WASH-1505

ENVIRONMENTAL STATEMENT

NATIONAL ACCELERATOR LABORATORY

Batavia, Illinois

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UNITED STATES ATOMIC ENERGY COMMISSION

RESPONSIBLE OFFICIAL:

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I. SUMMARY

The Atomic Energy Commission (AEC) is the executive agency responsible for management of the major share of the U. S. research effort in high energy physics. Approximately 90 percent of all Federal expenditures for high energy physics are funded by the Commission.

High energy physics research is the experimental study of elementary particles and, with the theoretical analysis of the properties and interactions of these particles, offers the promise of a better understanding of the basic constituents of the physical universe. This basic research is among the Nation's most prominent scientific undertakings, and several of the accomplishments have been recognized by the award of the Nobel Prize. The Joint Committee on Atomic Energy (JCAE) of the U. S. Congress in its FY 1972 authorization report stated it is in the national interest that the United States remain in the forefront of high energy physics.

The scientific tools used to carry out the experimental programs in the study of high energy elementary particle physics require many large and complex devices such as particle accelerators, particle detectors, and data analysis equipment. In support of the U. S. high energy physics program the U. S. Congress authorized $250 million to design and construct a National Accelerator Laboratory (NAL). The principal scientific instrument of the Laboratory will be a 200-500 billion electron volt (BeV) energy proton synchrotron.

One hundred and twenty-six proposals recommending more than 200 locations in 46 different states were submitted to the Commission for proposed siting of the Accelerator Laboratory. Weston, Illinois, a 6800 acre site 30 miles west of Chicago, was selected for the project. Construction started in December 1968, is on schedule, more than sixty percent complete, and is scheduled for completion in December 1973.

Benefits from development of the site into a National Accelerator Laboratory, coupled with the programs of site restoration and conservation, culture, and the construction of a major research tool for the frontier of science, far outweigh the minor detrimental effects such as the levels of radiation to be generated and the minor use of the area's natural resources. Therefore, plans are to proceed with project completion, which will be followed by implementation of a high energy physics experimental program.

II. NEED FOR HIGH ENERGY PHYSICS AND THE NATIONAL ACCELERATOR LABORATORY

High energy physics research is concerned with the experimental study of elementary particles and with the theoretical analysis of the properties and interactions of these particles. This research offers the promise of acquiring an understanding of the fundamental forces which control the behavior of the particles within atomic nuclei and is directed toward obtaining a more complete knowledge of the nature and behavior of the basic constituents of the physical universe. Investigations are carried out chiefly in experiments employing intense and well-controlled primary, secondary, or tertiary beams of elementary particles -- the basic elements of matter -- produced by high energy accelerators. Experimental studies in the recent past have resulted in a broader understanding of the significant phenomena which occur within the domain of elementary particles.

High energy physics in the United States is an exciting and vigorous field of basic research which ranks high among our most prominent scientific undertakings. Over the past decade, most of the major high energy physics developments and discoveries, throughout the world, have been made in U. S. laboratories. Several of these accomplishments have been recognized by the award of the Nobel Prize.[1]

In its FY 1972 authorization report in support of the high energy program, the Joint Congressional Committee on Atomic Energy stated:

> "High energy physics is a highly competitive field among nations as evidenced by the advanced machines[2] in operation or under construction in the Soviet Union and in Europe. It is, of course, in the national interest that the United States remain in the forefront of this field of scientific endeavor."

The success of the U. S. program has been based on the exceptional talent and enthusiasm of the individuals involved and on the willingness of the Federal Government to support a broad range of high energy physics activities. These activities include: the construction and operation of accelerators of many different characteristics; the development of complex particle detection and data analysis equipment; the conduct of extensive research programs which use the accelerators and auxiliary equipment; and the conduct of theoretical programs which interact with the experimental effort.

In order to continue the exploration of elementary particle structure down to even smaller distances with beams of particles, there is no suitable alternative to the construction of new accelerators aimed at reaching higher energies.

The rich discoveries of the past years have given us great confidence that there are fundamental new discoveries and insights to be achieved by studies that can be carried out in the 200-1000 BeV energy region.

The National Accelerator Laboratory (NAL), estimated to cost $250 million, was authorized by the U. S. Congress in Fiscal Year 1968, in the amount of $7.333 million, $25.0 million in FY 1969 and $217.667 million in FY 1970, and is being built to carry out experiments to study the basic forces and constituents of matter. Construction started in December 1968, is on schedule, is more than sixty percent complete, and is scheduled for total completion in December 1973. A long-range goal of experimentation by NAL is the discovery of the most fundamental laws governing the structure of the material universe. NAL will be a high energy physics laboratory centered around a particle accelerator, a 200-500 BeV proton synchrotron. When completed, this will be the most powerful particle accelerator in the world. The highest energy accelerators to date are the 33 BeV proton accelerator at Brookhaven National Laboratory, Long Island, New York; and the 76 BeV proton accelerator at Serpukhov, U.S.S.R. A 300 BeV proton synchrotron is scheduled for completion at CERN, Switzerland, in 1976. The NAL accelerator will enable experiments to be done in an energy range not accessible with present accelerators. The results of these experiments are vital for a better understanding of particle physics, the study of the fundamental constituents of atoms and atomic nuclei, and thus of all matter. In the twentieth century, great advances have been achieved in the understanding of atomic structure and of the atomic nucleus. The study of the elementary particles is the next logical step along this fruitful avenue of research.

The higher the energy of the bombarding protons, the more detail it is possible to discern in the structure of these particles. One can think of an accelerator and its detecting equipment as though it were a huge microscope; then its resolving power is proportional to the energy of the accelerator. Thus, the high energy protons produced by an accelerator allow one to examine and measure the properties of particles and, among other things, to see if they really are fundamental or whether they, in turn, are made of other more basic particles.

The new knowledge that derives from the procession of fundamental discoveries provides the elements that bring about new applied possibilities at later periods. Though it is impossible to predict what the future tangible benefits will be from the research to be carried out at NAL, it is evident there will be some because high energy physics -- possibly more than any other field of basic research -- involves many interactions with technology. This interaction is not through the results of high energy physics, but comes about from the fact that high energy physics demands tools which exceed the limits of existing technology and because the scientists traditionally engaged in high energy physics are willing to work both on improving their tools as well as using these tools for research.

As an example, in the early days of the accelerator development, large advances were made in the electrical power available from high-powered transmitting tubes since at that time tubes of sufficient output to power the accelerators were not available. The basis of all modern computer circuits had its origin in the scaling circuit used for particle detection since the 1930's. At present, development of pattern recognition using modern computers is being undertaken by high energy physicists for analysis of bubble chamber pictures, but these same techniques find applications in biomedical work and in air and space surveillance. In a more direct way, high energy accelerators developed originally for physics research have found application in food sterilization, in medical treatment, and in radiation-damage studies.

Much more important than the tangible benefits in applied technology derived from the procession of fundamental discoveries, is the effect on the intellectual life of a nation. The effort to achieve a better comprehension of the world's physical phenomena will continue to have a profound effect on man's philosophy, his well being, and on his whole social organization.

Thus, an important high energy physics basic research laboratory is being built, and it will play extensive and important roles in fundamental physical research and in international collaboration in science.

A. Site

The site of the Laboratory is a tract of 6,800 acres spanning the border of DuPage and Kane counties, approximately 30 miles west of the center of the City of Chicago, and approximately 15 miles northwest of Argonne National Laboratory (Figure 1). It was chosen by the Atomic Energy Commission in December of 1966 from over 200 proposed sites in 46 different states. Availability of land with adequate foundation capability, electrical power, and cooling water, proximity to major transportation systems, residential accommodations, and a university community were some of the important criteria that guided selection of the site. The entire site was purchased by the State of Illinois at a cost of approximately $26,000,000 and donated to the Federal Government for establishment of the NAL.

