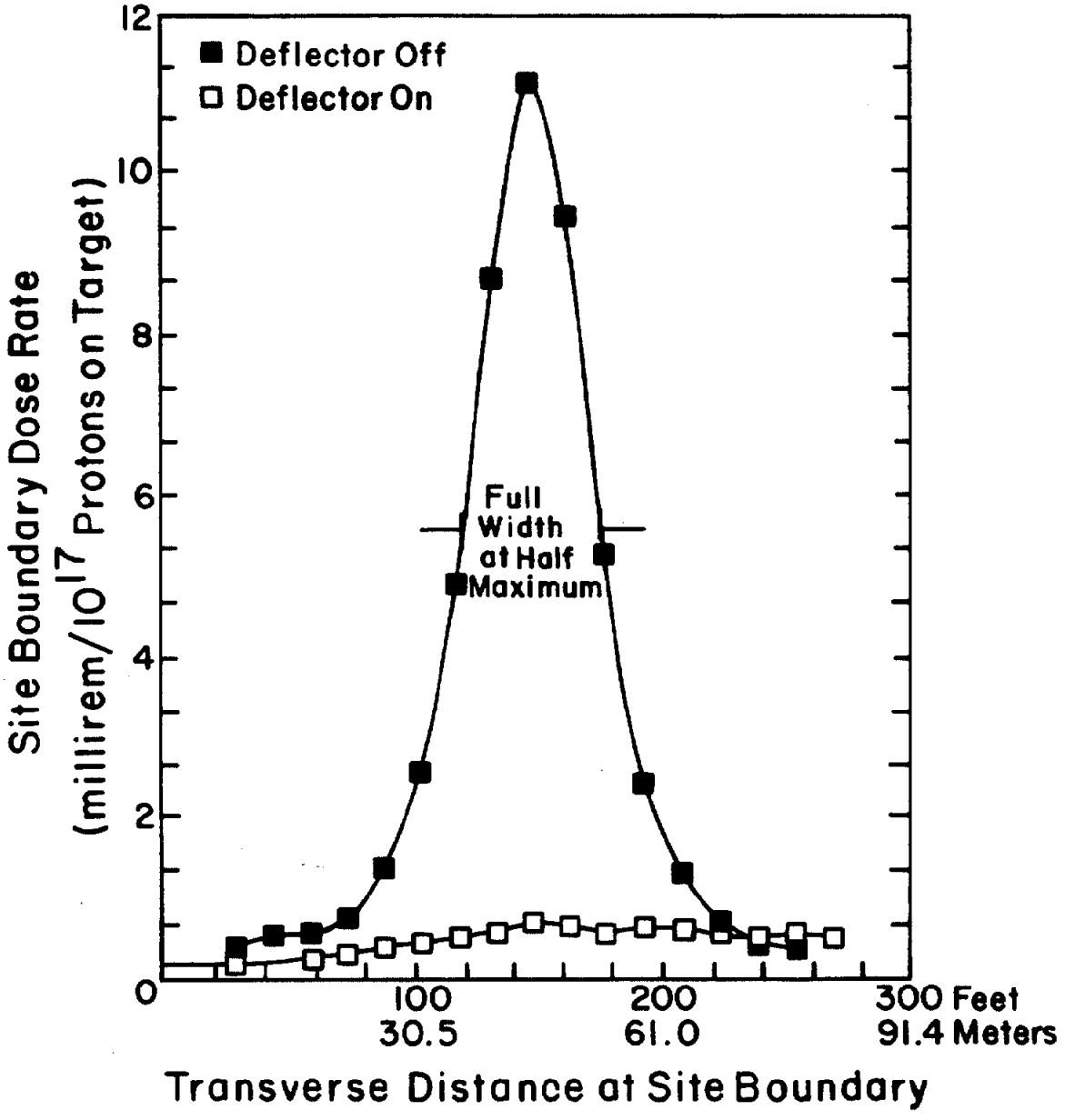


Figure 9. Surface Dose Rate Before
And After Muon Deflection

4.2.2 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-1982.[16,19] However, in CY-1983 additional shielding was added to this area resulting in negligible site boundary dose rates from neutrons since that time.

4.2.3 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. In 1987 radioactive material was moved into a new cave constructed at the southwest corner of the Boneyard. In addition, there was an area nearby designated for radioactive material storage for future use. A large amount of low-level radioactive material was placed in that area. The site boundary dose for CY-1987 was determined using thermoluminescent dosimeters (TLDs), the large volume ion chamber (Hippo), and a hand held NaI (Tl) scintillator (to measure the rate of decrease with distance). The radiation level at the nearest site boundary was 3.5 mrem for CY-1987. The maximum exposure to the individual living closest to that point on the site boundary would have been 0.5 mrem for 1987, assuming 24 hour per day occupancy and a dose rate inversely proportional to the square of the distance from the source. The distance from the site boundary to the residence was 550 m (1800 ft).

4.3 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 the first five months of 1987 the Antiproton Source was in operation and 120 GeV protons were focused onto a target ($\bar{p}$ target in Fig. 5) to produce antiprotons. This target was a source of radioactive gas resulting from interaction in air of secondary particles leaving this target. Because this target is heavily shielded and the air volume is small, there are many thermal neutrons also radioactivating the air. The result is a mixture of ^{11}C, ^{13}N, and ^{41}Ar in air. The ^{41}Ar has a half-life of 1.8 hours and is produced by neutron capture in ^{40}Ar. Air contains about 1% argon which is essentially ^{40}Ar. Interaction of high-energy secondary particles with nitrogen and oxygen in the air produces 20 minute half-life ^{11}C and 10 minute half-life ^{13}N. The total release was 54 Ci from the Antiproton Area Stack (colliding beam operation).

During the last seven months of 1987 the fixed target program was in operation. During that period 800 Gev protons were sent to the Research Area (Fig. 1). The most protons were delivered to the Neutrino Area primary target. This target has less shielding around it inside the enclosure and produces primarily ^{11}C (70% ^{11}C and 30% ^{13}N). The total release was 27 Ci from the neutrino Area stack (fixed target operation).

The site boundary concentrations were calculated using the computer program AIRDOSE-EPA[20,21] (a gaussian plume diffusion model). Wind conditions for O'Hare Airport about 43 km (27 mi) away were used as input. The terrain between Fermilab and the airport is relatively flat. The site boundary dose for CY-1987 found by summing the contributions from the two sources was 0.02 mrem.

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 conventional magnets are radioactive and have failed after years of accelerator operation in the Main Ring tunnel. 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 7) 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-1987 was 11 corresponding to a total release of 2 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. In CY-1987 the wind conditions were similar to those in past years.

4.4 Waterborne Radioactivity

During accelerator operations, some radioactivation of the soil will occur.[22,23] 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.[22] 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 - 36 Samples

2. Fermilab Water Supplies - Approximately 70 m Deep - 3 Samples

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

The wells routinely sampled are shown in Fig. 4. Water samples were also collected from sumps, creeks, and rivers. All surface and groundwater samples collected were analyzed by International Technology Corporation, 1550 Bear Creek Road, Oak Ridge, Tennessee 37831. Each monthly shipment included at least one sample containing accelerator-produced radionuclides in known amounts to check the accuracy of the assays. See Section 7 on quality assurance.

4.4.1 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 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.

