fermilab

highlights

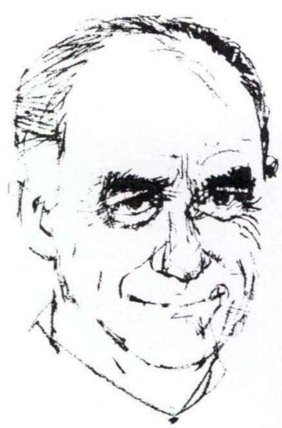
highlights

highlights

highlights

Fermi National Accelerator Laboratory

Leon M. Lederman, Director



Enrico Fermi

The Fermi National Accelerator Laboratory was dedicated in May, 1974 and named in honor of Enrico Fermi, a famous pioneering scientist who died in 1954. A Nobel Laureate for his discovery of neutron-induced (element) transmutation, he is best known in the United States for his leading of the test under the stadium of the University of Chicago which led to the development of atomic fission. In addition to his association with the atomic bomb, he is equally well known as a developer of peaceful uses of atomic energy. He is regarded as both a great theoretical and experimental physicist. Some of his ideas are being tested today in the experiments going on at Fermilab.

The Human Rights Policy of Fermilab
June 1, 1979

The policy at the Fermi National Accelerator Laboratory is to pursue its scientific goals with an emphasis on equal employment opportunity and a special dedication to human rights and dignity.

In any conflict between technical expediency and human rights we will stand on the side of human rights. This is because of our dedication to science. The support of human rights in our laboratory and its environs is inextricably intertwined with our goal of making the laboratory a center of technical and scientific excellence. The latter is not likely to be achieved with success without the former.

table of contents

Published by
THE PUBLIC INFORMATION OFFICE • FERMI NATIONAL ACCELERATOR LABORATORY
P.O. Box 500, Batavia, Illinois 60510 • Phone: (312) 840-3351
1-82

general information

The Fermi National Accelerator Laboratory (popularly known as "Fermilab") is operated by Universities Research Association, Inc. (URA) of Washington, D.C., a consortium of 54 major research-oriented universities, 53 in the United States and one in Canada. (See also page 24 for further description of URA).

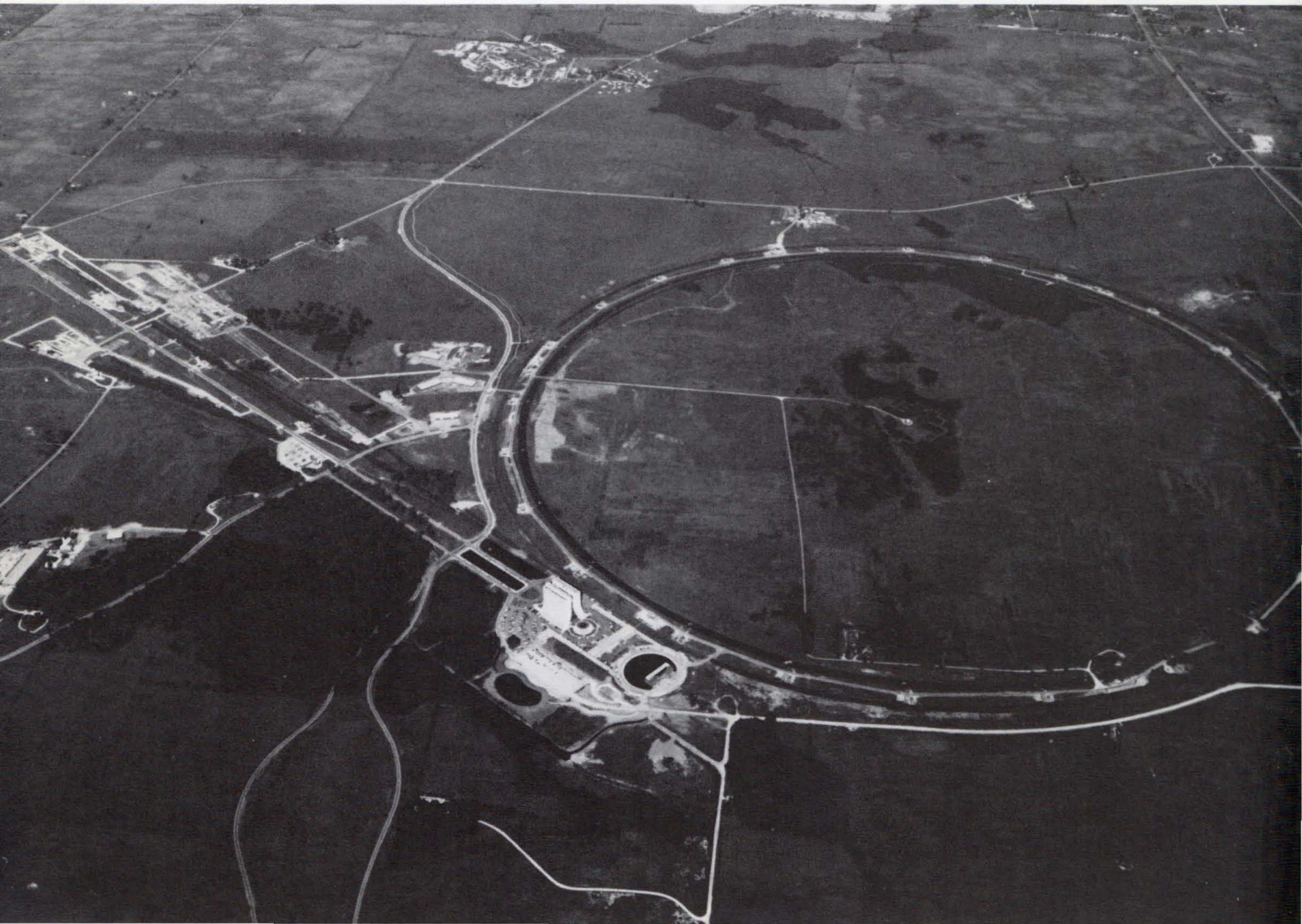
URA operates the laboratory under a contract with the Department of Energy (DOE). A DOE area office is located at Fermilab.

The Laboratory is located on 6,800 acres about five miles east of Batavia, Illinois. The land was donated by the State of Illinois to the U.S. government in 1969 for the construction of the Laboratory. About 5,500 acres are located in DuPage County; 1,300 acres in Kane County.

Fermilab is about 30 miles west of Chicago, north of the Illinois East-West Tollway (Illinois Rt. 5, the Farnsworth/Kirk exit), about 30 miles southwest of O'Hare International Airport.

Headquarters of the Laboratory are located in Robert Rathbun Wilson Hall, a 16-story structure near the main entrance to the Laboratory on Kirk Road, opposite Pine Street, Batavia. The entrance is about three miles north of the Farnsworth/Kirk exit of the East-West tollway. The suburbs of Aurora, Batavia, St. Charles, Geneva, West Chicago, Wheaton, Warrenville, and Naperville are within 20 minutes' driving time.

Fermilab has some 1,900 full-time employees of which 300 are scientists and engineers. In addition, about 2,400 visiting experimenters have done research at Fermilab.



purpose of fermilab

The research done at Fermilab is known as "high energy physics" or "particle physics." Its purpose is to explore the basic structure of matter. Previous generations of this basic research have revealed the structure of the atom, then the nucleus of the atom. Penetrating still deeper into this structure, present-day research concentrates on the individual particles of which the nucleus is composed, studying their properties and the ways in which they interact with one another.

In the 1960's, when the known sub-nuclear particles numbered in the hundreds, it became evident that they were not elementary but were themselves composite. Recent experimental results have consolidated the idea that the elementary particles are quarks, (which make up the strongly-interacting sub-nuclear particles); leptons (such as the electron and neutrino) and the particles which mediate interactions among them, such as the photon and the gluon.

Learning more about the behavior of particles has become possible through the use of particle accelerators of higher and higher energies. Fermilab's machine is a synchrotron which accelerates protons to 200-500 GeV (giga [billion] electron volts). Under construction is a superconducting accelerator to be completed in 1982. It will have the capability of accelerating protons to 1,000 billion electron volts (1 trillion electron volts, or 1 TeV). It will also have colliding beam capability in which a beam of 1 TeV protons will collide with 1 TeV antiprotons, giving an energy of 2 TeV in the center of mass. (See page 8.)

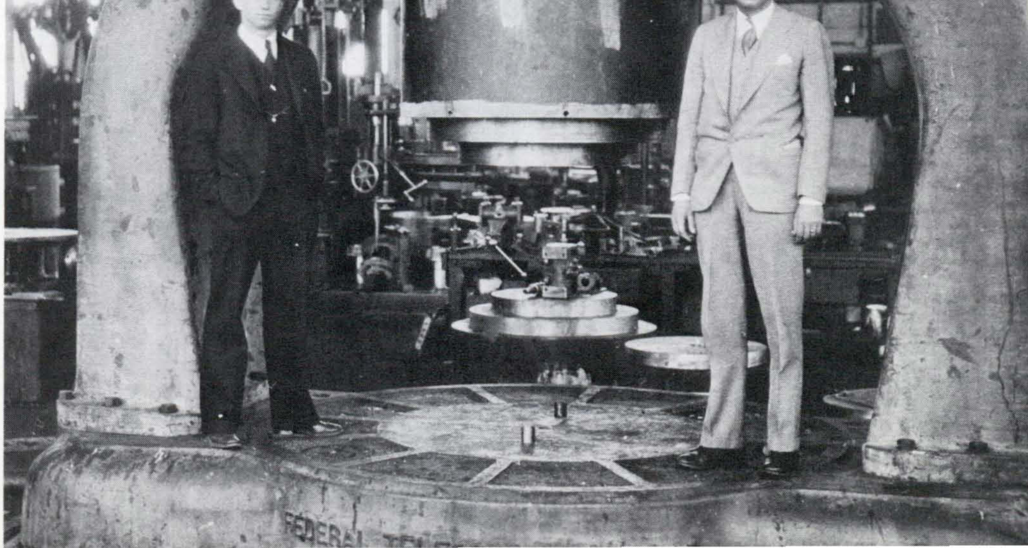
The Fermilab machine has no "product," nor does it produce electrical power as does a nuclear reactor. It is a scientific instrument (in a sense, a giant microscope) that permits study of atomic nuclei, searching always for the basic building blocks of Nature.

The United States has been the leader in designing, constructing, and financially supporting the development of a progression of accelerators of increasing energy. Ernest O. Lawrence developed such a machine at the University of California-Berkeley in 1930. In the years that followed, Lawrence and others, many of them his students, developed other more and more powerful machines. The field grew rapidly as scientists glimpsed the new worlds in the nucleus of the atom.

High energy physics research is carried on at present in the United States at such institutions as the Brookhaven National Laboratory, Long Island, N.Y., and at the Stanford Linear Accelerator Center, Palo Alto, California. The CERN Laboratory in Geneva, Switzerland is Europe's counterpart to Fermilab. The USSR, Japan, and the People's Republic of China also engage in high energy physics.

High energy physics is a field in which scientists from all over the world work together in a common endeavor. They come from all over the United States and from all over the world to participate in the Fermilab research program. Approximately 225 institutions are represented in the Fermilab research program. Of these about half are U.S. and half are foreign. U.S. scientists also participate in the research of foreign countries.

M. S. Livingston (L) and Ernest O. Lawrence with the magnet of the first cyclotron, built at the University of California at Berkeley in the early 1930's.



the 400 GeV accelerator

The principal scientific instrument at Fermilab is a system of four accelerators working in sequence to accelerate protons in the following manner:

1 Electrons are added to hydrogen atoms in an ion source contained inside a Cockcroft-Walton generator. The resulting ions, which are protons with two attached electrons, emerge from the high voltage accelerator with an energy of 750,000 electron volts (keV).