The site is roughly a square three miles on each side (Figure 2). Adjacent to the diagonal border, and just off the site on the southwest, is the Illinois Prairie Path, a nature trail on the abandoned right-of-way of the Chicago, Aurora, and Elgin Interurban Railroad. There are many municipalities in the area surrounding the site, the closest being Batavia (pop. 8,500) less than a mile to the west, Warrenville (pop. 3,000) about two miles to the southeast, and West Chicago (pop. 9,900) about one and one-half miles to the northeast. The Fox River, a major water source and recreational waterway for the area, flows through Batavia from north to south approximately two miles west of the site.

The land of the site itself is relatively flat; elevations differ by approximately 85 feet over the entire site, with the high point (el. 800 feet) near the western boundary and the low point (el. 715 feet) toward the southeast. The drainage is primarily toward this southeastern corner, toward the DuPage River, with a somewhat smaller amount to the southwest toward the Fox River.

Along the western edge of the site, there is a north-northeast trending upland (Minooka Moraine) rising about 40 feet above the relatively flat central portion. Along the eastern edge, the land surface is gently rolling.

The West Branch of the DuPage River flows southward adjacent to the eastern edge of the site. Kress Creek, across the northeastern corner of the site, and two unnamed drainages along the eastern edge are tributaries of the West Branch. Some drainage to the Fox River is also present in Indian Creek at the southwestern corner of the site. Small marshes are often associated with the smaller drainages.

The deposits present beneath the NAL site are the result of continental glaciation, primarily during the Wisconsinan Stage. Several advances and retreats of glacial ice are recorded in the sequence of deposits. The bedrock beneath the glacial drift at the NAL site is comprised of dolomites of Silurian age.

The glacial drift can be separated into several types of deposits, based primarily on their mode of deposition. Till, the most common glacial deposit, is an unsorted mixture of clay, salt, sand, and boulders deposited directly from glacial ice. Commonly present with the till are deposits of sand and gravel produced as outwash from glacial meltwaters. Ice-contact materials, generally sand and gravel, deposited in meltwater in close proximity to glacial ice, show various degrees of sorting. Also present are bedded silts and clays deposited in glacial or post-glacial lakes (lacustrine deposits), poorly sorted sand and silt deposited in drainage channels (alluvium) and deposits of peat and muck that were formed in enclosed or poorly drained depressional areas. A wind-laid silt (loess) is present at land surface throughout much of the area.

The individual deposits can be combined into five major groups on the basis of general textural similarities and genesis. In descending order these are as follows:

1. A surficial zone of loessal silts, lacustrine clays, silts and sands, and alluvial silts and sands.

2. Clayey silt and silty clay tills with minor interbedded lacustrine deposits.

3. Sandy silt and silt tills with major lacustrine, outwash, and ice-contact deposits.

4. A silt clay till.

5. A sandy silt and ice-contact and outwash deposits.

These major groups, comprised of units consistent within themselves and in a given sequential order, are generally continuous throughout the site. They may, however, have local abrupt changes in thickness, elevation, and occurrence. This material is underlain by dolomitic limestone bedrock at depths of 70 to 100 feet below natural ground surface.

There are three sources of water in this area:

1. Shallow wells and surface water.

2. The Fox River.

3. Deep wells.

1. The Silurian Dolomite aquifer can be reached by wells 80 to 90 feet deep. This aquifer is recharged locally by percolation of rain water at an estimated average rate of 60,000 gallons per day for the Laboratory site, which has an area of 10.6 square miles.

   The water can also be collected near the surface by use of the existing drain-tile network. This collection would be intermittent and undependable, and cannot be used without a storage system. The existing tile system will be maintained to prevent the site from reverting to a swamp.

2. The Fox River originates in Wisconsin and flows south to join the Illinois River. Flow in the river, as measured at Algonquin, Illinois, varies from a minimum of 8 million gallons per day to a maximum of 5,200 million gallons per day, averaging 470 million gallons per day.

3. Deep wells in this area are generally drilled to a depth of 1,200 to 1,600 feet into the Cambrian-Ordovician aquifer system. This is the principal water source for some neighboring communities. This aquifer is not recharged at a rapid rate and there has been some decline in water levels because of the withdrawal for municipal needs.

As discussed later in this report, the supply of water is more than adequate to meet the needs of the NAL.

Weather records[3] indicate that the temperatures in the area range from a low of minus 19°F in the winter to a high of 96°F during the summer. The average monthly temperature throughout the year is 48°F. Relative humidity normally varies from a low of approximately 26 percent in the spring and early fall to a maximum of 100 percent in the summer, with a monthly average throughout the year of approximately 74 percent.

Precipitation records, including snow, indicate a low of 1/10 inch in February and a high of over seven inches in June, with the monthly average throughout the year being approximately 2.6 inches, or a yearly average of 31.4 inches.

The prevailing winds are generally from the southwest, although they occur with lesser frequency from all other directions. The most frequent velocities are in the 4 to 7 mile per hour bracket and with a slightly lower frequency in the 8 to 12 miles per hour bracket. Winds above 30 miles per hour are infrequent, though a few gusts have been recorded above 80 miles per hour.

The site is located in seismic risk zone 1[4], and design of facilities is in accordance with criteria for seismic zone 1. Earth tremors in the Chicago area rarely occur. Chicago and a broad area surrounding it in northern Illinois and Indiana and extending into Wisconsin and Michigan are geologically very stable. This is evidenced by the rare occurrence of any earthquakes in this region and by the relatively low intensity of those that have occurred. In the Earthquake History of the United States, compiled by the U. S. Coast and Geodetic Survey, it is stated that only ten quakes are listed as having occurred in this broad area in the past 150 years. The only structural damage caused by any of these quakes was the shaking down of some old chimneys and loose plaster. Insofar as the site is concerned, it is expected that no buildings or other improvements will suffer any significant damage as a result of the infrequent and small earthquakes that may occur anywhere within 150 miles of the site.

B. Laboratory Facilities

The NAL is shown in an outline plan on the site in Figure 2. It is composed of three basic elements; the accelerator, experimental areas, and support facilities.

The accelerator, or accelerator system, is that part of the experimental device in which protons are speeded up to full energy (500 BeV*) and then extracted and transported to target and experimental areas. The accelerator system is made up of four separate accelerators consisting of a Cockcroft-Walton preaccelerator, a linear accelerator, a booster synchrotron, and a main ring synchrotron.

Protons are generated from an ion source and accelerated to an energy of 750 KeV (thousand electron volts) in the Cockcroft-Walton pre-accelerator (Figure 3), from 750 KeV to 200 MeV (million electron volts) in the linear accelerator (Figure 4), from 200 MeV to 8 BeV in the booster synchrotron (Figure 5), and from 8 BeV to 500 BeV in the main synchrotron ring (Figure 6).

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*BeV is billion electron volts - a proton passing through a potential difference of one volt will gain one electron volt.

The booster and main accelerators are housed in underground concrete tunnel enclosures, while the Cockcroft-Walton and linac are housed in structures that are below ground but also extend approximately one story above ground.

The enclosure housing the Cockcroft-Walton preaccelerator and the linac is a structure approximately 500 feet long, rectangle in cross-section, which averages approximately 30 feet in width by 20 feet in height. The structure extends above ground one story, or approximately 10 feet.

The concrete enclosure tunnel for the booster synchrotron is below ground, is approximately 500 feet in diameter, and is typically horseshoe shaped in cross-section with a diameter of approximately 12 feet.

The concrete enclosure tunnel for the main ring synchrotron is below ground, is approximately 1.24 miles in diameter, and is typically horseshoe shaped in cross-section with a diameter of approximately 10 to 12 feet (Figure 7). After reaching the desired energy (200-500 BeV) the protons are extracted and transported to the experimental areas.