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-1987 N1 sump was sampled seven times and N2 sump was sampled eight times. The MF5 sump was sampled seven times, the MF4 sump and the PW8 sump were sampled quarterly. Radioactivity was seen for the first time in a sump near the NM2 enclosure in 1986. This sump, designated NM2, was sampled bimonthly. The NM2 sump is near N1 in Fig. 6. 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. In CY-1987 the N1 sump pump controls were repaired and it is now pumping automatically. As a result the concentration of tritium in the NM2 sump has decreased.

6. The N1 retention pit was sampled bimonthly and the retention pit nearby in the south addition to the Neutrino Target Hall designated NØ1RP, was sampled five times during CY-1987. 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 Creek and Indian Creek were sampled three times and Kress Creek was sampled eight times in CY-1987.

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 semiannually upstream and downstream from the creek mouths.

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 was 24 in CY-1987.

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. More frequently, samples are analyzed on-site at the Nuclear Counting Laboratory. 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. Throughout CY-1987 effluent containing radioactivity from the regenerations went to a settling tank rather than to the Central Utility Building (CUB) tile field inside the Main Ring. After the salt (essentially NaCl), had precipitated, carrying the radionuclides out of solution with it, the water was drained off the top and sent to the tile field. The pH was adjusted before discharge to ensure that it was not a hazardous waste.

    Throughout 1987 the salt was pressed to remove water and is being stored until approval for disposal as radioactive waste is received.

13. In the past several samples were collected annually to look for radioactivity leached from activated steel. Only one sample was collected in CY-1987.

4.4.2 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 4.4.1 above. No accelerator-produced radionuclides were reported in three water samples taken from Ferry Creek (R2A in Fig. 6) and four 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 (both naturally occurring) from the deep well. One set of river water samples was obtained during CY-1987 from the Fox River in Aurora upstream and downstream from the mouth of Indian Creek. Also, one set of three samples was obtained from the west branch of the DuPage River in Warrenville (Fig. 2) upstream and downstream from the mouth of Kress Creek and farther downstream past the mouth of Ferry Creek. Neither river is utilized as a drinking water supply downstream from the creek entrances.

4.4.2.1 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. Water collected from around footings of buildings and underground enclosures and discharged from sumps is considered surface water. Water in aquifers is called groundwater. The total off-site release in surface waters was 266 mCi of tritium this year, about three times the 83 mCi released last year. This increase resulted primarily from resumption of automatic pumping from the sump in the Neutrino Area which collects water from under the primary target (N1 in Fig. 6). No measurable radioactivity was detected in the off-site release. 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.

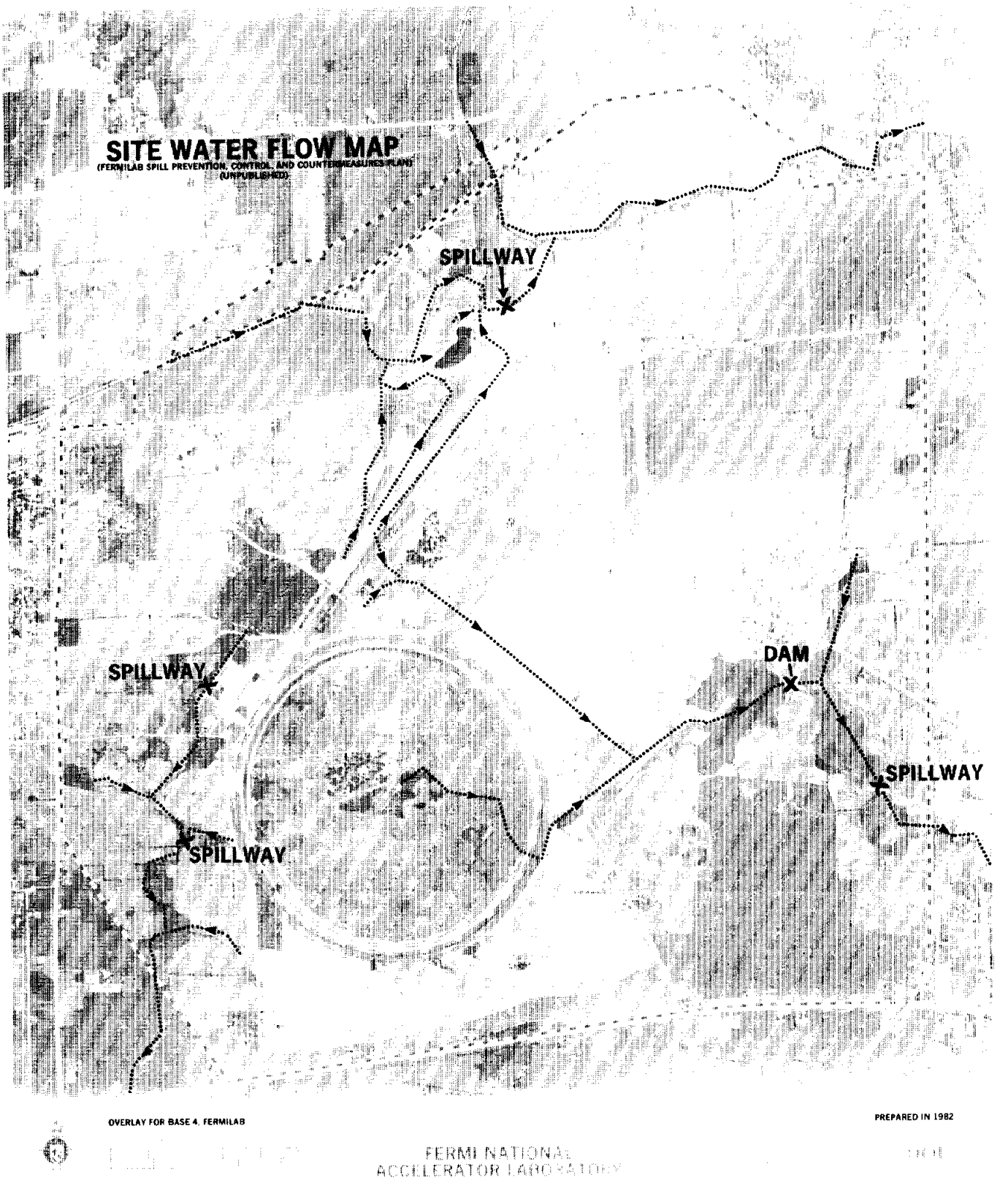
The surface water from the experimental areas (Fig. 5) flows into Casey's Pond except during wet seasons. Then, the pond fills up (68 million l or 18 million gal capacity) and barricades are placed at the two entrances to the pond to keep the water from flooding the pump room. When these barriers, called stop logs, are in place, the water bypasses the pond and leaves the site via Kress Creek (Figs. 5 and 10). This was the case for approximately 38% of the year in CY-1987 because of the much higher amount of rainfall than average. There were no discharges of radioactivity totaling greater than 1 mCi from a closed loop water system leak in CY-1987.