2 These ions enter the Linear Accelerator, approximately 500 feet long, which accelerates them to an energy of 200 million electron volts (MeV). The linac contains hundreds of copper electrodes between which oscillating electric fields are induced, tuned in such a way as to generate the electrical equivalent of a surf wave. The ions are accelerated as they ride this electrical wave.

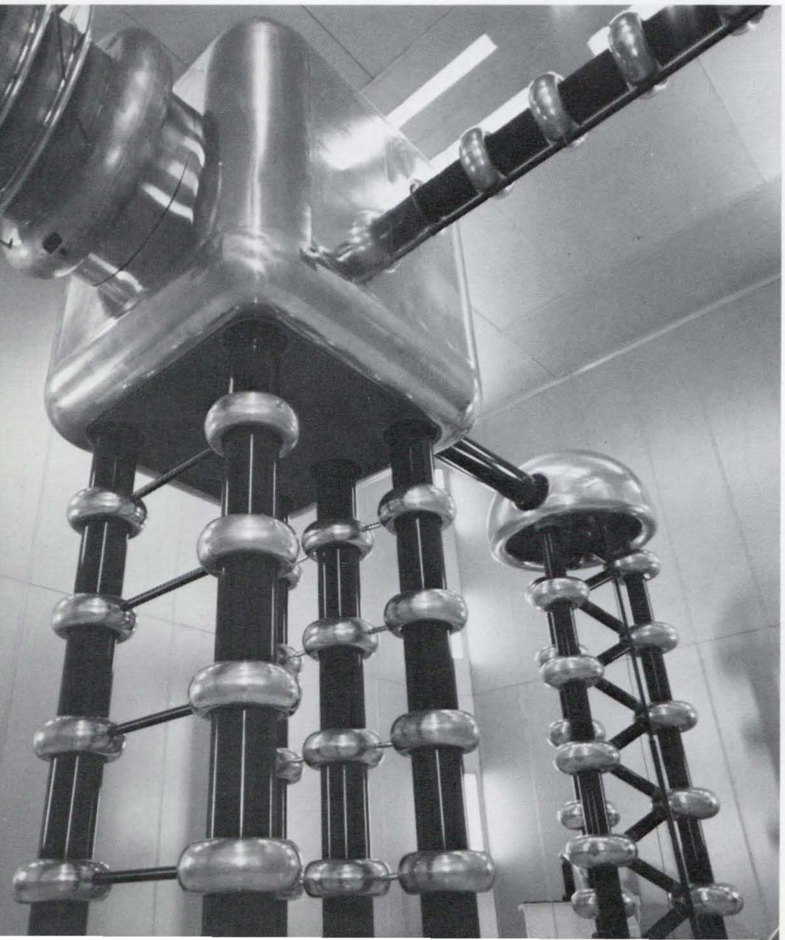
3 Next, they are injected into the Booster Accelerator, which is a circular machine, a rapid-cycling synchrotron, approximately 500 feet in diameter, which goes through its accelerating cycle 15 times per second. The ions are stripped of their electrons, leaving protons which are increased in energy to 8 billion electron volts (GeV). It normally cycles 13 times in rapid succession, loading 13 Booster pulses into the main accelerator for further acceleration.

The protons are injected from the Booster into the main accelerator - a synchrotron 6,562 feet in diameter, about four miles in circumference - and here they are accelerated to full energy (200-500 GeV).

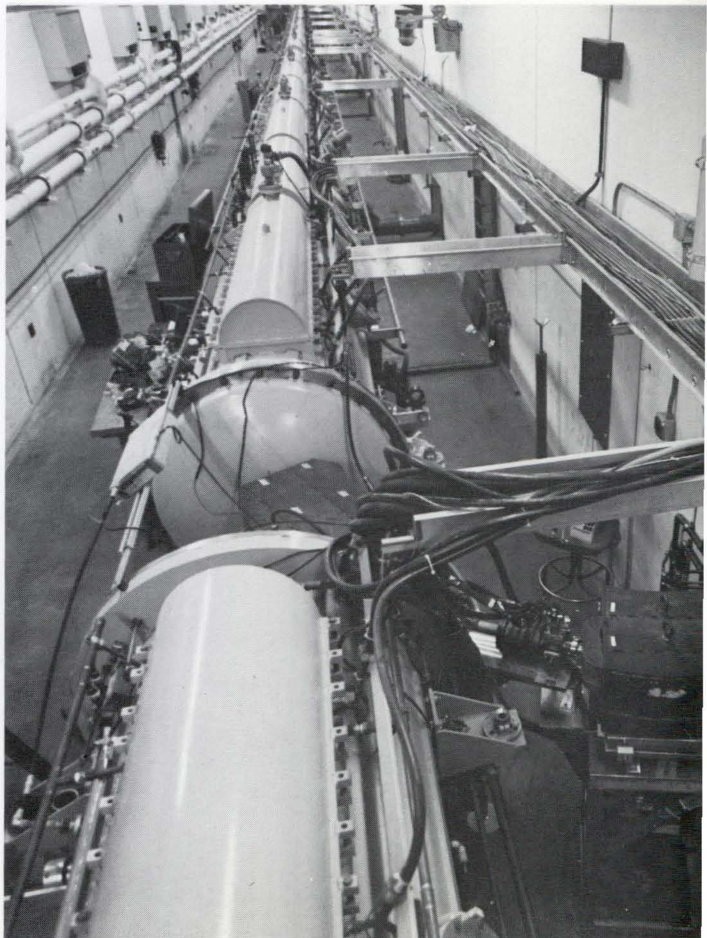
The main accelerator, also called the Main Ring, contains about 1,000 specially-developed magnets, spaced along the protons' orbit, to guide and focus the beam within the 2-inch by 5-inch vacuum chamber built into the center of the magnets.

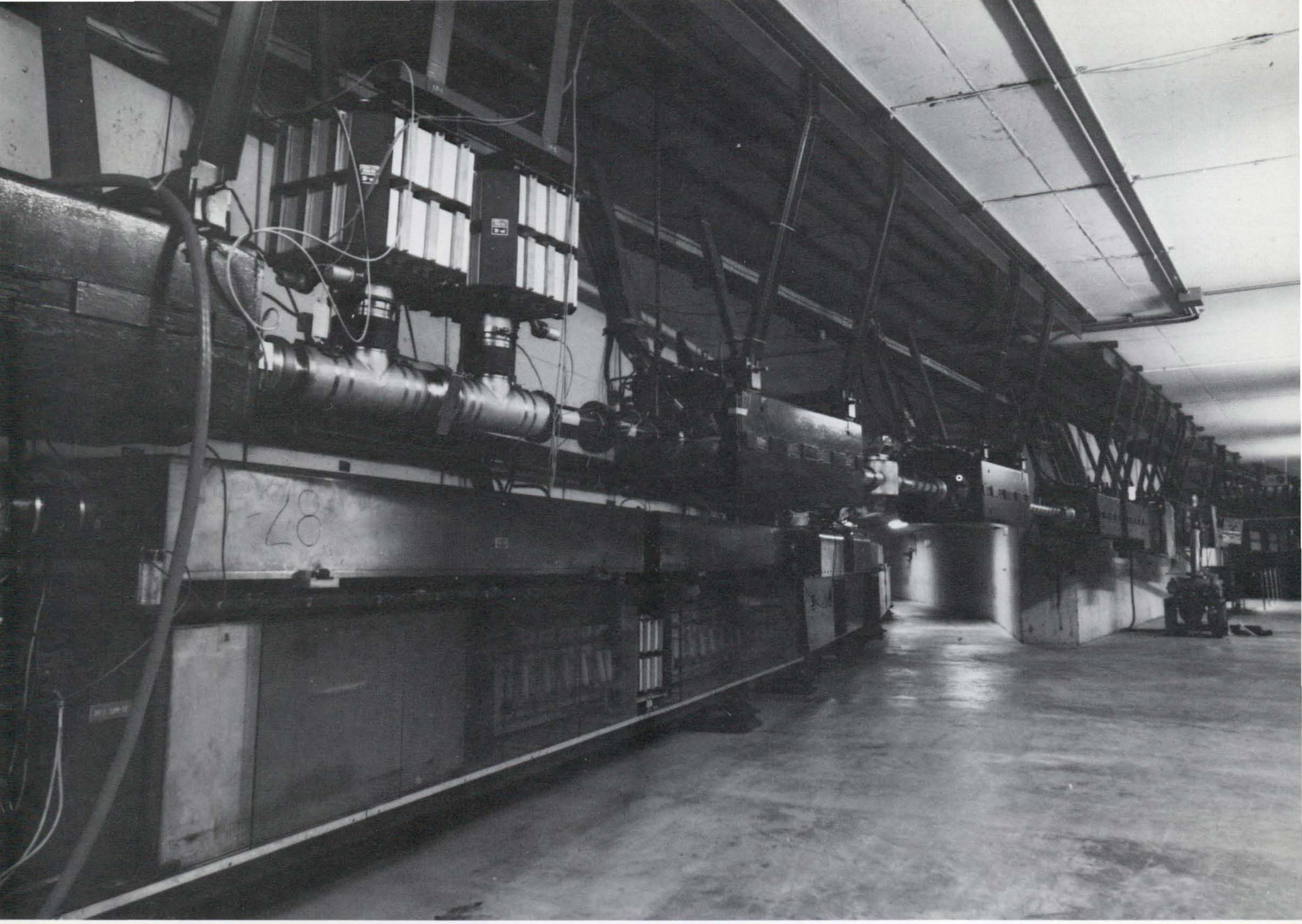
4 The protons travel around the ring about 50,000 times in one second. They receive a 3-million electron volt boost of energy on each turn through a series of radio frequency cavities. After reaching the desired energy, the protons are extracted from the Main Ring and transported to experimental areas.