The experimental areas (Figure 8) are those areas where experiments are performed with the primary or secondary beams of protons and consist of concrete beam tunnels and high-bay industrial type buildings which house the experimental apparatus used to conduct the experiments. There will be a number of experimental areas. The area straight ahead along the external proton beam line, called the Neutrino Laboratory, will be used primarily for "weak interaction" physics experiments. Its major particle detector will be a large liquid-hydrogen bubble chamber. The Meson Laboratory, to the west of the Neutrino Laboratory, will use primarily electronic detectors. The Proton Laboratory, south of the Neutrino Laboratory, will be used for special experiments with the proton beam. Other experimental areas are still in the early stages of planning. The target for each area will be appropriately shielded to contain the secondary particles generated by the primary beam.

The major support facility consists of a central laboratory and office building (Figure 9) which is a multi-story structure that is to be the headquarters for the entire Laboratory. In addition, there is a central utility plant, an electrical power substation, industrial buildings, and a utility and road network.

IV. ENVIRONMENTAL IMPACT

A. Physical Impact

1. Industrial Water. It is estimated that the Laboratory will have an installed capacity for use of 200 megawatts of electrical power by 1975 and will be using approximately 90 megawatts at that time. Power use will increase as the experimental program develops. In 1975 the linac and booster will require approximately 10 megawatts of power, the main ring approximately 25 megawatts, the experimental areas approximately 45 megawatts, and the supporting facilities approximately 10 megawatts. This power consumption, most of which will be dissipated as heat, creates a requirement for cooling of equipment. Heat will be dissipated by evaporative cooling and air cooling. The work of the Laboratory will not involve chemical or industrial processes producing pollution.

Basically, there are three alternative methods, or a combination thereof, by which the heat can be dissipated:

a. Raising the temperature of the cooling water which is returned to its source -- referred to as a once-through system.

b. Evaporating water from cooling ponds and towers -- referred to as an evaporative cooling system.

c. Raising the temperature of the air -- referred to as air cooling.

Use of the once-through system in which the water is returned to the source would require an estimated 100 million gallons of water per day for a temperature rise of 20^{o}F. Because of the large quantity of water required, it was decided not to use this system.

The cooling system planned by the Laboratory will be a combination of evaporative cooling and air cooling. The primary water source will be run-off water as collected in catch basins and shallow wells, with the Fox River as a first line backup system and a deep well as a second line backup system for emergency use. The linac and booster will use evaporative cooling, whereas the main ring will use air cooling backed up by evaporative cooling, and the experimental areas will use air cooling only.

Evaporative cooling requires only make-up water and has the added advantage that the heated water is held in retention ponds for cooling and is not returned to the area water system. The air-cooling system further reduces the water use by air cooling a fin-type tube, closed water system. With emphasis toward air cooling, the water supply from run-off on the site will be adequate for the Laboratory needs, which is less than 4% of the annual precipitation falling on the site. No significant diversion of the creeks flowing out of the site will be needed.

A large part of water needed will be obtained by collecting surface run-off on the site itself. This source is irregular and a storage system will be provided. Storage reservoirs will be constructed with large enough total capacity to meet the Laboratory's needs for several months during the low-flow season without replenishment. The reservoirs' volume will approximate 800 acre-feet. Their locations are planned in order to take advantage of the natural drainage courses, the existing farm drain tiles, and an existing abandoned natural-gas line. Pumping stations and pipe lines will be added to complete the interconnection between the reservoirs. A great deal of flexibility has been designed into this system, since the water will be recycled and used several times for cooling. Cooling ponds will approximate 30 acres averaging 3 feet in depth. The level of dissolved solids will increase by the evaporation process. When the level has been significantly increased, the water will be returned to the ground by watering the vegetation. There will be three or four interconnected basins placed in low-lying areas that are presently swampy in character. In addition to being functional to the accelerator operation, the basins will be beneficial to fish and wildlife as a natural preserve.

Calculations indicate that the maximum humidity added to the air in cooling is approximately 15% of that arising from transpiration of vegetation on the site alone, and the total vegetation on the site has been decreased by about that much as a result of the presence of the Laboratory. Since mixing occurs over much larger air volumes than that above the site, we expect an unmeasurably small effect on the humidity. Thus, any fog generated under the most unfavorable atmospheric condition would occur only locally and would be dissipated by winds before it reached the site boundaries.

2. Domestic Water. The needs of the Laboratory for drinking, cooking, washing, and sanitary-waste disposal will be relatively small. The Laboratory will have a staff of approximately 2,000 people, and the water needs will be less than those of an equivalent residential population. Planning has been based on an average daily use of 50,000 gallons and a peak use of 150,000 gallons per day for domestic purposes. This need will be supplied from shallow wells on site, and the supply is ample for Laboratory needs. (For discussion on radiation monitoring of ground water see paragraph b, page 15.)

3. Backup Water. A permit has been obtained from the State for use of Fox River water when the flow at Algonquin exceeds 130 million gallons per day. The storage system will be used so that there will be no necessity to take water in the low-flow season.

Discussions are in progress with local authorities concerning a route for the water pipe line from the Fox River to the NAL site. If the Laboratory depended totally on this water source, use would represent only 0.15% of the average flow of the river. However, the Fox River water will be used only for backup, and the quantity to be taken from the river will therefore be considerably less than 0.15% of the average flow.

Shallow wells on the site will provide a surplus of 450,000 gallons per day available after filling our domestic-water needs. It is expected that this source may be used for industrial water, particularly in the early stages of operation when the entire system is not yet complete.

4. Sanitary Sewers. With domestic use inevitably comes sanitary effluent. Discussions are underway with the City of Batavia for possible use of the City's treatment plant. If these discussions are unsuccessful, a full sewage-treatment plant will be built on site. Either of these alternatives will fully meet Federal and State standards.

The sanitary-sewer system will also be used to dispose of the small quantities of liquid shop wastes. (See 6 below for solid-waste disposal plans.)

5. Storm Sewers. A storm-sewer system is being constructed to carry run-off water to Laboratory reservoirs for use as industrial water.

6. Solid Wastes. Solid wastes, including those from water, cafeteria operations, and sewage treatment, will be disposed of by a contracted service. The Laboratory will ensure that all applicable local, State, and Federal standards are met. Waste such as scrap metal will be accumulated, packaged, and sold for scrap.

7. Noise. There will be no noise-producing components in the Laboratory that will have any effect beyond the site boundaries.

8. Radiation. The Laboratory has announced a policy that radiation at the site boundaries will be kept to the lowest level that can be reasonably achieved and in all cases to less than 10 mrem/yr[1/], a figure that is less than ten percent of the natural radiation of the environment, which is 108 mrem/yr in the Chicago area[5], and less than six percent of the maximum permitted for the general public under the Federal Radiation Council's guidelines (approximately 170 mrem/yr).

1/ In order to receive the estimated 10 mrem/yr, an individual would be required to be located on the site boundary 24 hours per day for 365 days a year while the accelerator is operating continuously at full energy and intensity.

A number of steps are being taken to implement this policy. The accelerator is designed for high efficiency, so that proton losses will be small during acceleration, extraction, and transport to the experimental-area targets. The accelerator will not be operated at high beam intensity until its operation is understood in enough detail to keep proton losses down to acceptable limits.

Second, the accelerator, beam-transport, and target systems are all within well-shielded housings. Care has been taken in the estimates and calculations, that are the design basis of this shielding, to resolve uncertainties or approximations always in the conservative direction to give more shielding and less radiation.

For the purpose of radiation monitoring, a central station has been in operation on-site at the village complex (see Fig. 2) for nearly a year. This station is equipped with an aluminum-Argon ionization chamber sensitive mostly to muons and gammas, a tissue-equivalent ionization chamber sensitive to neutrons as well as gammas and other directly ionizing radiations, a NaI dosimeter primarily sensitive to gammas, and a Bonner spectrometer system sensitive to neutrons. Preliminary operation of this station has helped to establish the levels of natural background radiation and, of course, will monitor any changes as the accelerator becomes operational.