Table 2

Tritium Detected in On-Site Water Samples
Tritium Concentration C (μCi/ml)*

Collection Point	Number of Samples	C Max	C Max Error	C Min	C Min Error	C Mean	Percentage of Standard
C1 Sump	2	4.5×10^{-6}	1.0×10^{-6}	$<3.0\times10^{-6}$	—	3.8×10^{-6}	0.19
G1 Minor Sump	1	9.4×10^{-6}	2.2×10^{-6}	9.4×10^{-6}	$2.2\text{-}10^{-6}$	9.4×10^{-6}	0.47
G3 Sump	5	4.6×10^{-6}	1.0×10^{-6}	$<3.0\times10^{-6}$	—	3.3×10^{-6}	0.17
G4 Sump	2	3.0×10^{-5}	3.0×10^{-6}	$<3.0\times10^{-6}$	—	1.7×10^{-5}	0.85
G5 Sump	2	2.1×10^{-5}	3.2×10^{-6}	3.8×10^{-6}	9.0×10^{-7}	1.2×10^{-5}	0.6
G7 Sump	5	2.1×10^{-5}	3.0×10^{-6}	$<3.0\times10^{-6}$	—	1.0×10^{-5}	0.5
MF4 Sump	4	9.4×10^{-6}	1.2×10^{-6}	$<3.0\times10^{-6}$	—	4.8×10^{-6}	0.24
MF5 Sump	6	8.0×10^{-5}	9.0×10^{-6}	2.9×10^{-5}	4.5×10^{-5}	6.0×10^{-5}	3.0
N1 Sump	7	3.3×10^{-4}	3.3×10^{-5}	2.4×10^{-5}	4.0×10^{-6}	1.3×10^{-4}	6.5
N2 Sump	8	1.7×10^{-4}	1.2×10^{-5}	5.1×10^{-5}	2.0×10^{-6}	8.9×10^{-5}	4.5
N2B Sump	2	6.3×10^{-6}	1.2×10^{-6}	4.6×10^{-6}	9.0×10^{-7}	5.4×10^{-6}	0.27
NM2 Sump	6	5.5×10^{-6}	1.0×10^{-6}	$<3.0\times10^{-6}$	—	3.7×10^{-6}	0.19
PW6 Sump	2	6.4×10^{-6}	1.3×10^{-6}	4.7×10^{-6}	1.0×10^{-6}	5.5×10^{-6}	0.28
PW8 Sump	4	1.5×10^{-5}	2.0×10^{-6}	5.7×10^{-6}	1.1×10^{-6}	9.6×10^{-6}	0.48

* 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 our location.


SITE WATER FLOW MAP
(FERMILAB SPILL PREVENTION, CONTROL, AND COUNTERMEASURES PLAN)
(UNPUBLISHED)
SPILLWAY
SPILLWAY
SPILLWAY
DAM
SPILLWAY
OVERLAY FOR BASE 4, FERMILAB
PREPARED IN 1982
FERMI NATIONAL
ACCELERATOR LABORATORY

4.4.2.2 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. The tritium remains in the cooling water system. These resins are regenerated in two separate systems located at the Central Utility Building (Fig. 5). The effluent from these two systems is sent to a settling tank for removal of almost all of the radioactivity before it is sent to a clay tile field inside the Main Ring (Fig. 8). 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 any residual radioactivity released will place no burden on the environment. The amount of ^{7}Be discharged to the tile field in CY-1987 was negligible.

4.4.2.3 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.

4.4.3 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 could 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-1987 Sediment Sampling Results

Location	Concentration (pCi/g dry weight)				
	^{7}Be	^{22}Na	^{54}Mn	^{60}Co	^{137}Cs
Ferry Creek	---	---	---	---	0.18±.02
Indian Creek	---	---	---	---	0.21±0.03
Kress Creek	---	---	---	---	0.24±.03
MS1 Sump	11.8±1.3	0.17±.03	---	---	0.11±.02
NØ1SP4 Sump	1.1±.6	0.25±.03	0.14±.02	0.24±.04	0.07±.02
NW4SP1 Sump	3.0±0.7	0.36±.04	0.07±.02	---	0.08±.02
PW6SP2 Sump	1.2±0.5		0.05±.02	0.02±.01	0.03±.01
T-3 Sump	1.0±.3	0.75±.06	---	0.04±.01	0.10±.02
CUB Tile Field	8.5±2.8	0.39±.04	0.03±.03	0.10±.01	0.21±.03
APØ Stack (0m)	0.99±.28	<0.04	---	---	0.07±.02
APØ Stack (1m)	4.0±1.1	0.06±.02	---	---	0.05±.02
APØ Stack (10m)	90.2±6.6	5.2±0.3	---	---	0.11±.02
APØ Stack (100m)	15.7±1.5	0.4±.04	---	---	0.20±.02
NØ1 Stack (0m)	---	---	---	---	0.07±.02
NØ1 Stack (3m)	15.4±1.2	0.04±.02	---	---	0.07±.02
NØ1 Stack (10m)	10.4±1.3	0.32±.03	---	---	0.05±.02
NØ1 Stack (100m)	13.8±1.5	0.19±.03	---	---	0.06±.02
MØ1 Stack (0m)	1.0±0.4	---	---	---	---

An annual vegetation sampling program was initiated in CY-1978. Vegetation samples were taken near the radioactive gas exhausts in the Neutrino Area (N1 in Fig. 7) and Antiproton Source ($\bar{p}$ target in Fig. 5) in addition to vegetation samples in areas with waterborne radioactivity. See Table 4.

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.[19] In other samples based on previous results[24] 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 correlation to CY-1986 data.[6] 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).

Table 4

CY-1987 Vegetation Sampling Results

Location	Concentration (pCi/g dry weight)				
	^{3}H	^{7}Be	^{22}Na	^{54}Mn	^{60}Co
Ferry Creek		5.7±2.8	---	---	---
Indian Creek		---	---	---	---
Kress Creek		11.3±3.0	---	---	---
MS1 Sump		11.4±2.5	3.75±.29	0.32±.08	---
NØ1SP4 Sump		21.7±2.3	4.11±.27	---	0.48±.04
NW4SP1 Sump		12.3±2.2	2.16±.16	---	0.08±.01
PW6SP2 Sump		11.4±1.4	---	---	---
T-3 Sump		27.2±2.1	0.51±.06	0.06±.03	0.12±.06
CUB Tile Field		7.9±1.4	0.08±0.4	0.10±.04	0.03±.03
APØ Stack (0m)	45.9±1.7	27.5±2.4	---	---	---
APØ Stack (1m)	35.2±1.4	16.0±1.9	---	---	---
APØ Stack (10m)	6.87±.83	11.8±1.5	---	---	---
APØ Stack (100m)	14.2±0.9	18.7±1.9	---	---	---
NØ1 Stack (0m)	12.6±0.9	11.5±1.9	---	---	---
NØ1 Stack (3m)	84.0±2.8	752±53	0.25±.10	---	---
NØ1 Stack (10m)	24.7±1.1	22.9±2.3	---	---	---
NØ1 Stack (100m)	10.5±0.9	10.4±1.5	<0.13	---	---
MØ1 Stack (0m)	20.1±1.2	7.7±2.2	---	---	0.12±0.0

4.4.4 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[25] - 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.[22]

In CY-1987 a soil boring was made 2 m (6 ft) from the end of the Switchyard Beam Dump (near G1 in Fig. 6). This beam dump is used intermittently during the adjustment of the numbers of protons delivered to different fixed target experiments in the Research Area (Fig. 1). The dump is water-cooled and has a separate outer container which can be checked for water leaking into it by opening a drain. This volume has remained dry since the dump was installed in 1971. Thus, any radioactivity in the soil or water leached from it should be from soil activation.