1



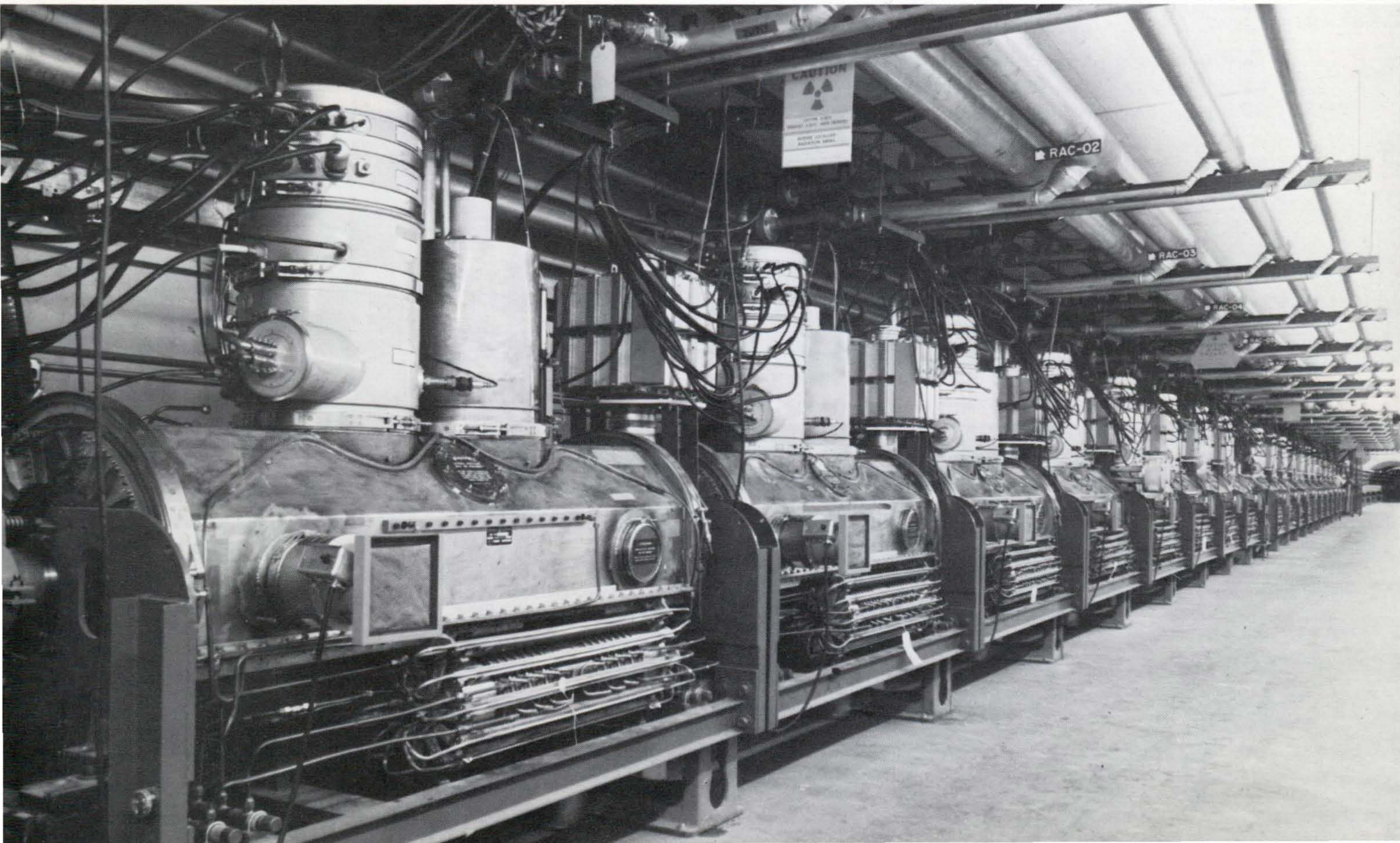
2





3

4



energy saver and tevatron I and II

8 An active project at Fermilab is the building and installation of a second ring of superconducting magnets below the present ring in the main accelerator tunnel.

Superconductivity is a phenomenon through the use of which electric currents can be transmitted with no concomitant loss of energy. The coils of superconducting magnets are made of a niobium titanium alloy that is superconducting when kept at a temperature of approximately -450° F (4.6 degrees Kelvin). To achieve these cryogenic temperatures the coils are surrounded by a cryostat so designed as to provide a continual flow of liquid helium around the coils. More than 1,000 of these superconducting magnets will be installed for the Saver and Tevatron projects, just below the present ring of conventional copper-coiled magnets. Not only must each superconducting magnet be kept at the constant -450° F temperature but also the entire ring (four miles in circumference). Much of the new technology for this system has been developed by Fermilab scientists and technicians.

The first phase of this project (the Energy Saver) provides for the installation of all of the superconducting magnets and the initial operation of the accelerator as a superconducting accelerator. Beam from the present accelerator will be injected into the superconducting ring at an energy of about 150 GeV. The machine will then be able to run at its present energy level of 400 GeV at a savings of $5 million a year in electrical power because of the increased efficiency of superconductivity.

Another phase of development, Tevatron I, will take advantage of the increased magnetic fields (45 kilogauss) possible with the superconducting magnets to increase particle energy to 1000 GeV (1 TeV [Tera electron volt]).

Tevatron I also includes the development of facilities for producing, storing and accelerating antiprotons so that a beam of antiprotons can run in the opposite direction simultaneously with the proton beam in the vacuum tube of the main accelerator. At one or two points on the four-mile ring the two beams will intersect, or collide, in a mode known as "colliding beam physics." These collisions will provide a center-of-mass energy of 2000 GeV (2 TeV), far beyond the range of any other accelerator in the world.

The components of the antiproton source are being designed by a Fermilab group, assisted by scientists from the Lawrence Berkeley Laboratory, the University of Wisconsin, Argonne National Laboratory and the Institute for Nuclear Physics at Novisibirsk, USSR.

Another group is designing the detector that will register the colliding beam interactions. The design, construction and initial use of the Collider Detector Facility (CDF) is being carried out by a Fermilab-led consortium of physicists from six U.S. universities (University of Chicago, University of Illinois, Harvard, Purdue, Texas A&M, and the University of Wisconsin), Fermilab, two other U.S. national laboratories (Argonne National Laboratory and Lawrence Berkeley Laboratory), and physicists from Italy (Frascati and the University of Pisa), and Japan (KEK and the University of Tsukuba). A Caltech group also participated in the detector design presented here.

other possibilities

In the dreams of high energy physicists, other schemes can be envisioned for future accelerators.

The Pentevac is a proposal to build a ten-mile accelerator ring on the Fermilab site that could reach an energy of 5 TeV. Another longer-range dream envisages a 40-mile ring based at Fermilab, an accelerator that would reach 20 TeV or higher.

Such machines not only depend on the availability of funds on a national or international basis, but also on the development of technology to build and operate machines of this energy.

1 *Cryostat of a superconducting dipole magnet moved into place for final assembly.*

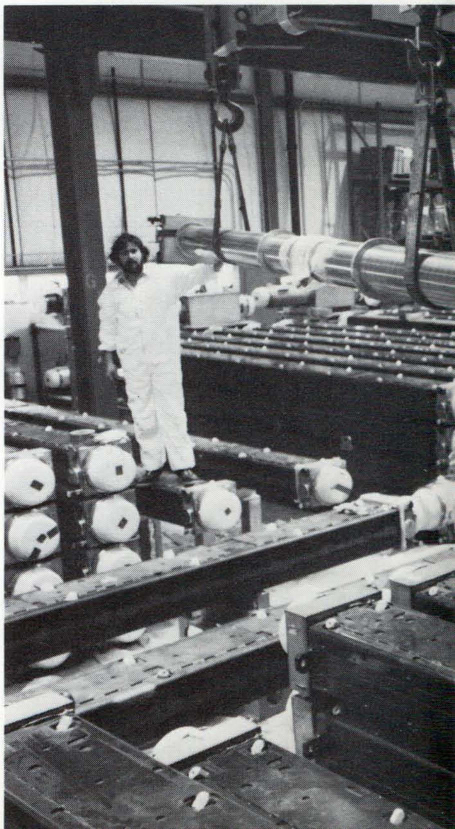
2 *Main accelerator tunnel showing magnets of 400 GeV accelerator (upper ring) and superconducting magnets (lower ring) for Energy Saver/Tevatron.*

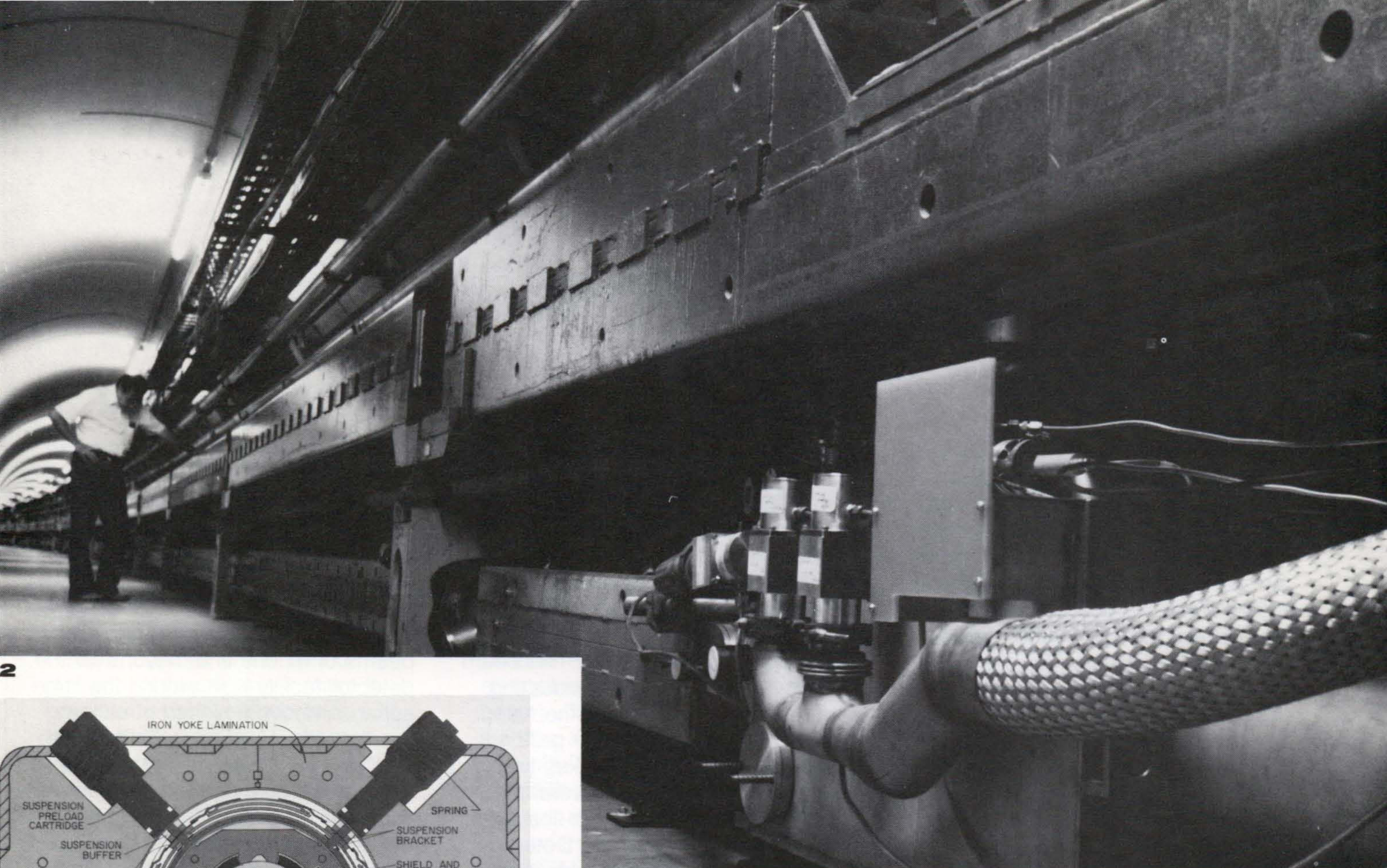
3 *Cross section of a Fermilab superconducting dipole magnet.*

4 *Partial installation of transfer line bringing liquid helium from central liquefier to satellite refrigerator building and to magnets in tunnel below.*

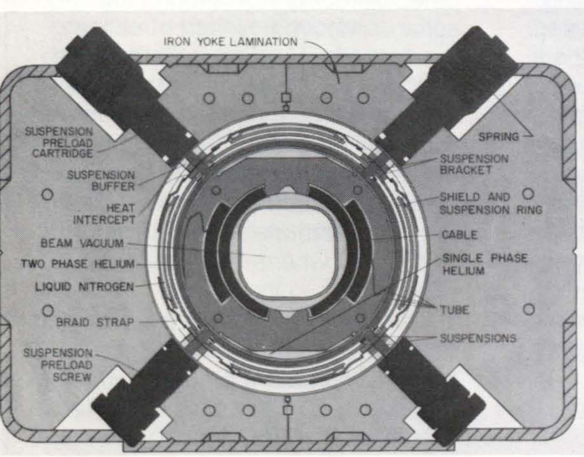
5 *The electron cooling system developed at Fermilab, to prepare for antiproton cooling for colliding beams.*