For on-site monitoring, in addition to the above station, there will be a net-work of detectors connected to a central computer which will continuously monitor dose rates at approximately 25 locations. These detectors will be a combination of 10 inch pseudospheres with fiber wrapped, thin wall Geiger-Mueller counters (sensitivity ~ 0.06 mrem/hour) and tissue equivalent ionization chambers. They will be located appropriately along external particle beams as well as along roads and buildings. The exact location of all detectors will be more firmly established as the present construction nears completion. Also some detectors will be located according to the particular experiments that will be scheduled. A number of these detectors are presently in operation around the accelerator footprint area (near the Booster and Linac in Fig. 2) for the preoperational phases of accelerator turn-on. Some radiation monitoring, particularly for muons near the site boundary and downstream of the experimental areas, will be accomplished with 55 gallon ionization chambers (sensitivity ~ 1 microrad/hour). These monitors are self-contained and portable.

Off-site radiation doses will be estimated by surveys from the above on-site instrumentation and also from detection instruments in a special mobile laboratory. The mobile laboratory will be able to survey the large expanse of the site perimeter as well as on and off site locations utilizing a wide range of instrumentation for all types of radiation.

It must be recognized that the NAL accelerator is a new device operating in a new energy range. There are few direct experimental data and therefore particle production by the primary beam is not precisely known. A continuous program of radiation monitoring over the entire site will therefore be carried out, beginning as soon as operation commences.

During the first year of operation, the accelerator will certainly operate at less than 10% of its design intensity and duty factor; measurements at these low intensities can be extrapolated directly to high intensity to determine the adequacy of the shielding. Space has been left to add more shielding if initial operation shows that the shielding is not adequate for high intensity. The Meson and Neutrino Laboratories are located approximately 7,000 and 5,000 feet respectively from the site boundary. These spaces could be completely filled with earth shielding, or a denser material, if needed, to augment the shielding and, therefore, reduce the radiation levels at the site boundaries. The radiation will be continuously monitored. Should it appear that radiation levels approach 10 mrem/yr at any time, the beam intensity will not be increased until the situation is corrected in order to maintain the radiation level below 10 mrem/yr.

Dose-rate estimates underlying the shielding design are discussed in detail in the attached NAL report TM-306, "NAL Off-Site Dose-Equivalent Rates Due to Accelerator-Caused Radiation," M. Awschalom, et.al. (Appendix B). The results are summarized below.

There is a general contribution from the main accelerator itself, mainly neutrons. Gamma radiation levels are minor. For purpose of calculation, the radiation source, the accelerator ring, is approximated by an infinite line source. This will certainly overestimate the radiation. If the accelerator operates at full energy of 500 BeV and full intensity around the clock throughout the year, the dose-rate at the point of the site boundary closest to the accelerator is estimated in this way to be 9.6 mrem/yr. In reality, the accelerator will have shutdown periods for maintenance and setup of experiments. These down periods and the ring nature of the true source (rather than the infinite line source assumed) should bring the dose-rate down to well below the estimated figure.

There are also contributions to the dose-rate from experimental area targets. These contributions come from low energy neutrons, which produce only local effects, and high energy muons (mu mesons). To make a dose-rate estimate for a target, assumptions must be made, not only about the energy and intensity, but about the sharing of the primary beam between targets. In each case, we assume that all the beam is used on the target considered. In reality, of course, the accelerator will not operate all the time, and the beam will be shared among at least three target stations, so that the dose-rate estimated will never be achieved.

The Meson Laboratory is designed for protons of only 200 BeV energy. At full intensity for the entire year, a 200 BeV beam would give rise to an estimated dose-rate of 26 mrem/yr at a point on the northern boundary of the site directly behind the Meson Laboratory. If actual measurements show that the rate of dose accumulation at this point is approaching 10 mrem/yr, the beam intensity to the Meson Laboratory will be cut down until additional shielding is put in place.

The Neutrino Laboratory points in the direction of the northeast corner of the site. The estimated dose-rate depends strongly on the energy of the primary beam. The dose-rate is estimated to be 4 mrem/yr at 400 BeV, if the full intensity beam were to be used in the Neutrino Laboratory for the entire year.

The TM-306 study covered 500 BeV operation; however, the Neutrino Laboratory was designed for 400 BeV operation, so that only the 4 mrem/yr estimate applies. The design is now being modified to add a steel plug and magnetic lens to deflect muons away at higher energy. The effect of this new system on the radiation at the site boundary has not yet been estimated quantitatively, but it will certainly be in the direction of reducing the muon intensity at a given point.

As in the case of the Meson Laboratory, continuous measurements will be made at the site boundaries during operation. Beam intensity will be cut down if required so that a rate of less than 10 mrem/yr is maintained.

The accelerator and target areas discussed here are being fenced. Access to these areas by Laboratory employees for maintenance will be allowed only under rigorous safety procedures.

a. Residual Radioactivity. Fractional losses from the beam, and the striking of targets and beam dumps by the beam will generate secondary radioactivity through nuclear reactions. This residual radioactivity will still be present in enclosure walls, technical components primary cooling water, tunnel air and ground water even when the machine is not operating. Except for the ground water, which is separately discussed, this radioactivity will be confined to the accelerator. The ^{24}Na produced from the secondary neutron interaction with sodium naturally present in the concrete walls of the tunnel will be confined to the tunnel. Aggregate with low sodium content was selected for use in the concrete of the tunnel, after an extensive series of measurements of available aggregates, in order to minimize this effect. Radioactivity in the enclosure air will be generated by the primary proton beam interacting with air molecules. This radioactivity has a very short half life. Since beam tunnel enclosures will be sealed during operation and for a period of time following shutdown, radioactive air will be confined until it has decayed to very low levels. The radioactivity in primary cooling water is produced when the water passes through coils close to the proton beam. However, this would have no adverse environmental impact since the primary cooling water is in a completely closed system and will not mix with other water.

b. Ground Water. The soil adjacent to external target areas is subjected to secondary radiation from targets. Through nuclear interactions, this radiation can produce radioactivity in the soil and ground water. The expected nuclides would include ^{55}Fe, ^{39}Ar,

^{14}C, ^{3}H, and ^{22}Na. These last two nuclides, with half lives of 12.3 and 2.6 years respectively, are the most significant because of their abundances and half lives. They could give rise to low level radioactivity in the ground water. As a precaution against this possibility, a collection system for percolating ground water is being built around target areas. Continuous monitoring programs for both soil and ground water activity, in both the shallow and deep aquifers, will provide data toward assuring that the system functions satisfactorily and that the ground water underlying NAL is afforded maximum protection. Calculations of maximum possible radioactive penetration have been performed to determine the degree of natural protection afforded by ion exchange in the soil and by radioactive decay if any radioactivity should escape the collection system.

The target areas have been designed to reduce the activation of ground water to negligible levels. These areas will be surrounded by shielding composed of granular backfill, which will release far less radioactivity than the much finer natural soil. The design also incorporates an impervious membrane and a system of drain tile designed to catch the water percolating down past the target areas. This water will be pumped to and stored in holding ponds on the site and continuously monitored for radioactivity prior to release for return to the Laboratory industrial water system.

An additional safety factor exists due to the naturally slow vertical migration rate of the radioactive sodium through the underlying soil on the site which empirical tests show to be approximately 3.2 feet per year. It is then estimated that it would take approximately 22 years for the radioactive sodium to reach the top of the first aquifer at 70 feet depth.

A calculation has been made of the maximum amount of radioactivity that could be produced, escape the collection system, and migrate downward to the aquifer and off the site. These calculations are given in detail in the NAL report TM-292-A, "Calculation of the Radionuclide Production in the Surroundings of the NAL Neutrino Laboratory," M. Awschalom (Appendix C). Under the most pessimistic assumptions, the sodium activity at the site boundary is estimated to be less than 31 microcuries per year, and the tritium activity is estimated to be less than 55 millicuries per year.

We cannot, of course, determine a priori the volume of water in which this activity is dissolved during a year. If one makes the hypothetical assumption for calculation purposes that all the sodium-22 activity would be concentrated in a single 1000 gallon-per-day well, an extremely small well, the resulting concentration would be approximately 0.2% of the Federal standard. The tritium concentration would be approximately 4% of the Federal standard. In a real well, the concentrations would be very much smaller.