The samples from the soil boring were analyzed for ^{3}H and ^{22}Na. The concentrations were the low values expected based on the number of protons incident on the dump. The highest ^{3}H concentration was 2.1 pCi/ml in water stirred with an equal amount of soil by weight for one hour. Before leaching, the soil was assayed for ^{22}Na and 0.7 pCi/g was found. Up to 20% of the ^{22}Na is leachable from soil depending on the soil type (particle size or surface area exposed).[22,26]

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.[27] 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 8). We have begun a program of pumping water from the sampling underdrain periodically to keep the concentration low. It was not necessary to pump any water in CY-1987.

5. Environmental Monitoring for Nonradioactive Pollutants

5.1 Domestic Water Supplies

The primary drinking water supply at Fermilab in CY-1987 was provided by a well pumping from an aquifer approximately 70 m (220 ft) deep. This well (1 in Fig. 4) is located in the Central Laboratory Area. A second 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). Water for the Village is no longer supplied by the Village well (62 in Fig. 4). On January 28, 1987, the Village system was connected to the supply from Warrenville, the neighboring community to the east. The Village well was totally removed from the system.

The Main Site system is chlorinated at the Central Utility Building when Well #1 is providing water. The alternate supply source for Well #1 is Well #3 which has its own reservoir and chlorinator. Our water laboratory conducts tests for pH and fecal coliform monthly. Tests of the Village system are also conducted monthly. Quarterly samples for total coliform per 100 ml were sent to IEPA for analysis for both systems. No fecal coliform was found and pH conformed to Illinois standards during 1987. The chlorine level in these chlorinated drinking water supplies is tested each workday. Test results for the Village conformed to standards except for two days in April when no chlorine was detected. There were 25 tests showing no free chlorine in the Main Site system. Total chlorine was not tested. Most of these tests were in June 1987 while Well #1 was shutdown for servicing. The pump was rebuilt, some column pipe replaced, and the standard technique of acidizing the well was used to open up silted channels in the bedrock. Well #3 served as the supply well during this period. The average use from Well #1 and Well #3 combined was approximately 447,000 l/day (118,000 gal/day) during 1987 an increase of 69% from 1986 and 24% from 1985.[6,27]

Wells are monitored periodically to see if water meets the State of Illinois standards even in cases where the standards are not mandatory.[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.

Several 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 are exempt from the standards for iron and manganese. These standards only apply to community water supplies serving larger populations.[27] Fermilab no longer has a community water supply. Water for the Village is obtained from Warrenville. The Fermilab Main Site supply (Well #1 and Well #3) and the well at Site 55 are currently the only site non-transient, non-community supplies and will need to meet the new regulations for these systems.[29]

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. No wells needed chlorination in CY-1987.

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 has a high total organic carbon value compared to other wells. This might indicate organic infiltration. This well is behind a former farm house. There is evidence for a dug well east of the existing well. Thus, there is a potential pathway for organic pollutants to reach the well.

5.2 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 Utility 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. 6) 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 10).

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 10).

The water in these systems normally meets the quality requirements of water in general use in Illinois (Section 7).

5.3 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 10). 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 1987 are found in Table 5. Tests for fecal coliform bacteria are made monthly in our water laboratory. Levels above 200 were found in Indian Creek and Kress Creek in CY-1987. 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 effects.

Table 5

Site Wide Water Quality Report for CY-1987

	pH		DO mg/l		BOD5 mg/l		Susp. Solids mg/l		Fecal Coliform mg/l	
	April	Oct	April	Oct	April	Oct	April	Oct	April	Oct
Ferry Creek	8.2	8.3	8.9	10.2	7.2	5.3	64	6	30	164
Kress Creek	7.8	7.8	8.7	8.4	2.5	1.9	10	2	396	28
Indian Creek	7.8	8.0	9.0	10.2	2.1	1.6	16	1	16	444
Casey's Pond	8.3	8.7	8.7	9.6	1.9	2.9	0	6	14	44
Fox River	8.3	8.5	8.7	10.2	7.2	5.3	97	12	20	56
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.

5.4 Sewage Treatment

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 IEPA terminated the NPDES permit for the Village Oxidation Pond on May 12, 1987, at the Department of Energy's request.

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

5.5.1 Chlorine

In addition to the routine chlorination of the Main Site water system and the swimming pool, 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.

Bromine was used for the first time in 1987 for water treatment at Fermilab. Water pumped from Casey's Pond was treated with a 1-Bromo-3chloro-5,5-dimethyl hydantoin chemical in a slowly dissolving granular form. This chemical, Nalco 85WT-037 PULV, is supplied by Nalco Chemical Company, One Nalco Center, Naperville, Illinois 60566. The bromamines formed when the chemical reacts with

agricultural based amines are more effective biocides than chloramines. Thus, better control of biological growth in the heat exchangers in the Research Area is expected using this treatment instead of chlorination. No treatment has been done in the past because air towers rather than industrial water heat exchangers were used. The long-term environmental effects of bromine use are under investigation. Also, a comprehensive monitoring program to minimize the amount of chemical required has been initiated. The total available halogen was adjusted to be 0.2 mg/l or less in the water as it leaves the heat exchangers. Also, a polyglycol biodispersant, Nalco 7349, was used initially to improve the effectiveness of the bromine treatment on heat exchangers fouled with significant amounts of slime forming bacteria. All treatment stopped when the weather got cold since the bacterial action diminished. The total amount of Nalco 7349 used in CY-1987 was 180 kg (400 lbs) and the total amount of Nalco 85WT-037 used was only 340 kg (750 lbs) since treatment began late in the summer.

5.5.2 Dalapon

Drainage ditches in the Neutrino Area, near the new Muon Laboratory north of the Neutrino Lab, in the Industrial Area and along the road inside the Main Ring (Fig. 1) were treated with Dalapon M, containing 2,2-dichloropropionic acid, in CY-1987 to control cattail (Typha sp.) growth. A total of 55 kg (122 lbs) was applied to 3.64 hectares (9 acres).

5.5.3 Aquazine

The Village Oxidation Pond was treated three times in CY-1987 in an attempt to control algae growth and reduce suspended solids. The total applied quantity of Aquazine, containing 80% simazine: 2-chloro-4, 6-bis (ethylamino)-s-triazine, was 218 kg (480 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-1987 (Fig. 5). Approximately 1633 kg (3600 lbs) of Aquazine was applied to the Main Ring Ponding System, 433 kg (954 lbs) was applied to the Swan Lake/Booster Pond System, and 63 kg (139 lbs) was applied to the reflecting ponds.

5.5.4 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 1987. 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. 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 (NaCl) is formed. Trace amounts of ^{7}Be are also removed (Section 4.4.2.2). 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. Concentration of the radionuclides by reducing the water content with a press has resulted in detection of ^{60}Co in the salt. Disposal methods are being investigated.

6. Evaluation of Environmental Impacts

6.1 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).[31] 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.[32] The detailed distribution of population as a function of distance and direction from Fermilab is given in Table 6.[32] The population distribution close to Fermilab is shown in Fig. 11. The estimated increase in population from 1980 to 1987 is 11% 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-1987 from Fermilab operations was primarily from muons from the new Muon Laboratory. The total dose to the individual receiving the maximum was 13 mrem for CY-1987. The point where that exposure occurred is along the northeastern site boundary. This is 12% of the background radiation dose.[33] The dose rate at the site boundary from the Boneyard was 3.5 mrem but decreased to only 0.5 mrem at the nearest residence.