1



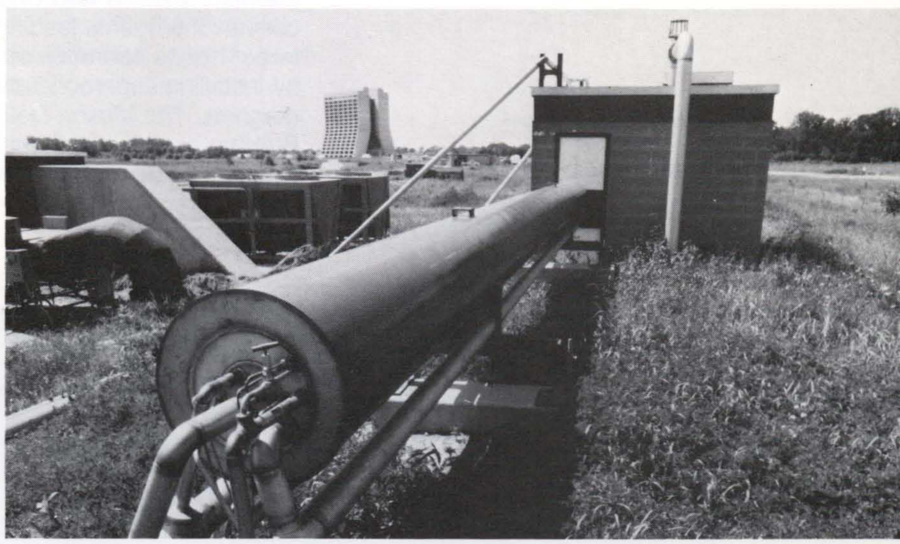


2

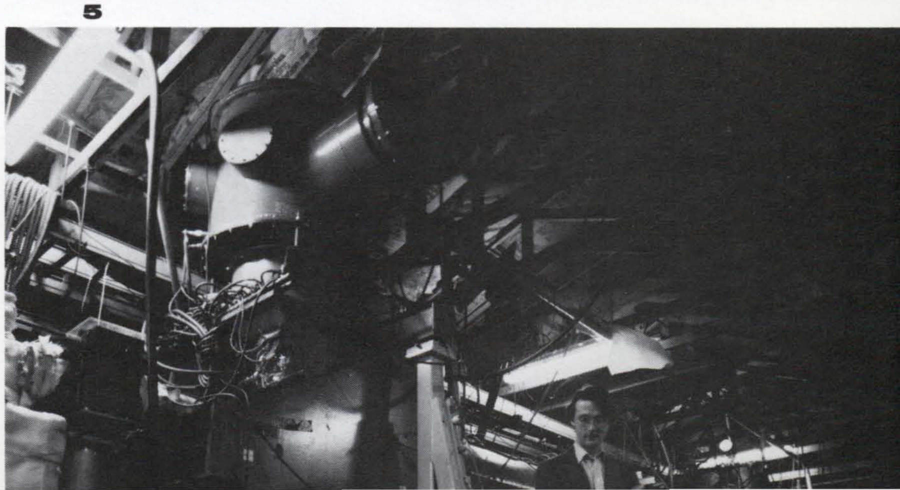

IRON YOKE LAMINATION
SUSPENSION PRELOAD CARTRIDGE
SUSPENSION BUFFER
HEAT INTERCEPT
BEAM VACUUM
TWO PHASE HELIUM
LIQUID NITROGEN
BRAID STRAP
SUSPENSION PRELOAD SCREW
SPRING
SUSPENSION BRACKET
SHIELD AND SUSPENSION RING
CABLE
SINGLE PHASE HELIUM
TUBE
SUSPENSIONS

3

4



5



experimental areas

10 There are four independent experimental areas at Fermilab. Normally at least three of the areas operate simultaneously, and more than ten experiments may be active at one time. A single experiment will typically run for several months and some have run up to several years, operating twenty-four hours a day, five-and-a-half days a week. A brief look at the activities in each of the areas is given below.

meson area

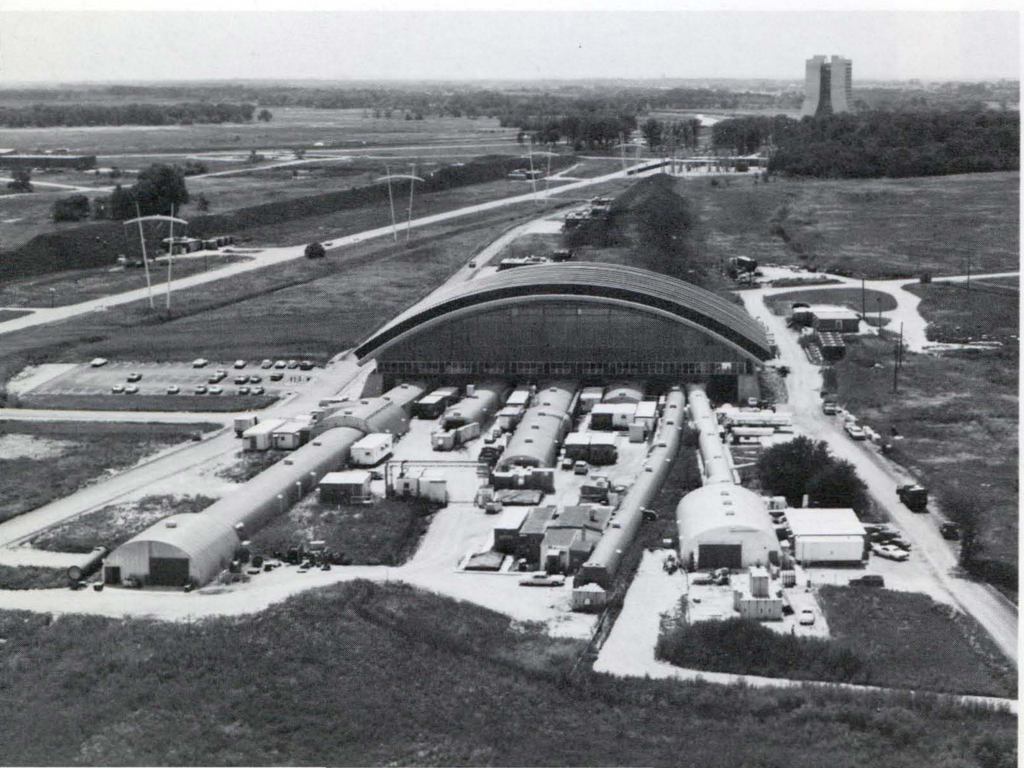
The external proton beam line from the main accelerator to the Meson Area target box is about 4,000 feet long. The protons from the accelerator are transported to the Meson Area by twenty-one superconducting magnets. This beam line is the longest superconducting beam transport system in the world. Upstream of the target the proton beam is split so that it strikes two separate metal targets several feet apart. Six secondary beam lines lead from the target box to the Detector Building where apparatus for doing high energy particle experiments is installed. Work is now underway to convert the beams leading from the target box to operation at 1000 GeV by installing superconducting magnets. The Meson Detector Building can be identified by its scalloped blue and orange roof.

neutrino area

This area has three primary functions: (1) to provide beams for neutrinos for the giant 15-foot bubble chamber and for other types of experiments which use filmless detector techniques; (2) to provide beams of muons and mesons for the detector facility built around the large superconducting cyclotron magnet formerly used by Enrico Fermi at the University of Chicago; (3) to provide beams of protons and mesons for experiments in the 15-foot bubble chamber and a second smaller bubble chamber which comes to Fermilab from the Argonne National Laboratory where it did lower energy experiments in the 1960's.

The Neutrino Area extends for one mile from its target point where particle beams are produced, through a series of control points to the final detectors used for neutrino

Meson Detector Building, housing experiments carried out on the Meson experimental line.



experiments. It is necessary to make these detectors very large since neutrinos have little interaction with matter. Neutrinos are produced by radioactive decays of subatomic particles in the three-foot-diameter, thousand-foot-long steel pipe buried under the prominent dirt shield. Recent replacement of part of the dirt with surplus iron will make it possible to continue operation with the increased machine energies of the Tevatron. The terminus of the Neutrino Area is recognized by the location of a laboratory building topped by a modified geodesic dome fabricated out of metal cans and multi-colored plastic sheets.

proton area

The accelerator beam to the Proton Area can be directed into three below-grade-level experimental locations: P-West, P-Center, and P-East. A beam splitting system provides beam to each location simultaneously. Underground beam enclosures and laboratories have been built to house the target stations and other apparatus for experiments. Work will start shortly to install superconducting magnets that will make experiments possible with energies up to 1000 GeV. The Proton Area can be identified by a stylized pagoda building standing at the top of a yellow circular stairway. The control center for the Proton Area is located on the upper level of the pagoda.

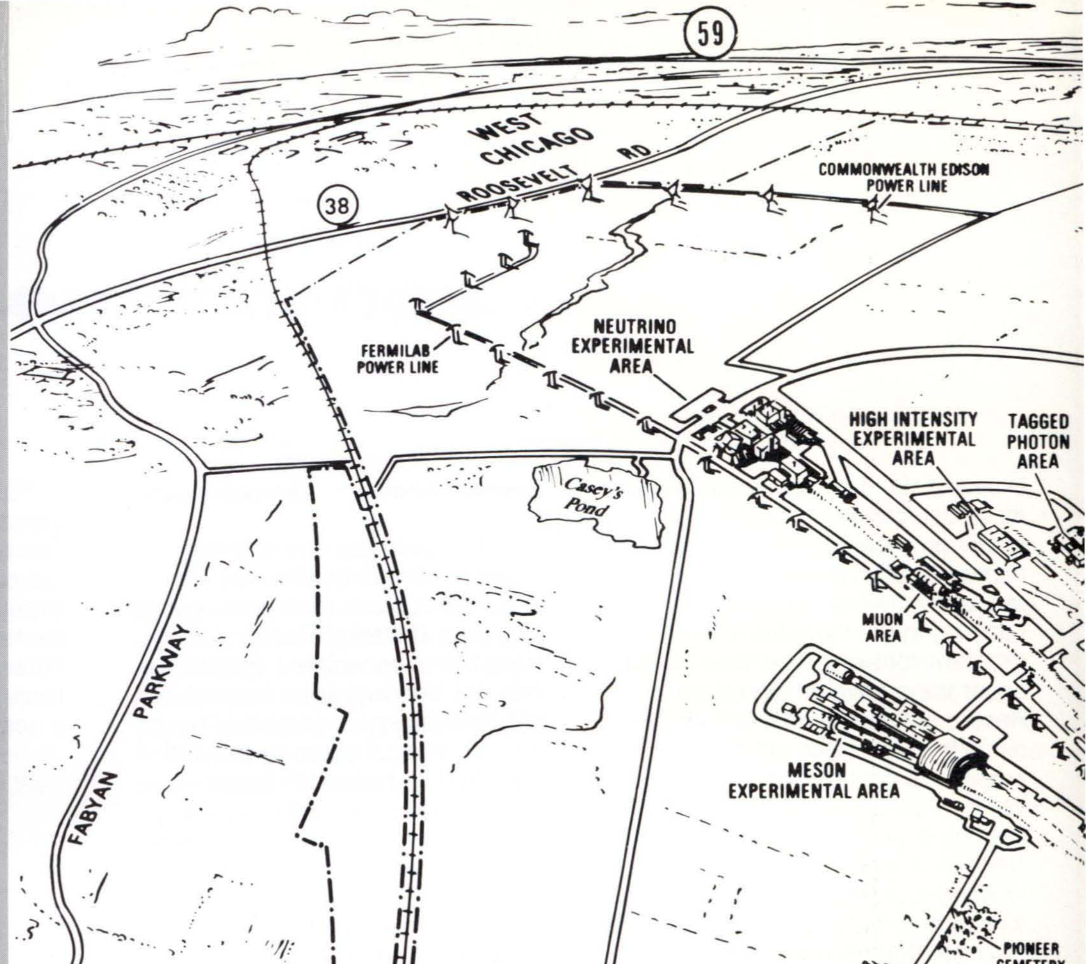
Further details about the capabilities of the experimental areas can be found in the periodically issued booklets titled "Procedures for Experimenters," and "The Fermilab Research Program Workbook." These booklets are available from the Program Planning Office, WH2-E, for a nominal cost.