A water sampling program was initiated in September 1970. The U.S. Testing Company (Richland, Washington) is the contractor performing the major analysis of the samples for the detection of possible radionuclides. Samples have been collected in the accelerator foot print area during 1970 to establish a base-line for naturally occuring radionuclides. During early 1971, samples have been taken from a sump in the 8 GeV Booster area which collects much of the ground water in the accelerator control area, and thus provides a means of early detection of any developing contamination problems in that area. Also water from farm wells on site have been sampled.

The current program consists of periodic sampling of water from sumps throughout the accelerator complex as well as from the neutrino underdrains. Equipment exists at the NAL Nuclear Counting Laboratory for frequent evaluation of samples for ^{22}Na activity. Monthly samples are shipped to U.S. Testing for comprehensive analysis. A total of twenty farm wells on site have been designated for sampling. Of these, three are sampled every month and twelve are sampled regularly, three per month on a four month cycle. In summary, thirteen samples are shipped to U.S. Testing each month, and include:

6 from farm wells,
1 from the NAL deep well,
4 from drains and sumps,
1 from local town water, and
1 spiked sample.

The analysis specifications are detailed in NAL report TM-323 (September 1971).

c. Treatment of Radioactive Waste. Radioactive waste generated as a consequence of operation is expected to consist of a small number of machine components induced with radioactivity and a small quantity of rags and paper waste and miscellaneous trash containing residual contamination. The waste will be stored on site in a controlled access area pending appropriate packaging and shipment to an approved waste burial site. The transportation of waste will be performed in accordance with applicable State and Federal codes and regulations pertaining to such shipments.

9. Air Cleanliness. There will be no industrial or other activities producing air pollution. Heating of buildings will be by natural gas, a particularly clean fuel. The backup system will use No. 2 residual fuel oil, which has a low sulfur content (less than 1%).

10. Construction. Construction activities are conducted in compliance with the AEC design criteria, which stipulate, in part, "During construction of facilities, provisions will be made to minimize soil erosion and water and air pollution. Site studies shall include information required to plan and design the measures needed to provide an acceptable degree of pollution and erosion control for the site." The criteria also specify measures to be considered in the preparation of plans and specifications to effect minimal disturbance to the environment. Included in these measures are the following:

a. Minimization of the area and duration of exposure of readily erodible soils and scheduling construction of roads, streets, parking, and other areas as soon as practicable. Where finished paving is not practical, consideration should be given to early placement of permanent base or subbase courses. Early paving will not only reduce erosion and pollution but in many cases will result in more economical construction operations. Road construction is required to conform to local State Highway Department standards and practices. Surface changes resulting from road construction should be minimal since road design generally follows the natural contour of the ground with cuts and embankments held to an absolute minimum.

b. Minimization of soil erosion by requiring temporary vegetation or mulch and by scheduling the establishment of permanent vegetation as early as practical.

c. Installations of structures to retard the rate of runoff from the construction site, control disposal of runoff, and trap sediment resulting from construction.

d. Requiring application of water or dust suppressants, or otherwise restricting dust to within tolerable limits on access and site roads.

e. Specifying temporary bridges or culverts where fording of streams is objectionable. Requiring treatment of borrow areas to avoid water or air pollution from the operation.

f. Providing for protection against pollutants such as chemicals, fuel, lubricants, sewage, etc.

g. Scheduling construction to avoid rainy seasons if practical.

h. Prohibiting the location of sanitary facilities over or adjacent to live streams, wells, or springs, or requiring portable chemical toilets.

i. Specifying precautions to avoid grass or brush fires since burned-over areas are vulnerable to erosion.

j. Disposing of construction refuse in such a manner as to reasonably minimize environmental pollution. Even though environmental pollution from construction activities is of a temporary nature and localized, every effort will be exercised to minimize the impact on the environment.

B. Social and Economic Impact

1. Roads. The site contains several local traffic arteries, namely Wilson Road and Batavia Road, that run east-west across the site. There are, in addition, a number of farm roads that terminate inside the site.

State and local authorities are designing and constructing roads to take the place of Wilson Road and Batavia Road, whose closing will be made necessary by construction of the experimental areas. Batavia Road has now been closed by construction of the Meson Laboratory and through traffic is detoured to Wilson Road. Laboratory management is cooperating with local authorities in attempting to keep Wilson Road open for public use as long as possible, consistent with the construction program. In addition, provision has been made and a right-of-way granted along the western site boundary for a major north-south limited-access highway planned by the State of Illinois.

2. Housing. Since the population of the area surrounding the Laboratory has grown quite rapidly over the last decade, it is not likely that the Laboratory population will appreciably affect the demand for homes and consumer services there. A variety of adequate housing is available. In addition, a survey has indicated that Laboratory staff members are residing in about seventy-five different cities, towns, and villages in the area, including the City of Chicago.

3. Schools. With the pre-existing rate of population growth in the area surrounding the Laboratory, and with the geographic dispersion of employee residences, there will be very little effect on school enrollments within the area. Presence of the Laboratory will not create an impacted enrollment situation. Although the site, as Federal

property, is no longer subject to taxation for school purposes, the State of Illinois agreed, prior to selection of the site by AEC, that no payments by the Federal Government in lieu of taxes would be claimed. An association of affected school districts has taken steps to attempt to persuade the State to provide a tax-equivalent grant to the districts in view of their loss of tax revenue.

4. Public Services. The Laboratory maintains its own fire department and has, in addition, contracted with the City of Batavia for supplementary service. While the contract does not require the NAL fire equipment to respond to the City's fires, in the event of an emergency, NAL assists the City as required.

The Laboratory has contracted for private guard service. This service cooperates fully with the cognizant public authorities, and the sheriffs of DuPage and Kane Counties (only a very small part of the site is in a previously incorporated area).

The Laboratory plans to be using approximately 90 megawatts of electrical power by 1975. This will present no supply problem because an existing transmission line along the eastern site boundary, which supplies a large part of the metropolitan area, will supply the site. The Commonwealth Edison Company and the Laboratory have jointly studied the Laboratory's planned power needs.

5. Job Opportunities. The major part of the Laboratory staff has been drawn from the local area, although top-level professional people have come from all over the United States and from some foreign research facilities. Laboratory management and AEC have been active in sponsoring training programs for hardcore minority groups leading to their employment at the Laboratory.

6. Economic Impact. The Laboratory is not a large addition to the industry and commerce of the area. Nevertheless, the annual payroll of the Laboratory will reach an estimated $20 million, most of which will be spent in the Chicago area. Many area businesses also participate in supplying the Laboratory with materials, services, and equipment.

7. Cultural Contributions. Presence of the Laboratory will contribute an additional dimension to the existing cultural amenities in the area. There will be a large number of lectures, seminars, and conferences, many nationally and internationally attended. The Laboratory will have close associations with, and long- and short-term visitors from many universities across the country. In addition, it is expected that numerous scientific exhibits, youth science fairs, art exhibits and other cultural events will be held at the Laboratory. Archaeological and historical studies will develop knowledge and displays of interest to many citizens in the area.

V. UNAVOIDABLE ADVERSE EFFECTS

Creation of the Laboratory will preserve to a very large extent existing ecological systems. NAL and AEC, through the use of nationally known architectural, engineering, and construction firms[6], combined in a joint-venture effort and through use of consultants[7] and cooperation with local land-conservation groups[8], have developed a land use plan and designed facilities to assure that no major adverse effects will be produced on the environment from land, air, and water use, or from radiological effects. The overall appearance of the site will be aesthetically pleasing. Technology exists and is being applied to assure that air and water pollutants released to the environment will be well below applicable standards.