The radiation exposure to the general population from operation of Fermilab in CY-1987 was approximately 5.3 person-rem (Table 7). This exposure was primarily from penetrating radiation (muons and gamma rays). The exposure to the general population was smaller this year than in some years when the dose to the individual receiving the maximum dose was much lower. The reason was that the muons from the Muon Laboratory came out in a cone only 18 m (60 ft) full width at half the maximum intensity (FWHM) at the site boundary 3700 m (12,100 ft) from the source. (See Fig. 9.) As a result fewer people were exposed. The total exposure in CY-1987 of 5.3 person-rem 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.[32,33] 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-1987.[34]

The magnet debonding oven was used to debond 11 radioactive magnets in CY-1987. The resulting ^{3}H release from the debonding oven stack had negligible impact.

TABLE 6

Incremental Population Data in Vicinity of Fermilab, 1980

LATITUDE = 41.832 LONGITUDE = 88.251

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

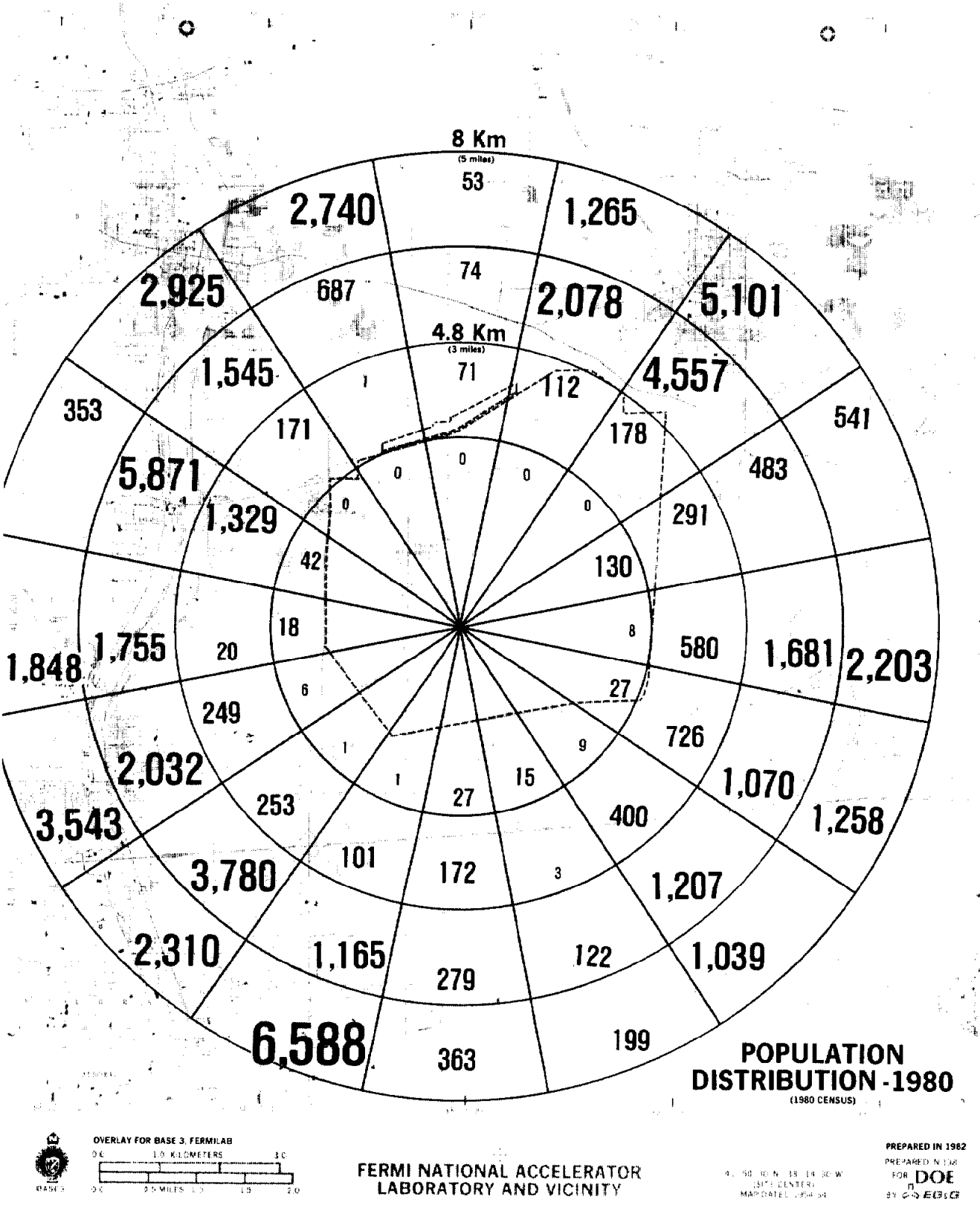

8 Km
(5 miles)
4.8 Km
(3 miles)
53
74
71
112
178
541
483
291
130
580
1,681
2,203
726
1,070
1,258
400
1,207
1,039
122
279
199
363
6,588
1,165
2,310
3,780
101
172
3
253
27
15
3,543
2,032
249
20
1,848
1,755
1,329
5,871
42
18
6
1
0
0
0
0
0
0
171
1
1,545
353
2,925
687
2,740
1,265
2,078
5,101
4,557
8
9
27
POPULATION
DISTRIBUTION - 1980
(1980 CENSUS)
OVERLAY FOR BASE 3, FERMILAB
1.0 KILOMETERS
FERMI NATIONAL ACCELERATOR
LABORATORY AND VICINITY
PREPARED IN 1982
FOR DOE

Table 7

Summary of Population Exposures for CY-1987 Within a 80 km (50 mi) Radius of Fermilab

Sources	Contributions to Population Exposures (person-rem)
Penetrating radiation (muons) from the Research Area	2.0
Penetrating radiation (gamma rays) from the Boneyard	2.9
Airborne radioactivity from the Antiproton Area	0.4
Airborne radioactivity from the Neutrino Area	0.0
TOTAL	5.3

Some releases of radioactive water occurred from sumps collecting water from under areas where protons interacted. About 38% 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 Derived 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 was negligible.

Between April and July 1987, a radon survey was conducted at Fermilab. The survey included Village residences, office areas and beam tunnels. The charcoal canister method[35] was used. A total of 41 canisters were used in this study. Four locations had results greater than the EPA residential standard of 4 pCi/l (Section 8). None of these locations has a high occupancy factor. The highest result was 8.0 pCi/l and the geometric mean was 1.4 x+ 2.3 pCi/l.

The results of the survey do not indicate a need for remedial action in any area. Based on measurements covering a large portion of the site, it appears that the site is a normal radon concentration area.

6.2 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-1987, efforts were made to keep these treatments as low as possible in order to protect wildlife and fish. Aquazine is biodegradable and no environmental impact is expected. There is a program to look for persistent chemicals in the Fermilab environment periodically.

There were no activities during CY-1987 which created problems with respect to nonradioactive airborne effluents. There was a fire in the Research Area on October 3, 1987, which released some lead into the air; however the concentrations were at background levels at the site boundary. Some water with low concentrations of lead in it was pumped out onto the ground adjacent to the Wide Band Laboratory. This water came from the sprinkler system which discharged during the fire. The soil was analyzed to see if it was a hazardous waste using the extraction process required by EPA.[36] It was not a hazardous waste. An electromagnetic calorimeter, a large detector containing alternating thin plates of lead (1.59 mm or 0.0625" thick) and plastic scintillator (3.18 mm or 0.125" thick), was ignited from an electrically short-circuited cable. The experiment was delayed by nine weeks.