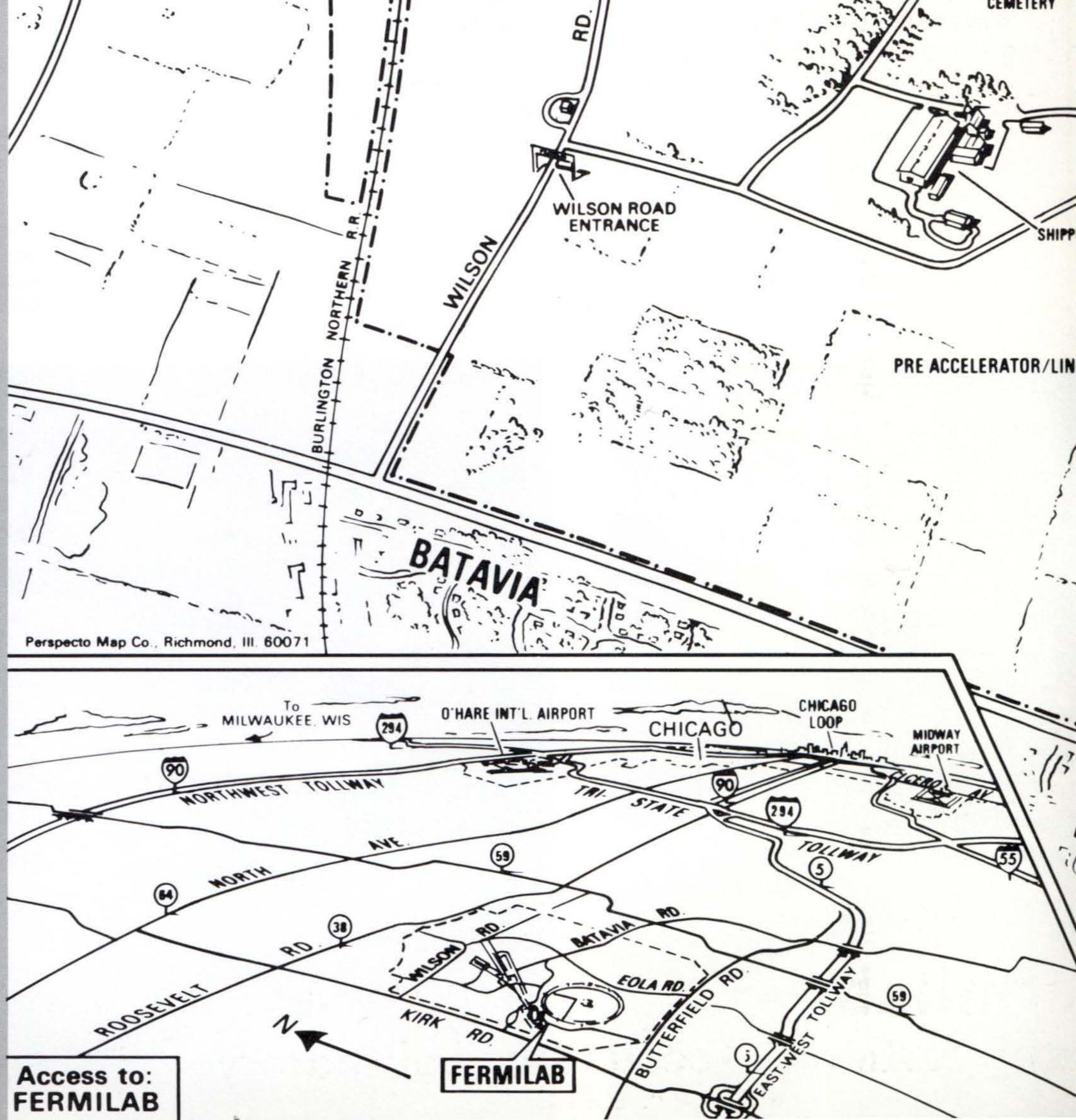
Complex of buildings at the end of the Neutrino experimental line.

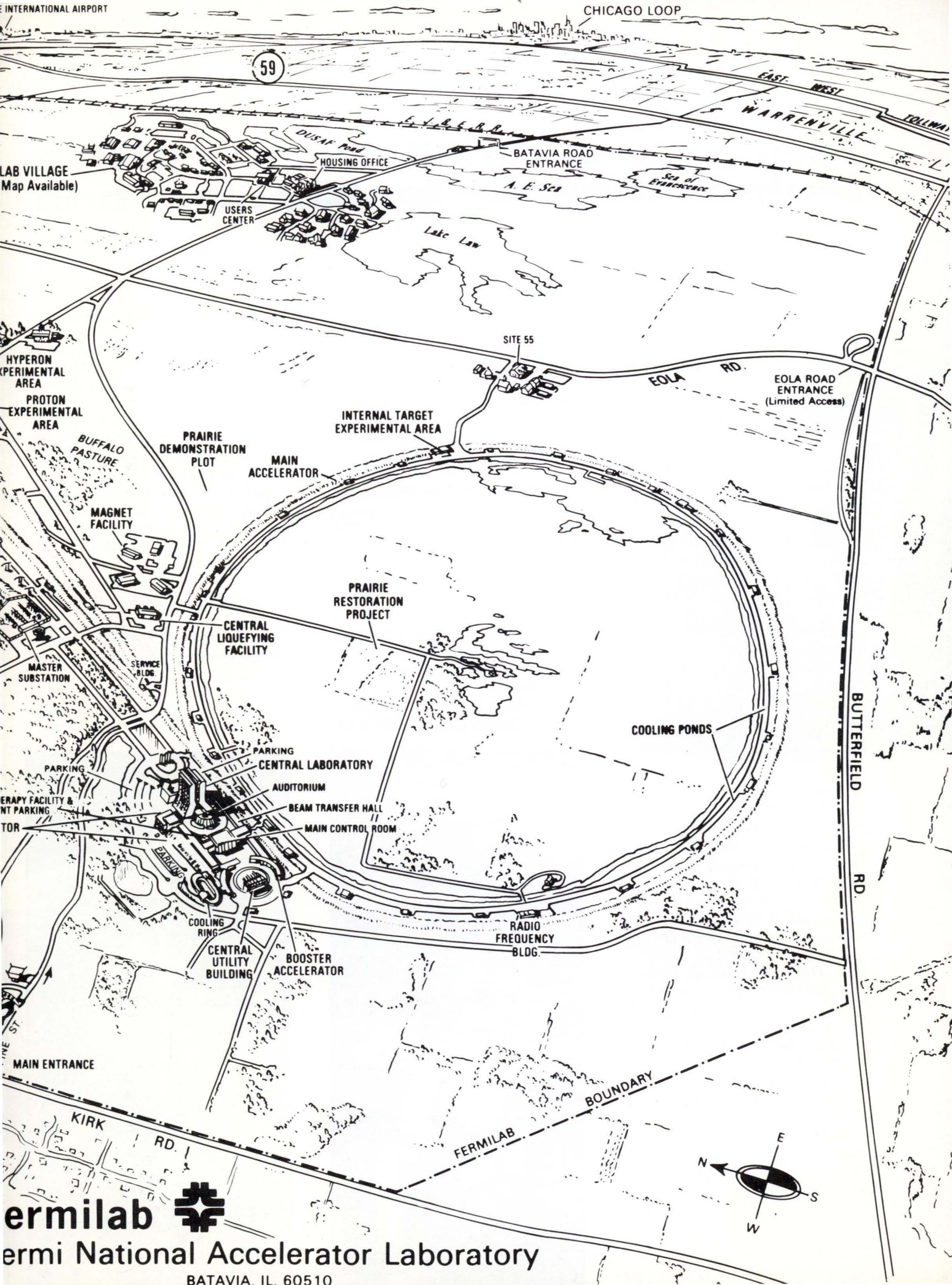
Proton experimental area including underground pits (beneath scalloped roofs) and, at upper left, high intensity and tagged photon areas.

location map

12







ermilab

ermi National Accelerator Laboratory

BATAVIA, IL 60510

neutron therapy facility

A new type of radiation therapy, called neutron therapy, is being offered as an experimental program at Fermilab. To conduct this research, the Laboratory has established a Neutron Therapy Facility (NTF). This research program, together with two other centers in the United States, tests the effectiveness of neutron beams by comparing them with conventional radiation in the management of certain tumors.

The Fermilab NTF opened in September 1976. It evolved from studies on laboratory animals and patients who have undergone neutron therapy here, elsewhere in the United States, and around the world. The linear accelerator is used to produce neutrons for this facility. This is possible because during seven seconds of the ten-second cycles of the accelerator system, the linac is in standby, waiting for the main accelerator cycle to be completed. During those intervals, beam from the linac is extracted to an adjoining room where it strikes a beryllium target. The neutrons resulting from that collision are the particles that are used for cancer therapy research.

Neutrons are particles found in the nucleus of every atom. Neutrons act on human tissues much like x-rays. These radiations destroy cells by changing their genetic character and thus creating offspring that cannot survive. There are, however, some cells in the tumor that are oxygen deficient (hypoxic cells) and these are known to be resistant to the effects of x-rays. These cells are believed to be responsible for the reappearance of the tumor after conventional (x-ray) therapy. Hypoxic cells are less resistant to fast neutrons. Hence, the use of this beam will hopefully increase tumor control. This, however, must be scientifically proven.

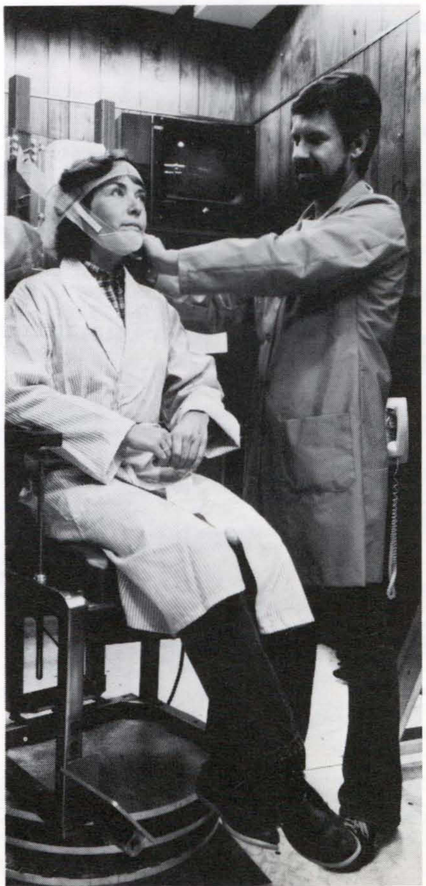
The cancers treated are described in study protocols designed by a national group of radiation therapists under the auspices of the National Cancer Institute. Patients are referred by a radiation therapist to the study only if they have been identified as having a suitable cancer which will benefit from fast neutron therapy. This further assures that the neutron treatment is in the best interest of the patient.

Certain tumors of the mouth and upper respiratory passages, cervix, prostate, bladder and brain are being treated at U.S. neutron centers. In addition, at Fermilab some cancers of the lung, pancreas, esophagus, as well as certain bone and soft tissue malignancies are irradiated in conjunction with surgery and chemotherapy.