No unresolved conflicts exist concerning alternative uses of available resources. Plans have been implemented to maintain and to enhance the long-term productivity of the environment. For example, most of the site will be converted from cultivated farmland to grassland and forest, with trees, foliage, and wildlife remaining undisturbed, except in that portion of the site, less than ten percent, that will be occupied by buildings, roads, and parking lots or other capital improvements. This is because the main accelerator enclosure, although four miles in circumference, is a relatively thin ring in cross section (10-12 feet). Except for the protrusions of accelerator utility and access structures, the enclosure is completely below ground, thereby occupying very little land area.

Some experimental areas will have liquified flammable gases present. Extreme care has been taken in the design to prevent the possibility of fire or explosions. Should an accident occur in one area, the facility is designed sò that damage is localized and will have no effect either off the site or on the remainder of the site.

Radiation levels at the site boundaries will be kept to the lowest level that can be reasonably achieved and in all cases, to less than 10 mrem/yr. There is no known economical method to completely eliminate or preclude all radiation from the site boundary. It is significant to note that the maximum limit of less than 10 mrem/yr. constitutes less than six percent of the maximum of 170 mrem/yr. permitted under the Federal Radiation Council's guidelines.

On site, residual radioactivity from fractional losses from the beam and the striking of targets and beam dumps by the beam will generate secondary radioactivity through nuclear reactions with sodium, naturally, in the concrete walls. This residual activity will be confined to the accelerator and beam tunnel walls. Aggregate with a low sodium content will be selected to minimize this effect.

The target areas have been designed to reduce the activation of ground water to negligible levels; however, the soil adjacent to external target areas is subject to secondary radiation from targets. This could give rise to low-level radioactivity in the ground water. As a precaution against this possibility, a collection system for percolating ground water is being built around the target areas. Continuous monitoring programs for the soil and ground water activity will afford additional protection.

Radioactive waste generated as a consequence of operation will consist of a small number of machine components, rags, paper waste, and miscellaneous trash. This material will be packaged and shipped to an approved waste burial site in accordance with state and Federal codes.

Heat dissipation will be by an evaporative cooling system and by air cooling. The effluent water from the evaporative cooling system will be held in retention ponds until cooled and not returned to the area water system. Calculations indicate that the maximum humidity added to the air in cooling is approximately fifteen percent of that arising from transpiration of site vegetation. Since mixing occurs over much larger air volumes than that above the site, an unmeasurably small effect on the humidity is expected. Thus, any fog generated under the most unfavorable atmospheric condition would occur only locally and would be dissipated by air currents before reaching the site boundary.

VI. ALTERNATIVES

The AEC evaluated over 200 proposed sites in 46 states before selection of the NAL site at Weston, Illinois, in December 1966. Engineering design of NAL is approximately 85 percent complete, and construction is slightly more than 60 percent complete. Therefore, consideration of alternatives to site location is not feasible at this time and will not be discussed herein.

Alternatives to program development would include the following:

A. Stopping construction and elimination of the project would deny scientists a tool essential to further exploration at the forefront of particle physics. To dismantle the existing Laboratory facilities and to restore the site to a farm-type environment would result in economic waste estimated to cost in excess of $200 million.

B. Delay of Laboratory completion would seriously retard advancement of high energy physics in this Nation and probably result in loss of this Nation's preeminent position in this important area of science. This would not be in the national interest. A delay would result in an economic loss, the amount unknown but to some extent dependent upon the length of the delay, because of the current contract obligations within agreed to scheduled times for completion of major elements of Laboratory work. At the same time, a delay would not technologically solve or further minimize environmental costs of low radiation or heat dissipation.

C. Suitable alternative experimental tools to higher energy accelerators are unknown. Whereas an accelerator with an energy lower than 200-500 BeV, but higher than 33 BeV, the Nation's highest energy proton synchrotron, could be built, it would not provide the necessary next step in experimental tools for high energy physics technology. Reduction in accelerator energy would not reduce the planned boundary radiation levels during operations or the heat dissipation levels because these levels are more directly related to beam intensity and the number of hours the accelerator is turned on. In accordance with NAL's plan of operation, radiation and heat dissipation will be held to the lowest practical levels.

D. To proceed with engineering design and construction of an accelerator having an energy range substantially above 500 BeV is not considered reasonable at this time because the current state of the technology has not yet progressed to that point.

VII. LOCAL AND SHORT-TERM USE AND ENHANCEMENT OF LONG-TERM PRODUCTIVITY

The site is relatively flat with elevations varying from 715 feet to 800 feet over the entire area. The slope and drainage is primarily toward the southeastern corner and to a lesser extent to the southwest toward the Fox River. Until the time of World War I, the 6,800 acres comprising the site were largely swampy. Individual landowners then began installing extensive drain tiling that permitted the land to be farmed more productively. Crops were typically Midwestern, primarily corn and soybeans. Most of the land was still being farmed at the time the site was selected for construction of the National Accelerator Laboratory. The only exceptions were some forested areas on the western portion of the site and the area occupied by the village of Weston (with approximately one-hundred homes) near the eastern site boundary. The former village of Weston had been envisioned by its developer as the first part of a much larger residential development covering most of the site. The small former residences in the village are presently in use by the Laboratory as working space.

The Laboratory is sponsoring a Northwestern University archaeological study of the previous Indian camps and settlements on the site. The site was a portion of an Indian reservation until about 1832. Residential, commercial, and industrial development of the area around the Laboratory site has clustered along the railroads feeding Chicago, of which the closest major lines are the Chicago and Northwestern going north of the site through West Chicago and Geneva, and the Chicago, Burlington, and Quincy going south of the site through Naperville and Aurora to the west. Development guidelines described by the Northeast Illinois State Planning Commission[9] have followed these lines of development, evolving a "finger" plan for residential and commercial development along the railroads, with recreational green belts situated between the densely populated fingers. The Laboratory fits naturally into one of these green belts, together with the Morton Arboretum (1,500 acres), Cantigny Park (500 acres), and several forest preserves. Since the population of the area is growing rapidly (DuPage County had approximately 300,000 residents in 1960, and presently has almost 500,000), these green preserves become increasingly significant to the natural ecology and advantageous to the residents of the area.

The major forest, near the western boundary, dates from Indian times. This forest was named "The Big Woods" by the first French explorers. Preservation of the forest and other wooded areas was a criterion in locating the Laboratory buildings. After a thorough examination of the site, the accelerator ring itself was located to prevent any damage to the timber of "The Big Woods." An intensive timber-management and conservation program has been followed since the beginning of the project. In addition, a program of reforestation is being undertaken on the site. The new stands will provide windbreaks and will be planted in such a way as to be aesthetically pleasing. One aspect of the reforestation program involved the transplanting of numerous trees from a tree nursery that was necessarily displaced by relocation of the main power line and gas lines to the eastern site boundary.

Wildlife and habitat restoration, with reestablishment of such species as sharptail grouse, quail, prairie chicken, and buffalo, is planned. Abandoned vehicles, trash dumps, and dilapidated buildings are being removed from the site. Sound, useable structures are being moved to a central location for Laboratory use.

The presence of the Laboratory will contribute to enhancement of the current social environment through cultural amenities to the area in the form of lectures, seminars and conferences, many nationally and internationally attended. There will be close ties with universities across the country and numerous science fairs, scientific exhibits, art exhibits and other cultural events will be held at the Laboratory.

The establishment of the NAL on the site when compared with urbanization, commercialization and industrialization of the area clearly indicates that the Laboratory will make far fewer demands on the existing environmental resources than would planned future higher density development. Programs currently being sponsored by the Laboratory such as the site archaeological study, preservation of the forest and wooded areas, reforestation, reestablishment of animal species, preservation of useable structures and cleanup of abandoned vehicles, trash dumps, and dilapidated buildings will improve substantially the current physical environment.

It appears evident that the existence of the NAL and its programs, sponsored and planned, strongly support preservation and enhancement of the environment, for the current and future generations.