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 Utility Building. These boilers are adjusted annually to maintain proper combustion efficiency.

6.3 Potential Impact of Other Toxic Substances

6.3.1 Pesticides

In addition to the water treatments mentioned in Section 5.5, 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 1987. In addition, Trimec herbicide containing 27.6% 2,4-D, 13.9% 2-(2-methyl-4chlorophenoxy) proponic acid (MCPP), and 2.8% 3,6-dichloro-o-anisic acid (Dicamba), was applied to turf areas to control broad leaf weeds in the Village and Sauk Circle just south of the Village (Fig. 1), around Wilson Hall,

the east reflecting pond, Swan Lake, West Pond (near Swan Lake in Fig. 5), Sites 38, 52, 58 (Fig. 5), the Experimental Areas Operations Center in the Experimental Areas or Research Area (Fig. 1), Neutrino Area bubble chamber area (Fig. 1), the Industrial Area, and Central Helium Liquefier (near the Industrial Area in Fig. 1). Approximately 511 l (135 gal) was applied in 1987.

Roundup, containing 40% isopropylamine salt of N-(phosphonomethyl) glycine, and 40.4% Surflan A.S., containing Oryzalin (3,5-dinitro-N4,N4-dipropylsulfanil-amide) were applied in equal amounts around bases of trees, fire hydrants, sign posts, foundations, and liquified petroleum gas tanks. The rate of application was approximately two liters (one-half gal) each per 0.4 hectare (acre). The weeds and grasses treated were in the Village and Sauk Circle just south of the Village (Fig. 1), along major Fermilab roads, around Wilson Hall, Collider Detector Facility near the Industrial Area, Industrial Area, new Muon Laboratory, Neutrino Area bubble chamber, Experimental Areas Operations Center and Sites 38, 50, 52, 56, 58, and 64 (Figs. 4 and 5).

Corn was planted by licensees in CY-1987 on 7.35 km^2 (1817 acres). Licensees are persons who pay the Laboratory for use of a portion of the land on the site for agricultural purposes. Pesticides were applied as follows:

4168 l (1101 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 4.46 km^2 (1101 acres).

7170 kg (15808 lbs) Counter insecticide, containing 15% terbufos (S-{[(1,1-dimethylethyl)thio] methyl}0, 0-diethyl phosphorodithioate) applied to 7.35 km^2 (1817 acres).

811 l (214 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 1.54 km^2 (381 acres).

1405 kg (3097 lbs) Lorsban 15G insecticide, containing 15% chlorpyrifos [0,0-diethyl 0-(3,5,6-trichloro-2-pyridyl)phosphorothioate] was applied to 1.44 km^2 (356 acres) at planting time to control soil insects. Aerial application of 4119 kg (9080 lbs) was required later for 5.65 km^2 (1397 acres), including 0.4 km^2 (106 acres) previously treated. The extra application was done quickly to control cornstalk borers which were widespread in the area because the mild winter did not kill the European corn borer moths (Pyrausta nubilalis) responsible for the larvae.

Soybeans were planted by licensees in CY-1987 on 2.22 km^2 (50 acres). The following pesticides were applied to this land:

1.36 kg (3 lbs) Sencor DF herbicide, containing 4-Amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4 triazin-5(4H)-one 75%.

53 l (14 gal) Dual 8E herbicide, containing Metolachlor: 2-chloro-n (2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl) acetamide 86.4%.

For mosquito control, an ultra low volume application of CYTHION Premium Grade Malathion was performed at 21 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 (Figs. 4 and 5), and the Meson, Proton and Neutrino experimental areas (Fig. 5).

Contrac Rat and Mouse Bait, EPA #12455-36, a rodenticide containing 0.005% 3-[3-(4'Bromo-[1,1'-biphenyl]-4-yl)-3-hydroxy-1-phenylpropyl]-4-hydroxy-2H-1-benzopyran-2-one 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-1987.

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.

Several walnut trees at Site 58 (south of 55 in Fig. 4) were treated with 0.15 kg (0.33 lb) of Orthene 75 S, containing Acephate (O.S-Dimethyl acetylphosphoramidothioate) 75% to remove aphids and scale.

The services of a contract exterminator, licensed by the State of Illinois and using EPA registered pesticides, was retained during CY-1987 for the control of miscellaneous pests found in kitchens, laboratories and living areas throughout the site.

6.3.2 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.[37] The PCB Status Report as of January 1, 1987, listed 51 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 one askarel-filled (60-70% PCBs) transformer and one oil-filled transformer were properly disposed of.[6] 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.

The inventory of large PCB capacitors in use, in storage for use or in storage for disposal was reduced from 1860 to 1718 in CY-1987. 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.

6.3.3 Hazardous Wastes

Responsibility for disposal of hazardous waste 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.

6.3.4 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. Thus, the environmental impact from heavy metals released in CY-1987 should be negligible.

6.3.5 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 8. 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.

6.3.6 Ethylene Glycol

Ethylene glycol is used in closed loop low conductivity water systems which might freeze in the winter. One such system in the Neutrino Area (near R4 in Fig. 6) developed a leak underground in late 1987. About 2050 l (542 gal) of ethylene glycol went into the ground. Some of it was detected in the water discharged from a sump.

That concentration was about 10,000 mg/l which is at the level where fish can be affected. By the time the water reached Casey's Pond, dilution was sufficient to result in no adverse environmental impact.

7. Quality Assurance in CY-1987

7.1 Quality Control

Water samples collected in CY-1987 were analyzed by International Technology (IT) Corporation, 1550 Bear Creek Road, Oak Ridge, Tennessee 37831. In addition, such samples were counted at the Fermilab Nuclear Counting Laboratory. Fermilab now has the necessary liquid scintillation counting system to do tritium analyses, but all ^{45}Ca analyses were done only by IT Corporation. Chemical separations have been found necessary for ^{45}Ca assay in the presence of ^{22}Na and other radionuclides. Each shipment to IT 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.

7.1.1 Analytical Procedures at IT Corporation

IT Corporation analyzes water samples using similar procedures to those described previously.[38] Liquid scintillation counting is done using the scintillator "Pico-FluorLLT" and a counting system, both of which were manufactured by Packard Instrument Co., Inc., 2200 Warrenville Road, Downers Grove, Illinois 60515. Gamma spectroscopy is done with intrinsic germanium semiconductor detectors with efficiencies 20% to 30% that of a 7.6 cm dia. x 7.6 cm high NaI (Tl) scintillator. Alpha detection is done using a scintillation counter after whatever specific chemical separation is required. Screening for ^{45}Ca is done by liquid scintillation counting. Any necessary chemical separation of ^{45}Ca is followed by beta counting using gas-flow proportional counters.[39]

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 8.

Table 8

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/ml) Surface Water	Groundwater
^{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 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.

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 drinking water systems on-site which supply water to more than 25 people during the workday.

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 8.

7.1.2 Quality Assurance Samples

During CY-1987 Fermilab participated in the DOE Environmental Measurements Laboratory (EML) quality assurance program.[40] Results are given in Table 9. Also, Fermilab sent quality assurance samples monthly to IT Corporation, who analyzed Fermilab water samples independently. There were problems with the vendor's performance for samples sent by Fermilab. See Table 10. The ^{60}Co prepared concentrations are believed to be in error because Nuclear Counting Laboratory results agreed well with IT Corporation on these split samples counted by both labs.