The effects of neutron treatment, like all radiation therapy, depend on the part of the body being treated. Effects on normal tissues are minimized by careful planning and by dividing the total radiation dose into many fractions. Some side effects may be anticipated. Many of these side effects are transient and tissue recovery occurs with time. Some late effects may be expended in the irradiated areas.

Operation of the Neutron Therapy Facility is made possible by grants from the National Cancer Institute. No charge is made to patients for the use of the beam or the facilities at Fermilab. Patients have to arrange for their own transport. Further information about the Neutron Therapy Facility is available by calling 312-840-3865.

Simulation of patient preparation in Neutron Therapy Facility for irradiation of head area.



public information office, tours and cultural activities

tours and cultural activities public information office

The Public Information Office, located on the west side of the main floor of Wilson Hall, is the source of general information about Fermilab. A number of pieces of literature are available at no charge. Several relevant layman's science books are sold here. Slides and photographs are also for sale. A bibliography of layman's level readings about particle physics can also be obtained here.

Two kinds of tours of Fermilab are available:

A self-guided tour may be taken by groups of six or less every day between 8:30 a.m. and 5:30 p.m. Such a tour begins at the reception desk in Wilson Hall; a pamphlet available there outlines the self-guided tour route.

Guided tours for groups of ten or more, ninth grade age and over, are given by appointment at either 9:30 a.m. or 1:30 p.m., Monday through Friday. At least three months' notice is advised. For further information, or to make an appointment, call the Fermilab Public Information Office, (312) 840-3351.

sigma XI

Scientists at Fermilab have joined with scientists at the Amoco Oil Company and Wheaton College to form a local chapter of Sigma Xi, the Research Society of North America.

New members or transfers from other chapters of Sigma Xi are welcome.

Contact Dr. Marvin Johnson at Fermilab, (312) 840-3168 or Dr. Dixon Bogert, (312) 840-4010, for further information about Sigma Xi.

cultural activities

Fermilab sponsors cultural activities to which the public is invited. The Programs are all presented in Norman F. Ramsey Auditorium, located at the rear of Wilson Hall.

The Science and Human Values Lecture Series is intended to bring together science and the humanities in a way which shows their interrelationship and which will make both more understandable. Tickets and information about the lectures may be obtained in person at the reception desk in the atrium of Wilson Hall, or by sending a check and a stamped self-addressed envelope to the Auditorium Committee, Fermilab, P.O. Box 500, Batavia, Illinois 60510 in advance of the lecture.

Other cultural programs are presented from time to time, also with paid admission. The same procedure is followed for obtaining tickets.

From October to June, the Physics Department presents a colloquium at 4 p.m. each Wednesday. Guest speakers from many scientific disciplines present interesting aspects of their work. The spirit of the meeting is to broaden the scientific outlook of the Laboratory by

listening to specialists in fields other than particle physics.

The public is welcome to attend these colloquia but no publicity about them is sent outside of the Laboratory.

The Fermilab International Film Society presents a film on the second Friday of each month at 8 p.m. and also special films and film festivals from time to time. No reservations or tickets are necessary in advance. There is a nominal charge for the films. An annual schedule is available from the Fermilab Public Information Office.

exhibits

From time to time, special exhibits are shown in the second floor gallery of Wilson Hall. The public is invited to view these exhibits during business hours.

research program

Proposals for experiments to be conducted at Fermilab are reviewed by the staff and discussed with a Physics Advisory Committee composed of eminent physicists in the field of high energy physics. The committee periodically recommends proposals which might be accepted and makes suggestions as to their priority.

Once a proposal is accepted, the Laboratory staff works closely with the experimental group in reviewing equipment needs, developing cost estimates and planning for experimental runs. Most of the small light laboratories, workshops and offices for these support facilities are located in Wilson Hall; about 200,000 square feet of other support facilities are located near the experimental areas and in the Fermilab Village. To date, 320 experimental proposals had been approved to run at Fermilab out of 703 proposals submitted; of the approved experiments 279 had been completed.

Some highlights of Fermilab research include:

neutral weak currents

Discovery of a new type of neutrino reaction - "muonless" events - was announced by a Harvard-Pennsylvania-Wisconsin-Fermilab collaboration in 1973. Similar events had also been seen in the bubble chamber at CERN. These observations provided the missing link in a theory that proposed to unify the weak (radioactivity) and electromagnetic interactions, because they could not be explained without invoking a force not previously detected: the "neutral current." In historical perspective, these results may be seen to equal in significance the discovery by Oersted in 1823 that an electric current produces a magnetic field, which led to the unification of electricity and magnetism.

Many later experiments have been devoted to the quantitative study of neutral current phenomena. Together with measurements performed at other laboratories, these experiments provided remarkable confirmation of the unified theory of weak and electromagnetic interactions. (For their part in conceiving this unified theory, S. L. Glashow and S. Weinberg of Harvard University and A. Salam of the International Center for Theoretical Physics in Trieste were awarded the 1979 Nobel Prize in Physics.)

One of the most decisive contributions, because of its freedom from theoretical uncertainties, was the measurement of the rate for elastic scattering of the muon's neutrino from the electron. This was carried out in 1978 by physicists from Brookhaven National Laboratory and Columbia University using the Fermilab 15-ft. bubble chamber filled with neon and hydrogen. Since the muon's neutrino and the electron scatter only by means of neutral current interactions, this process is especially suited for study of the neutral currents. This experiment showed that the interaction rate is only about one-tenth of that for an ordinary "charged-current" weak interaction, in agreement with the Weinberg-Salam model.

In 1979, a larger sample of neutrino-electron scatters, promising still more incisive tests of the theory, was gathered in an electronic detector operated by physicists from the Virginia Polytechnic Institute, the National Science Foundation, University of Maryland, and the Institute for High Energy Physics in Peking.

what are "elementary particles" made of?

Experiments throughout the 1960's revealed a dazzling array of hundreds of strongly-interactive particles with markedly different characteristics. A degree of order was brought about when it was found that these particles could be grouped in families with as many as ten members each. Buy why should particular familial relationships exist, and not others? The family structure could be explained by the hypothesis that the "elementary particles" were made up of three more fundamental objects, called quarks, arranged in simple patterns. The three varieties of quarks are called Up, Down and Strange.

quarks as constituents

Two high-precision measurements completed in 1978 have reinforced the conviction that the static properties of hadrons are governed by the quarks within them. Experimenters from Rutgers University, the University of Michigan, and the University of Wisconsin have determined the magnetic moment of the lambda hyperon $\Lambda°$, ten times more precisely than earlier measurements. The new result is in striking agreement with quark model expectations. So too is the measurement of the distribution of electric charge within the neutral K meson, performed by scientists from the University of Chicago, the University of Wisconsin, and the Swiss Federal Institute of Technology, Zurich. Although the $K°$ meson carries no electric charge when viewed as a whole, its interior consists of regions of net positive and negative charge. (A similar discovery was made for the neutron in the late 1950's.) The measurements at Fermilab support the view that $K°$ consists of a d-quark in orbit around a more massive strange anti-quark.

how do quarks move?

Fermilab experiments have provided incisive "photographs" of the quark motions. Experiments E-26, E-98 and E-398 in sequence, studied the deflection of high energy muons from nuclear targets. The groups included scientists from Cornell University, Michigan State University, Princeton University, the University of California-Berkeley, and the

University of California at San Diego; and from the University of Chicago, Oxford University, the University of Illinois, Harvard University, Virginia Polytechnic Institute, the University of Maryland.

It is known that the deflection arises from the electromagnetic force and thus may be used as a probe to "see" electrically-charged quarks inside the hadrons. Experiments carried out in the late 1960's at SLAC provided the first such pictures of the three quarks within protons and neutrons, and suggested that quarks do not interact at all when bound within hadrons. Non-interacting quarks could not be accommodated by any theory, but a theory known as quantum chromodynamics predicted that a feeble but observable interquark force would be present. Its consequence for the muon deflection experiment is that "photographs" of the proton interior taken with different resolving power will differ in subtle but regular ways. Variations of this kind were first observed in the Fermilab experiments which have been analyzed to yield precise mathematical forms describing the motion of three quarks in a proton. This apparent success of quantum chromodynamics has given the first quantitative indications that a true theory of the strong force is at hand. From this point of view, the forces between quarks are fundamental, and the famous and long-studied nuclear force between protons and neutrons now appears to be a complex manifestation of the constituent quark forces.

Experiment E-288 (consisting of scientists from Columbia University, the State University of New York at Stony Brook, and Fermilab) illuminated a more ephemeral aspect of the proton quark structure, the transient "cloud" of quarks and antiquarks that appear and disappear because of the forces between the principal three quarks in the nucleon. These experimenters were able to make very precise measurements on the antiquark content even though this comprises a small fraction of the proton. They were able to do this because the process they studied, production of muon pairs in collisions of two protons, requires the annihilation of a quark from one proton and an anti-quark from the other.

quarks inside the pion

Perhaps the most spectacular new result on quark structure focuses attention on the pi meson or pion. This particle, studied in accelerators since 1950, plays the major role in the nuclear forces problem. It is composed of a quark and an antiquark. The quark structure of the pion has long been a goal in particle physics. A group from Princeton University and the University of Chicago (E-444), succeeded in obtaining a photograph of the pion quark structure. Since the pion lives only a hundredth of a millionth of a second and is found only near high energy collisions, this is a formidable technical feat. The pion photograph shows a structure quite different from that of the proton, as qualitatively anticipated. In the future, Fermilab experiments will seek more refined pictures of these and other hadrons.

charmed particles

A discovery of a new kind of particle was made both on the East coast at the Brookhaven National Laboratory and on the West coast at the Stanford Linear Accelerator Center, in November, 1974. The result was confirmed at Fermilab within weeks of the first announcement. Using protons and photons at Fermilab, an experiment started producing and observing the new particle (named the "Psi" or "J") by the hundreds.

The evidence was clear that another clue to elusive quarks was provided by the new data from these experiments. Theorists interpreted these data as convincing but circumstantial evidence for the existence of a conjectured fourth kind of quark known as a "charmed" quark, and indicating a new kind of matter. Many experiments at Fermilab searched for charmed particles and many have found pieces of the puzzle.

An experimental group from Fermilab, Harvard, the University of Pennsylvania, Rutgers University, and the University of Wisconsin in the neutrino beam saw patterns of new phenomena: two-muon (di-muon) events, which signal the production and subsequent decay of charmed particles in neutrino interactions. A CERN-Lawrence Berkeley Laboratory-University of Hawaii-University of Wisconsin experiment in the Fermilab 15-foot bubble chamber also saw evidence of charm-like events in its giant detector. Subsequent neutrino experiments in both the 15-foot bubble chamber and electronic detectors have extended these early observations and provided key information on the behavior of charmed particles.

In 1976 a team of experimenters from Columbia University, the University of Illinois, and Fermilab pieced together fragments of particle decay to find a "charmed baryon." They examined 15 million fragments in very different combinations and found some 40-50 examples of the new particle.

Very recently, several experiments studying the interactions of neutrinos in photographic emulsions have begun to collect significant numbers of charmed particle decays. This technique permits the determination of the lifetime of the unstable charmed particles, which is an important test of theoretical predictions. These collaborations involve more than 24 institutions around the world. Using the emulsion technique, the exposed films can be removed to other locations for analysis.

how many quarks?