VIII. IRREVERSIBLE AND IRRETRIEVABLE COMMITMENT OF RESOURCES

Creation of the Laboratory will make no irreversible of irretrievable commitment of natural minerals or fuel resources. The presence of the Laboratory will preserve a large area of open green space which, prior to selection of the site, had been designated in long-range land planning by the Northeast Illinois State Planning Commission for high density development. In addition, the NAL site will provide an area for possible ecological and archaeological studies, and will add to the human environment by its equal-opportunities program and by providing a center for collaborative work of people from all over the world. Except for that small portion of the site occupied by major buildings and structures, the land could be easily and economically restored to its farm-like atmosphere or to some other productive use should future circumstances require it.

IX. COST BENEFIT ANALYSIS

The report, "High Energy Physics Program: Report on National Policy and Background Information," published by the Joint Committee on Atomic Energy[10], states that the wavelength of visible light limits the detail that can be explored with the microscope. To study structure on a smaller scale electromagnetic waves, x-rays, and gamma-rays are used. In order to continue the exploration of elementary particle structure down to even smaller distances, high energy beams of particles are required and there is no alternative to the construction of new accelerators aimed at reaching higher energies. Much of the new basic scientific progress to be accomplished with the higher energy accelerators is difficult to envisage since it is the major new surprises which cannot be extrapolated or planned from present experience that generally lead to the most fundamental progress.

The promise of this scientific tool is that of acquiring a better understanding of the fundamental forces which control the behavior of the particles within the atomic nuclei which is one of the most prominent scientific undertakings in America. The JCAE of the U. S. Congress in the FY 1972 authorization report indicated it was in the national interest for this Nation to remain in the forefront of high energy physics.

The Laboratory site originally was devoted to farming operations, with rapidly moving and increased pressures toward urbanization, commercialization, and probably industrialization. The former village of Weston was originally conceived by its developer as merely the beginning of a much larger densely populated residential development that would have covered most of the site. Use of the area as the site for the Laboratory requires fewer demands upon the natural resources such as water and forests than its use for dense residential development. The Laboratory will attempt to maintain, and in some instances reestablish, the natural ecological balance of the area.

The Laboratory will add cultural amenities to the area through lectures, seminars, conferences, science fairs and exhibits and art exhibits.

The unavoidable adverse effects to the environment of low radiation levels and dissipation of heat are minimal and cannot be totally eliminated.

The only alternatives presently available for avoiding or reducing the adverse environmental effects are stopping or delaying the project or operating at lower energy levels. Pursuance of any one of these alternatives would not provide a tool at the frontier edge of science and thereby make possible the achievement of the benefits set forth above.

In weighing the benefits of this proposed course of action against the environmental cost of implementing it, and after considering the available alternatives, it is concluded that the AEC should proceed to completion of design and construction of NAL and to subsequent operations at the planned energy levels.

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   1960 - Donald A. Glaser
   1961 - Robert Hofstadter
   1963 - Eugene B. Wigner and Maria Geoppert Mayer
   1965 - Richard P. Feynman and Julian S. Schwinger
   1967 - Hans A. Bethe
   1968 - Luis W. Alvarez
   1969 - Murray Gell-Mann

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   76 BeV Proton Synchrotron, Serpukhov, USSR. Completed 1967.

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6. DUSAF: a joint venture consisting of the following firms:

   a. Daniel, Mann, Johnson & Mendenhall - Architect - Engineers, Los Angeles, California.

   b. The Office of Max O. Urbahn - Architects, New York, New York.

   c. Seelye, Stevenson, Value & Knecht, Inc. - Architect - Engineers, New York, New York.

   d. George A. Fuller Construction Company, Dallas, Texas.

7. Morton Arboretum, DuPage County, Illinois
   Professor Stuart Struever, Northwestern University, Chicago, Illinois.

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   Conservation Group, DuPage County Board.
   Conservation Group, Kane County Board.

8. (cont'd)
Northeastern Illinois State Planning Commission.
State Area Forest Preserve District.
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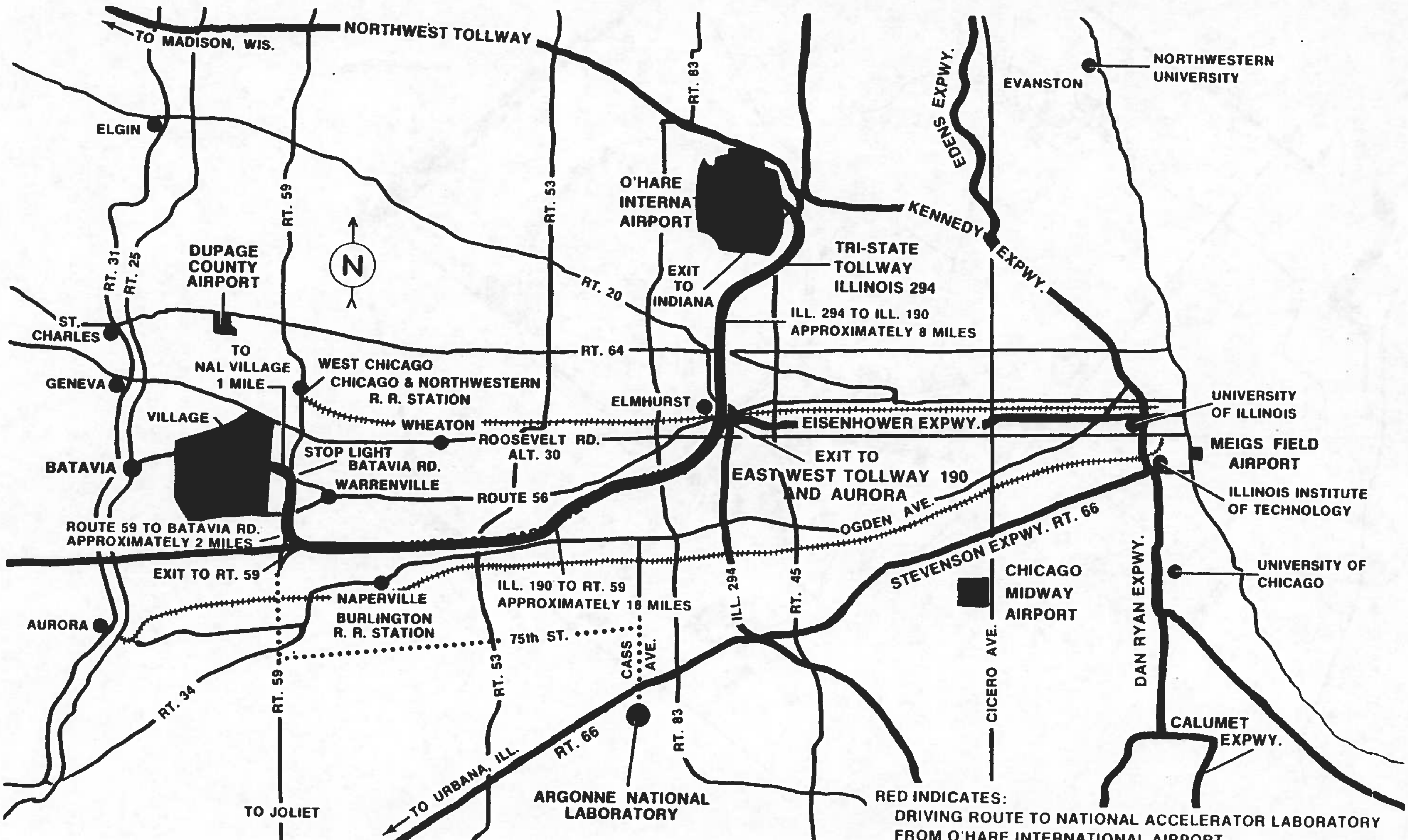
10. Comprehensive Plan, The Northeastern Illinois State Planning Commission, 400 West Madison Street, Chicago, Illinois 60606, 1968.

LOCATION OF
national accelerator laboratory

Figure 1
LOCATION MAP

Post Office Box 500 • Batavia, Illinois 60510 • Telephone AC-312. 231-6600



RED INDICATES:
DRIVING ROUTE TO NATIONAL ACCELERATOR LABORATORY
FROM O'HARE INTERNATIONAL AIRPORT

Operated by the Universities Research Association Inc. for the U.S. Atomic Energy Commission.