Table 9

Quality Assurance Results for Fermilab

Sample Date	Radio-Nuclide	Percentage of Concentration Guide for Surface Waters*	Prepared Concentration	Ratio of Fermilab Result to Prepared Concentration
5/87	^{3}H	1.68	3.37x10-5 μCi/ml	0.95
	^{54}Mn	9.44	4.72x10-6 μCi/ml	1.10
	^{60}Co	91.8	4.59x10-6 μCi/ml	1.06
	^{7}Be	+	4.64x10-3 μCi	0.96
	^{54}Mn	+	4.55x10-4 μCi	1.00
	^{60}Co	+	4.44x10-4 μCi	0.98
9/87	^{54}Mn	4.56	2.28x10-6 μCi/ml	1.00
	^{60}Co	45.4	2.27x10-6 μCi/ml	1.08
	^{7}Be	+	8.96x10-4 μCi	0.94

*Prolonged Exposure (Table 8)
+Air Filter

7.2 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 10

Quality Assurance Results for IT Corporation for CY-1987

Sample Number	Radio-Nuclide	Percentage of Concentration Surface H_2O	Prepared Concentration	Ratio
8701	^{3}H	0.065	1.3 x 10-6	Ok,Ok*
	^{3}H	0.065	1.3 x 10-6	0.85, 0.77*
8702	^{3}H	0.113	2.6 x 10-6	0.58
	^{7}Be	0.046	4.6 x 10-7	Ok
	^{22}Na	11	1.1 x 10-6	1.2
	^{45}Ca	3	1.5 x 10-6	0.67
	^{54}Mn	3.8	1.9 x 10-6	0.97
	^{60}Co	11	5.7 x 10-7	0.39 +
8703	^{3}H	0.032	6.4 x 10-7	Ok
	^{7}Be	0.46	4.6 x 10-6	1.6
	^{22}Na	23	2.3 x 10-6	1.3
	^{45}Ca	---	Blank	Ok
	^{54}Mn	6.6	3.3 x 10-6	1.1
	^{60}Co	58	2.9 x 10-6	0.36 +
8704	^{3}H	---	Blank	Ok
	^{7}Be	---	Blank	Ok
	^{22}Na	---	Blank	Ok
	^{45}Ca	---	Blank	Ok
	^{54}Mn	---	Blank	Ok
	^{60}Co	---	Blank	Ok
8705	^{3}H	0.65	1.3 x 10-5	1.3
	^{7}Be	2.7	2.7 x 10-5	1.6
	^{22}Na	57	5.7 x 10-6	1.2
	^{45}Ca	7.6	3.8 x 10-6	2.4
	^{54}Mn	6.6	3.3 x 10-6	1.1
	^{60}Co	17	8.6 x 10-7	.34 +
8706	^{3}H	32	6.4 x 10-4	1.1
8711	^{3}H	6.5	1.3 x 10-4	0.7
8720	^{3}H	0.44	8.9 x 10-6	1.8, 1.8*
8721	^{3}H	2.3	4.5 x 10-5	0.72, 0.76*
8722	^{3}H	6.5	1.3 x 10-4	0.77

Ok=Vendor reported results correctly as less than the required sensitivity
*Prepared sample was split for a second analysis
+Prepared concentration believed in error based on Nuclear Counting Lab results for split samples

Fermilab has a 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 8), 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 flood plains, specifically addressed in the National Environmental Policy Act (NEPA).

Groundwater protection from organic chemicals has become a concern throughout the nation 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[36] to have a waste minimization 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.

Some radioactive water solidified in CY-1986 and some low-level radioactive scrap metal which normally have been declared waste and shipped off-site for burial were recycled by using them in the construction of shielding blocks in CY-1987. 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.

8. 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.7. 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 including exposures from drinking water and airborne radioactivity. 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 8. These Derived Concentration 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 $2 \times 10^{-8}8$ μCi/ml because submersion dose must be included for ^{11}C. Of the 100 mrem/year for prolonged exposure, a maximum of only 25 mrem/year per person is allowed from 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 source for EPA guidance on radon exposure is document EPA-OPA-86-004, issued in August 1986. The recommended residential limit is 4 pCi/l.

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.[29] 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. Thus, of the 100 mrem/yr permitted for prolonged exposure of the general population, only 4 mrem is allowed from drinking water. 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 well 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.[41] 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.[42] 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.[41]

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.[43]

References to Material Cited in The Text:

1. E. Sieben, Kane County Planning Commission, March 1988, private communication, 1986 estimated population increased by 1/24 of the percentage increase projected for the year 2010.

2. J. Charlton, DuPage County Planning Department, March 1988, private communication, 1985 estimated population increased by 2/25 of the percentage increase projected for the year 2010.

3. J. Duncker, United States Department of the Interior, Geological Survey, 102 East Main St., Urbana, Illinois 61801, Provisional data, March 1988.

4. Measurements made on-site by State of Illinois Water Survey Division, 101 North Island Ave., Batavia, Illinois 60510.

5. R. T. Sasman et al., Water Level Trends, Pumpage, and Chemical Quality in the Cambrian-Ordivician Aquifer in Illinois 1971-1980, Illinois State Water Survey, Champaign, Illinois (1982).

6. S. I. Baker, Fermi National Accelerator Laboratory Site Environmental Report for Calendar Year 1986, Fermilab Report 87/58, May 1987.

7. J. P. Corley et al., A Guide For: Environmental Radiological Surveillance at U. S. Department of Energy Installation, U. S. Department of Energy Report DOE/EP-0023, July 1981.

8. Operational and Environmental Safety Division, Environmental Protection, Safety, and Health Protection Program for DOE Operations, DOE Order 5480.1A, Chapter XI, U. S. Department of Energy, Washington, D.C., August 1981.

9. J. P. Corley and C. D. Corbit, A Guide for Effluent Radiological Measurements at DOE Installations, U. S. Department of Energy Report DOE/EP-0096, July 1983.

10. U. S. Code of Federal Regulations 40 CFR 302, Table 302.4.

11. R. A. Landon and J. P. Kempton, Stratigraphy of the Glacial Deposits at the National Accelerator Laboratory Site, Batavia, Illinois, Circular 354, Illinois State Geological Survey, Champaign, Illinois, 1971.

12. M. Awschalom et al., "Radiation Monitoring at NAL: Instruments and Systems," International Conference on Protection Against Accelerator and Space Radiation, CERN Report 71-16, p. 1035, Geneva, Switzerland, July 1971.

13. C. Moore and S. Velen, Muon Beam Halo Studies, Fermilab Report TM-497, June 1974.

14. C. D. Moore, Comparison of Halo Predictions with Experimental Measurements of Off-Site Muons Arising from 275 GeV/C Muon Line Operations, Fermilab Report TM-680, August 1976.

15. J. D. Cossairt, Health Physics 45, 651 (1983).

16. J. D. Cossairt and L. V. Coulson, Neutron Skyshine Measurements at Fermilab, Fermilab Report FN-394, November 1983.

17. J. DePangher and L. L. Nichols, Pacific Northwest Laboratory Report PNWL-260 (1966).

18. A. J. Elwyn and W. S. Freeman, Muon Fluence Measurements During the 1987-1988 fixed target Run, Fermilab Report TM-1518 , April 1988.