The discovery of the massive vector meson, the upsilon, in the summer of 1977 was reported at Fermilab by a team of physicists from Columbia University, Fermilab, and the State University of New York at Stony Brook. That particle, now almost universally identified as a state consisting of a hitherto unknown b-quark and an anti b-quark, is three times more massive than any particle discovered earlier. Since the initial discovery at the Laboratory, extensive work has been underway to refine and amplify the original observation.

In late 1977 and 1978, much of the work centered around improving the resolution of the detector system and gathering more data. The improved experiment showed that the upsilon was only the first of a sequence of particles with similar properties. Further experimentation is required to discover more of the attributes of the b-quark, the fifth species known.

architecture and sculpture

The design of the facilities and buildings at Fermilab was greatly influenced by the first director of the Laboratory, Robert R. Wilson, a physicist and artist/sculptor of renown. It was Dr. Wilson's philosophy that a research laboratory should be an attractive cultural center in the community and the nation. He personally suggested designs and in many cases, such as the central laboratory building, was intimately involved in the detail design, as well as watching the evolving construction work. The architectural and engineering services for the conventional facilities were provided by a joint venture of four firms: Daniel, Mann, Johnson and Mendenhall of Los Angeles; Seelye, Value and Knecht, New York; Max O. Urbahn, New York, and George A. Fuller Construction Co., Chicago.

1 Robert Rathbun Wilson Hall (formerly the Central Laboratory) is a 16-story building. Its twin towers are joined by crossovers at the 1st through the 5th floors, and 13th through the 16th floors on the south, and 7th through the 16th floors on the north. In the center is one of the world's largest atriums, featuring a variety of plants and indoor shrubs. The Laboratory's main cafeteria is on the first floor, providing a central meeting place on the site.

The building was inspired by a cathedral at Beauvais, France, built in A.D. 1225 which also featured twin towers with a chancel on the main floor.

Concrete sections forming the outer walls of the building were poured, using staggered boards in the forms which give the resulting texture to the finished concrete.

The building houses the administrative functions of the Laboratory and as well, small technical laboratories and a large computer. It was completed at the time of the dedication of the Laboratory in May, 1974.

Adjoining the Wilson Hall is the Norman F. Ramsey Auditorium building seating 807 people. The external walls contain 40 feet high elements poured off site, brought to the building structure and placed in their present vertical position. Acoustics in the auditorium were designed with special care and are highly regarded by performers in the auditorium.

experimental area trademarks

The identification of each experimental area is marked by a building of distinctive architecture.

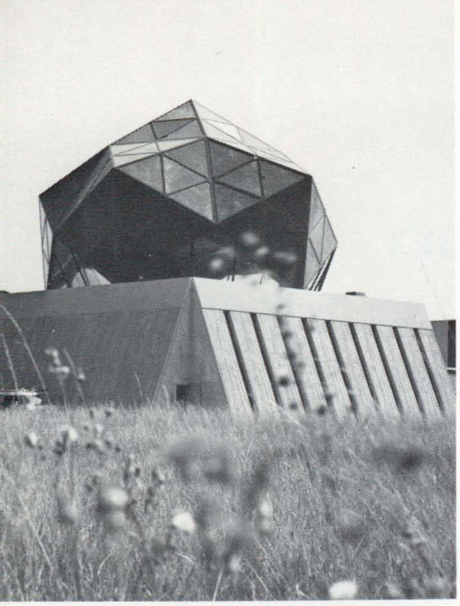
2 The Meson Detector Building is capped by a roof constructed of inverted half-sections of steel culvert, creating a giant scalloped effect. The culvert sections are painted blue on one side, orange on the other. They are approximately the same size as the concrete sections forming the tunnel of the main accelerator.

3 A modified geodesic dome tops the assembly building of the Neutrino Area. Each triangular section is ten feet on a side and is constructed of two triangular pieces of colored reinforced fiberglass forming a sandwich over stacked beverage cans. There are 120,000 cans in the dome, all donated by the public. Looking through the panels resembles a huge honeycomb.

4 The control center for the Proton Area is located in a stylized pagoda sitting on legs 26 feet tall with a yellow spiral staircase in the center of a glass tube leading from the ground to the control center.

1

2



3

5

6

the fermilab village

5 The Fermilab Village was once the village of Weston, Illinois. It lies on the eastern boundary of the site, transversed by Batavia Road. The entire village was absorbed into the land package purchased by the State of Illinois in the late 1960's for the construction of the Laboratory. The houses in the original village served as offices for the Laboratory during the construction period 1968-1974. Many of the houses have since been returned to residences and are leased to visiting experimenters. A number of the best of the original farm homes on the site were moved to form an additional complex adjoining the village on the west. These too have been renovated and remodeled to provide residential accommodations for visitors.

Other architectural landmarks include a concrete archimedes spiral covering the pumping station at Casey's Pond and several unique midwest barns and brick farm homes still in their original locations.

sculpture

Under Dr. Wilson's direction, several pieces of sculpture have been erected. Two are Dr. Wilson's work:

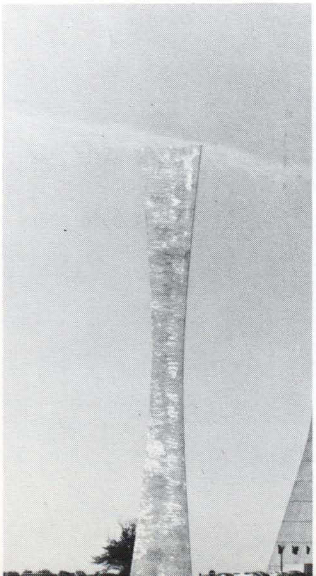
6 A mobius strip mounted on the roof of the auditorium. It is built of 3″ x 5″ pieces of stainless steel which he welded on a tubular form eight feet in diameter.

7 "Hyperbolic Obelisk" stands at the foot of the reflecting pond in front of Wilson Hall. It is 32 feet high, fabricated of three stainless steel plates each 1/4″ thick. Each plate is made up of 23 smaller plates which were edge-welded by Dr. Wilson.

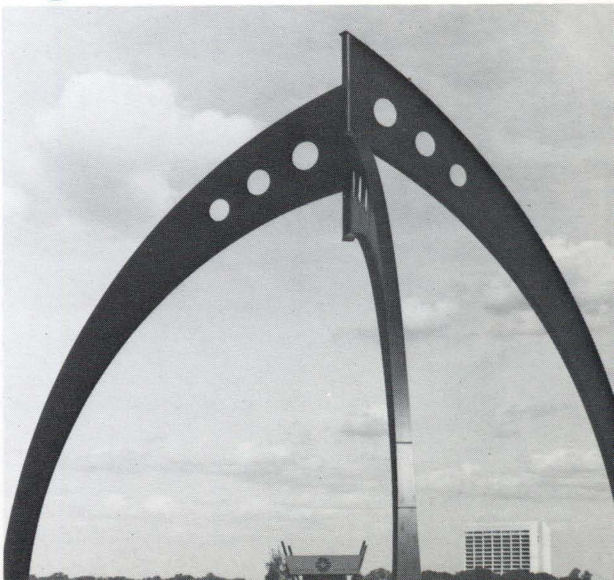
8 "Broken Symmetry" is erected over the entrance road to Fermilab, a three-span arch symmetric when viewed directly from underneath, but with carefully calculated asymmetry from its other views. The sculpture was designed by Dr. Wilson and fabricated by the Fermilab Machine Shop.

Several pieces of sculpture by other artists are located in the second floor lounge of Wilson Hall.

7



8



(L-R) J. O'Meara, H. Hinterberger at the passive solar wall they designed for a Fermilab warehouse.

conservation programs

solar energy

Fermilab has received grants for the following demonstration projects:

1. Fermilab's Energy Conservation group has designed and built a solar non-tracking concentrator array of a novel geometry. The orientation of the solar collectors is such as to suppress all convection losses without resorting to expensive means such as evacuated tubes.
2. The Energy Conservation group also designed and built a passive solar wall to heat the main storeroom warehouse. This is a large installation (400 ft. long), but kept extremely simple so as to be cheap and therefore cost effective. This installation will provide about one-third of the heat required in this large warehouse.
3. In a small greenhouse, coils containing water heated by the sun course through soil, keeping seedlings and plants from damage when the ambient heat is kept at 55 degrees F.

electrical power

Electric power at Fermilab is obtained from Commonwealth Edison Company's transmission lines which pass along Fermilab's eastern boundary. The Fermilab master substation takes its power directly off the C-E lines using a new technique to power the accelerator. Aesthetically-appealing poles have been built to bring in the electrical power. They are modified "H" structures built on two wooden poles with curved cross-arms to link them.

use of gasohol

In April, 1979 Fermilab began to use gasohol in all its vehicles. Gasohol is a mixture of 85% lead-free gasoline and 15% ethanol (alcohol). The purpose was to save gasoline and, after solving a few early problems, the use of gasohol is proceeding routinely. Fermilab was the first national laboratory to use gasohol in the majority of its vehicles. The cost of gasohol is competitive with super unleaded gasoline. Originally, Fermilab mixed its own gasohol, but now the supply is purchased from a bulk supplier in the Chicago area.

water conservation

Extreme care is taken at Fermilab to avoid long or short-range depletion or contamination of natural water sources in the area. Fermilab's cooling water is obtained from specially-developed water retention basins for run off from on-site rainfall, supplemented by water taken from the Fox River only during periods of high water level. A deep well has been drilled but never used; it exists only as an emergency back-up system.

An example of preserving natural water supply is the water system that cools the Booster accelerator ring. The heated water from the accelerator is pumped into an outdoor waterway. The water flows in a full circuit, cooling on the way. The two large ponds through which the water flows form natural, comfortable habitats for fish, geese, ducks and swans, through the winter. Prior to the building of this system, elaborate mechanical cooling towers were necessary to cool this water. The cost of replacing those towers prompted the design of the air cooling system.

prairie restoration project

In February, 1974, Fermilab accepted a plan of The Nature Conservancy (a national organization for promotion of conservation practices) which proposed to restore prairie landscape on the 660 acres inside the Fermilab main accelerator ring. About 250 acres have now been planted, thanks to the several hundred volunteers from the area who harvested seeds from prairie remnants in the Chicago area.

The project has now reached a point where much of the harvesting and planting can be done with mechanical equipment, but volunteers will continue to search for seeds of certain species to make it an authentic mix of prairie plants.

Rare, vanishing species of the Illinois prairie bloom again in the Fermilab prairie restoration.

wildlife

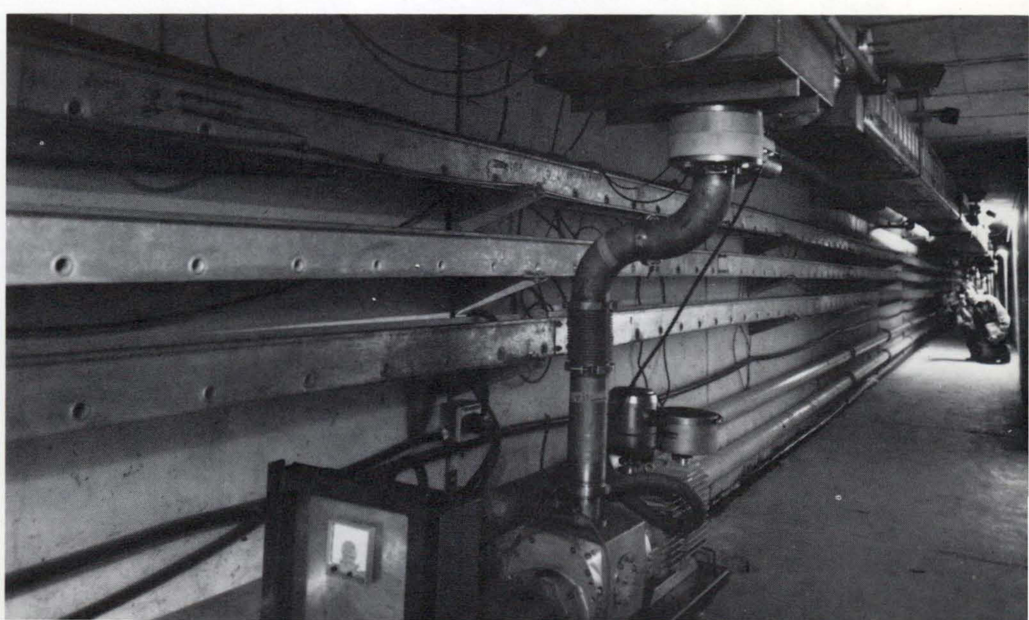
The planting of trees, grasslands, and placement of water catchment lakes and reservoirs has created a park-like atmosphere at Fermilab. A herd of buffalo is maintained. The buffalo herd is a combination of animals brought from Colorado, from the State of Illinois herd, a few others purchased in South Dakota, and their offspring. The preservation of existing groves of trees will maintain and expand the native deer on site. As a result of the development of surface water collection lakes, a waterfowl habitat has been established and has resulted in an increase of the waterfowl population on site.