19. S. I. Baker, Fermi National Accelerator Laboratory Environmental Monitoring Report for Calendar Year 1982, Fermilab Report 83/29, May 1983.

20. R. E. Moore et al., "AIRDOSE-EPA: A Computerized Methodology for Estimating Environmental Concentrations and Dose to Man from Airborne Releases of Radionuclides," Oak Ridge National Laboratory Report ORNL-5532, June 1979.

21. R. E. Moore et al., "CAAC, Code System for Implementation of Atmospheric Dispersion Assessment Required by the Clean Air Act," Oak Ridge National Laboratory Report CCC-476, December 1986.

22. T. B. Borak et at., Health Physics 23, 679 (1972).

23. P. Gollon, Soil Activation Calculations for the Anti-proton Target Area, Fermilab Report TM-816, September 1978.

24. S. I. Baker, Fermi National Accelerator Laboratory Environmental Monitoring Report for Calendar Year 1978, Fermilab Report 79/26, May 1979.

25. Measurements and Calculations by R. Schicht and A. Wehrmann, Illinois State Water Survey, private communication, 1978.

26. S. I. Baker, "Soil Activation Measurements at Fermilab," Third ERDA Environmental Protection Conference, Chicago, September 23-26, 1975, ERDA-92, pp. 329-347.

27. S. I. Baker, Fermi National Accelerator Laboratory Environmental Monitoring Report for Calendar Year 1985, Fermilab Report 86/37, May 1986.

28. Illinois Pollution Control Board Rules and Regulations, Chapter 3, Article 204.

29. U. S. Code of Federal Regulations 40 CFR 141.

30. C. H. Wolf, Nalco Chemical Company, private communication, 1981.

31. R. C. Durfee, Oak Ridge National Laboratory, private communication, 1982.

32. 1980 U. S. Census, General Population Characteristics, Report PC 80-1-B15, Census Bureau, U. S. Department of Commerce, Washington, D.C., 1982.

33. CRC Handbook of Environmental Radiation, A. W. Klement, Jr., editor, CRC Press, Inc., Boca Raton, Florida 33431, 1982, pp. 55-56.

34. S. C. Bushong, The Physics Teacher, p. 136, March 1977.

35. R. J. Countess, "Radon Flux Measurements with a Charcoal Canister," Health Physics 31, 455 (1976).

36. U. S. Code of Federal Regulations 40 CFR 260-265.

37. U. S. Code of Federal Regulations 40 CFR 761.

38. S. I. Baker, Fermi National Accelerator Laboratory Environmental Monitoring Report for Calendar Year 1981, Fermilab Report 82/22, May 1982.

39. J. Harvey, IT Corporation, private communication, 1988.

40. C. G. Sanderson and M. S. Feiner, Semiannual Report of the Department of Energy, Operational Safety, Health, and Environment Division - Quality Assurance Program, U. S. DOE Environmental Measurements Laboratory Reports EML-498, September 1987 and EML-503, January 1988.

41. Illinois Environmental Protection Act, Chapter 111.5, Illinois Revised Statutes, Section 1012 (f) (1975). Illinois Revised Statutes, Illinois Pollution Control Board Rules and Regulations, Chapter 3, Part II.

42. Illinois Revised Statutes Part VIII Public Drinking Water, IEPA Supplement No. 1 304D, Table 2.

43. U. S. Code of Federal Regulations 21 CFR 109 (44FR38330).

9. Acknowledgments

D. W. Grobe compiled the data for Section 4.4, Waterborne Radioactivity. R. A. Allen revised Section 7 on quality assurance. The manuscript was reviewed by L. Coulson. All three are staff members of the Fermilab Safety Section. The figures containing photos came from the Fermi National Accelerator Laboratory Graphic Overview System complied for the Department of Energy by H. Berry, Z. Burson, and others in the EG&G Energy Measurement Group, P. O. Box 1912, Las Vegas, Nevada 89101. The Department of Energy review was conducted by R. Kolzow of the Chicago Operations Office Environmental Protection Group.

10. Distribution List

No. of Copies	Recipient
21	U. S. Department of Energy R. W. Starostecki (10) A. E. Mravca (10) E. Temple
122	Fermi National Accelerator Laboratory

L. Lederman, Director
J. Bjorken, Associate Director
B. Chrisman, Associate Director
R. Lundy, Associate Director
J. Abbott
M. Adamus
R. Allen
C. Anderson
E. Arko
R. Auskalnis
D. Austin
M. Awschalom
S. Baker (12)
J. Baldwin
J. Barry
D. Bowron
C. Brown
S. Butala
W. Butler
D. Carpenter
H. Casebolt
D. Cathey
S. Childress
F. Cole
K. Cooper
D. Cossairt
L. Coulson (12)
R. Dixon
R. Dorner
R. Doyle
H. Edwards
A. Elwyn
D. Emery
H. Falk
R. Fenner (2)
D. Fichtel
J. Finks, Jr.
J. Finks III
W. Freeman
P. Garbincius
M. Gerardi
D. Green
D. Grobe
R. Hall
M. Harrison
F. Hartman
R. Haynes
D. Hockin
S. Holmes
A. Jonckheere
D. Jovanovic
B. Kobiella
R. Kramp
F. Krueger
V. Kuchler
J. Lach
C. Lang

J. Larson
A. Lennox
P. Loomis
E. Major
P. Mantsch
F. Markley
C. Marofske
C. Mau
R. Mau
M. McKenna
J. McDowell
T. Miller
C. Moore
W. Nestander
R. Orr
C. Owen
J. Paulk
T. Pawlak
T. Prosapio
J. Rapovich
R. Rebstock
R. Rubinstein
W. Salsbury
C. Sazama
R. Scherr
F. Shockley
D. Sigmon
K. Stanfield
R. Stefanski
L. Teng
R. Thatcher
D. Theriot
T. Toohig
G. Tool
J. Upton
A. VanGinneken
E. West
S. Wilson
T. Yamanouchi
D. Young
P. Yurista
C. Zonick

2 Argonne National Laboratory
L. Cheever, N. Golchert

1 Battelle Columbus Laboratory
G. Kirsch

2 Battelle, Pacific Northwest Laboratories
J. Corley, R. Jaquish

3 Brookhaven National Laboratory
R. Miltenberger, J. Naidu, R. Casey

2 CERN
K. Goebel, G. Rau

1 CEBAF
G. Stapleton

1 DESY
H. Dinter

1 EG&G Energy Measurements Group, Las Vegas
H. Berry

3 Illinois Environmental Protection Agei
R. Carlson, T. Denning, M. Swartz

1 Illinois Historic Preservation Agency
W. G. Farrar

2 Illinois State Geological Survey
D. Gross, J. Kempton

1 Illinois State Natural History Survey
W. Brigham

1 Illinois State Water Survey
K. Benson

1 Institute for Radiation Protection
Peoples Republic of China
C. Mingjun

1 International Technology Corporation
J. Harvey

1 KEK
K. Kondo

2 Lawrence Berkeley Laboratory
R. Thomas, J. Young

1 Los Alamos National Laboratory
J. Miller

2 Oak Ridge National Laboratory
R. Durfee, D. Parzyck

1 Princeton Plasma Physics Laboratory
J. Stencel

1 Stanford Linear Accelerator Center
G. Warren

27 Technical Information Center
Oak Ridge

3 U. S. Environmental Protection Agenc
V. Adamkus, L. Johnson, N. Philippi