Fermilab's buffalo herd roams in a pasture east of the magnet facility.

applied superconductivity

In its Energy Saver superconducting accelerator, Fermilab will demonstrate the world's first large-scale application of superconductivity. (See description of this accelerator on page 8.) In addition to the scientific merits of the project, the application of superconductivity can save as much as 50% of the cost of electrical power for operating the accelerator.

Superconducting magnets are also being used in the experimental beam lines, replacing whenever possible the conventional, more expensive magnet use. A string of 21 superconducting magnets operates in the "left bend" beam line to the Meson experimental area. Prior to the operation of this superconducting system, the beam was transported by 56 ordinary electro-magnets. The original system used one megawatt of electricity, while the new system uses 1/5 of a megawatt. This is the first large superconducting system in the world to deliver particle beams on a regular basis.



The "left bend" superconducting magnets carry beam to the Meson experimental area.

safety programs

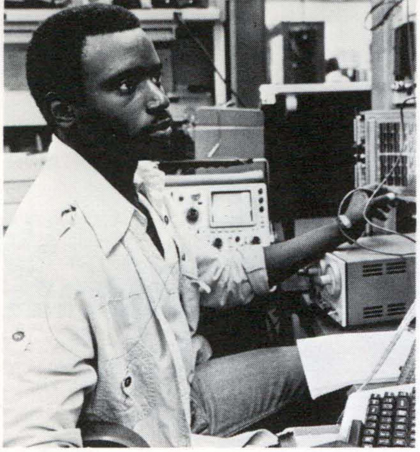
safety programs

Qualified radiation safety experts on the Fermilab staff advise the planning and operation of Fermilab to insure that visitors and the surrounding area will not be exposed to any significant radiation. Off-site advisory committees frequently review the radiation protection plan. The accelerators are covered with earth shielding to keep on-site radiation at permissible levels outside of enclosures.

The ultimate responsibility for safety at Fermilab rests with the Laboratory Director. The responsibility for the safety of personnel within each of eight Laboratory subdivisions is delegated, by the Director, to the eight Division/Section heads.

The Safety Section monitors the carrying out of the safety procedures and reports directly to the Director.

A Safety Committee, composed of representatives of several sections of the Laboratory, advises the Director. The Safety Committee has several sub-committees in specialized areas such as, Cryogenic Safety, Electrical Safety, Fire Safety, and Mechanical Safety.



educational programs

employee development

Fermilab makes available to full-time employees considerable opportunity to further their skills and education. Tuition reimbursement which covers full tuition, required fees and required books for accredited college work at all degree levels is a corner-stone of employee development. On a continuing basis the Lab offers courses, workshops or seminars in supervisory development, employee assistance, equal opportunity training for managers, and various aspects of safety. In addition, skills courses are offered as needed; for example, microprocessor technology and word processing. Special programs, such as Pre-retirement Planning, are also offered when appropriate.

educational outreach

Fermilab sponsors and/or participates in a number of educational activities whose over-all goal is to encourage talented persons to commit themselves to careers in the sciences.

At the college level there are four programs. Through the Summer Internships in Science and Technology for Minority Students, college students majoring in physics or related sciences are employed at the Lab for eleven weeks in the summer and are assigned to work with scientists and engineers on research assignments and projects.

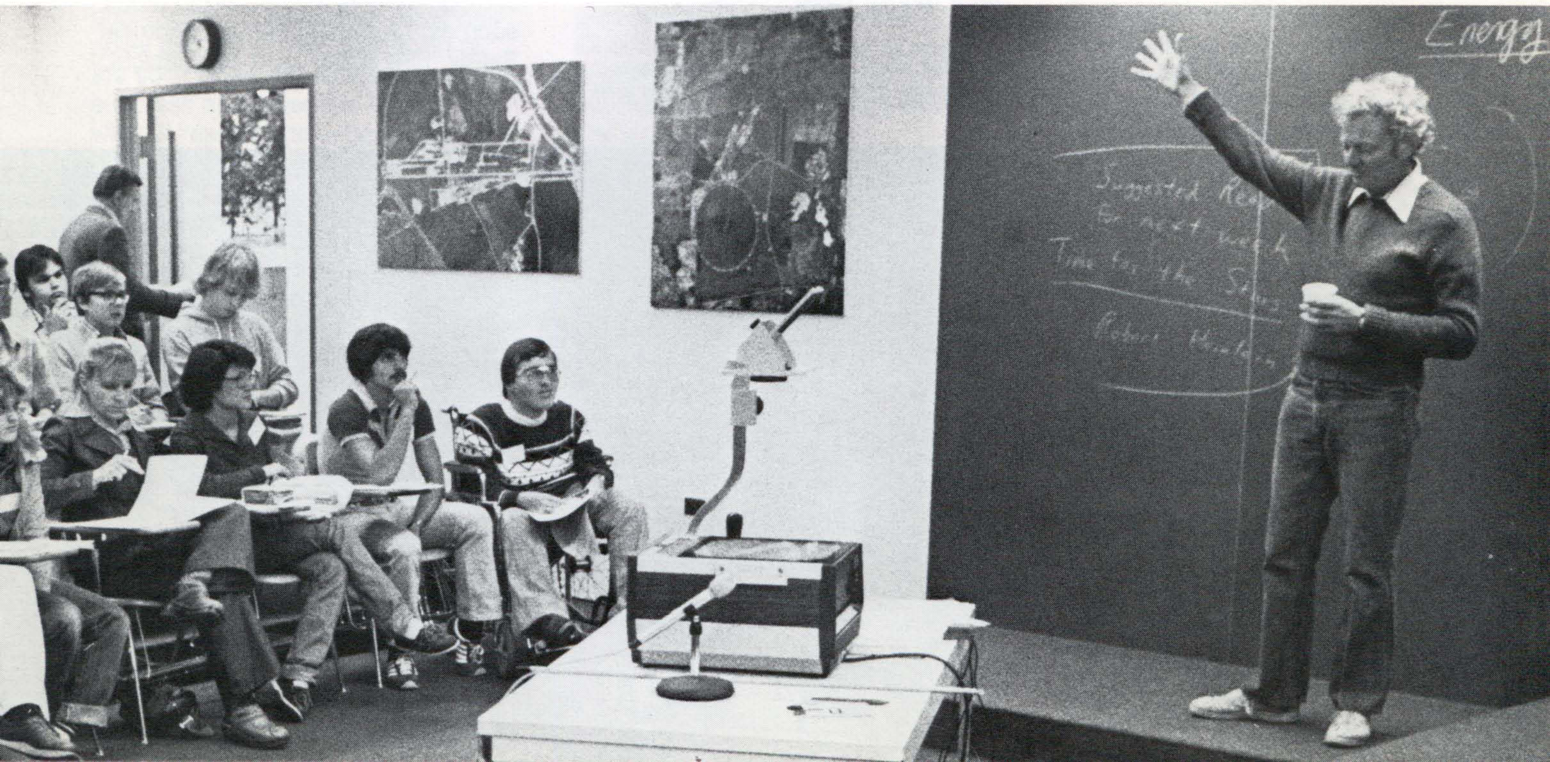
Fermilab is a member of the National Consortium for Graduate Degrees for Minorities in Engineering. As part of its commitment to the GEM program, the Lab sponsors several students by providing summer work their senior year and through graduate school.

On an ongoing basis, the Lab's Co-operative Education Program provides employment for several undergraduate students for the work terms of their academic programs.

In collaboration with the institutions which make up Universities Research Association, Fermilab sponsors a graduate fellowship program in physics for minority students. In addition to some financial support during the school year, the Lab provides summer employment.

For high school students, Fermilab sponsors two programs. The Lab conducts a Saturday Morning Physics Program for gifted high school upper classmen who are interested in science. For ten consecutive Saturday mornings, eighty students and instructors come to the Laboratory to attend lectures and take tours led by volunteer Fermilab scientists and engineers. Three ten-week sessions are scheduled throughout the year.

During the summer Fermilab has run a program called Target: Science and Engineering for High School Students. High potential junior and senior students are given the opportunity to investigate aspects of science and engineering in hopes of motivating them toward science careers. Students receive both hands-on experience and classroom instruction.



fermilab industrial affiliates

Fermilab Industrial Affiliates is a group formed to stimulate the transfer to private industry of the technical innovations born in the basic research done at Fermilab. Interested firms and individuals become members after paying an initial fee of $1,000.

Symposia, tours, and exhibits are held at Fermilab during which an exchange of information takes place between Fermilab staff members and the Affiliates describing Fermilab's technological developments in such areas as superconductivity, cryogenics, data processing, computer hardware processing, computer controls, fast electronics, ion beams and sources, high power radiofrequency designs, cryogenic vacuum technology, and particle detectors.

Further information about the Fermilab Industrial Affiliates may be obtained from Leon M. Lederman, Director, 312-840-3211.

The membership roster of the FIA includes: Bell Laboratories, Caterpillar Tractor Company, Chicago Bridge and Iron Company, Combustion Engineering, Inc., Commonwealth Edison, Deere and Company, Digital Pathways, Inc., Eaton Corporation, General Electric Corporation, The Harshaw Chemical Company, IBM, International Harvester Company, Kinetic Systems Corporation, Lester B. Knight and Associates, Inc., Litton Industries, McGraw-Edison, Nalco Chemical Company, New England Nuclear Corporation, Nuclear Data, Inc., Raychem Corporation, Sargent-Welsh Scientific Company, Shell Development Company, Standard Oil Company (Indiana), State of Illinois, Texaco, Inc., Westinghouse Electric Corporation.

universities research association, inc.

Universities Research Association, Inc. (URA) was formed in June, 1965 by 34 major research universities after a meeting of university presidents at the National Academy of Sciences, Washington, D.C. to provide a broad national basis for the management of the then-anticipated 200 GeV accelerator and similar unique facilities in other fields.

The URA corporation is governed by a Council of Presidents comprised of the presidents of the member universities, now numbering 54 (53 in the United States and one in Canada).

Management of URA is delegated to a Board of Trustees. Eight of the 23 members of the Board of Trustees are appointed at large; the other 15 are chosen by the Council of Presidents from the member universities.

James C. Matheson is the vice-president of URA with offices at 1100 Connecticut Avenue, Washington, D.C., 20036. Phone: 202-293-1382.

Locations of member institutions of Universities Research Association Inc., which operates the Fermi National Accelerator Laboratory as a contractor for the U.S. Department of Energy.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1982—554-749