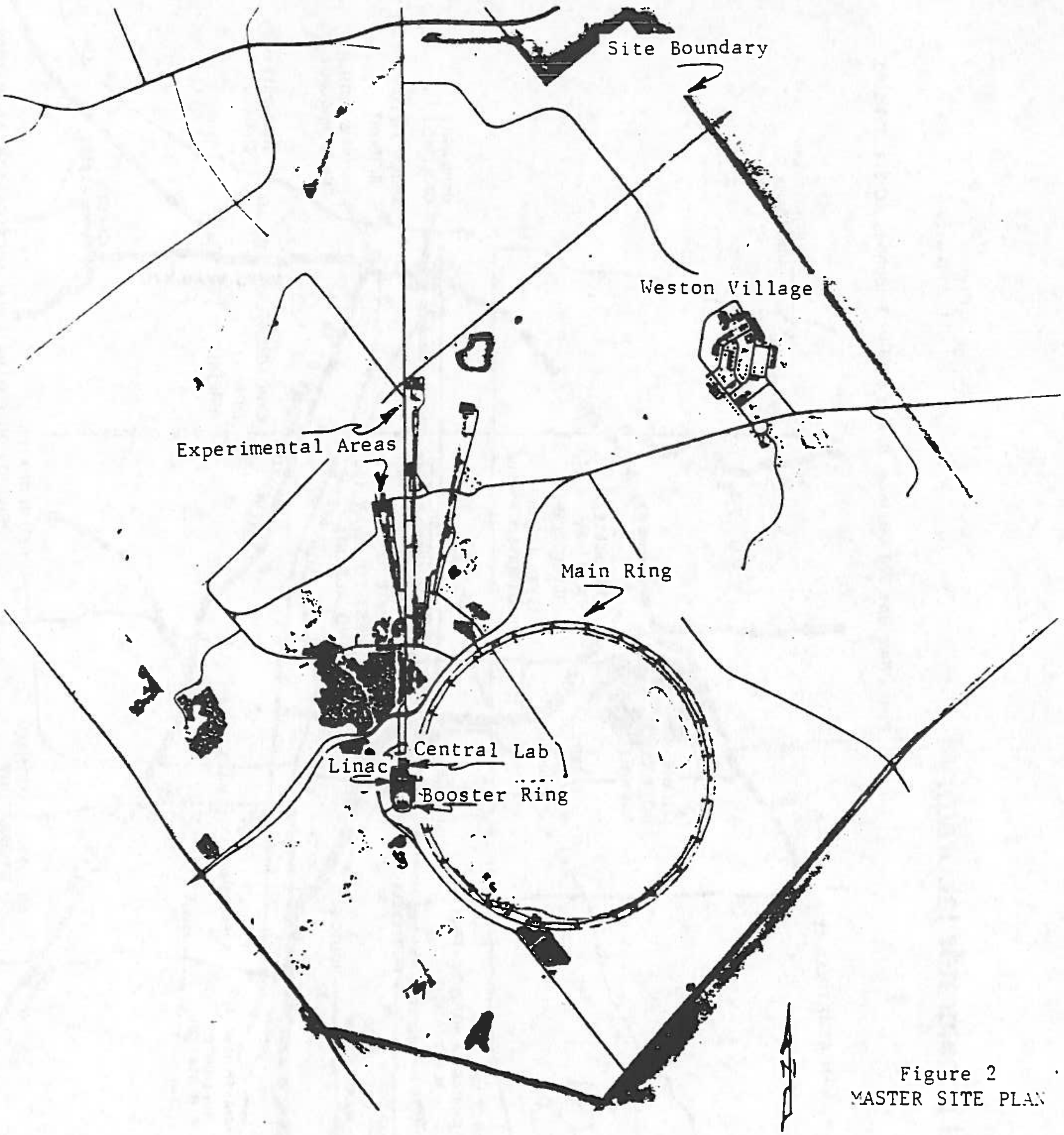


Figure 2
MASTER SITE PLAN

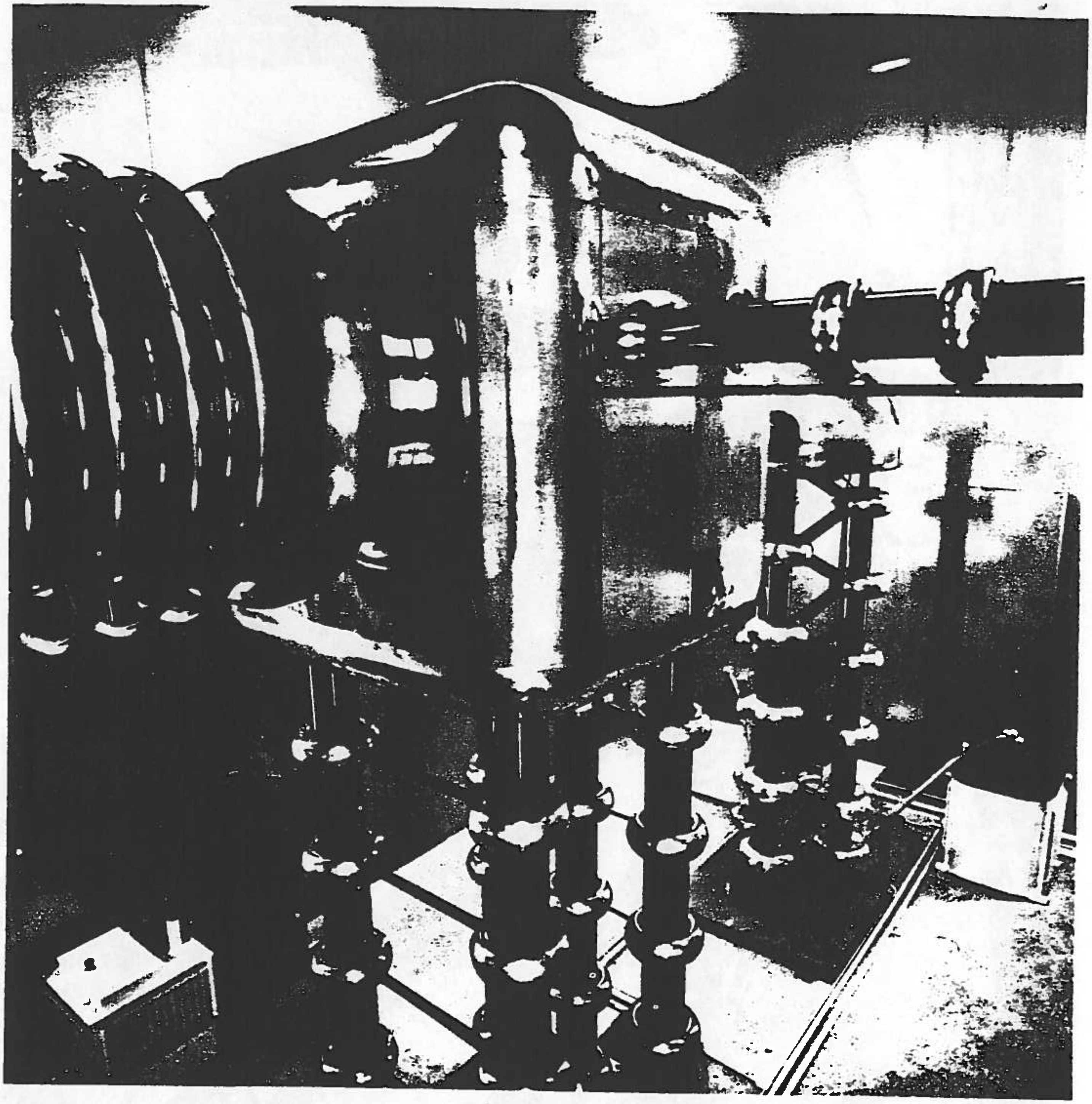


Figure 3
COCKCROFT-WALTON - PREACCELERATOR

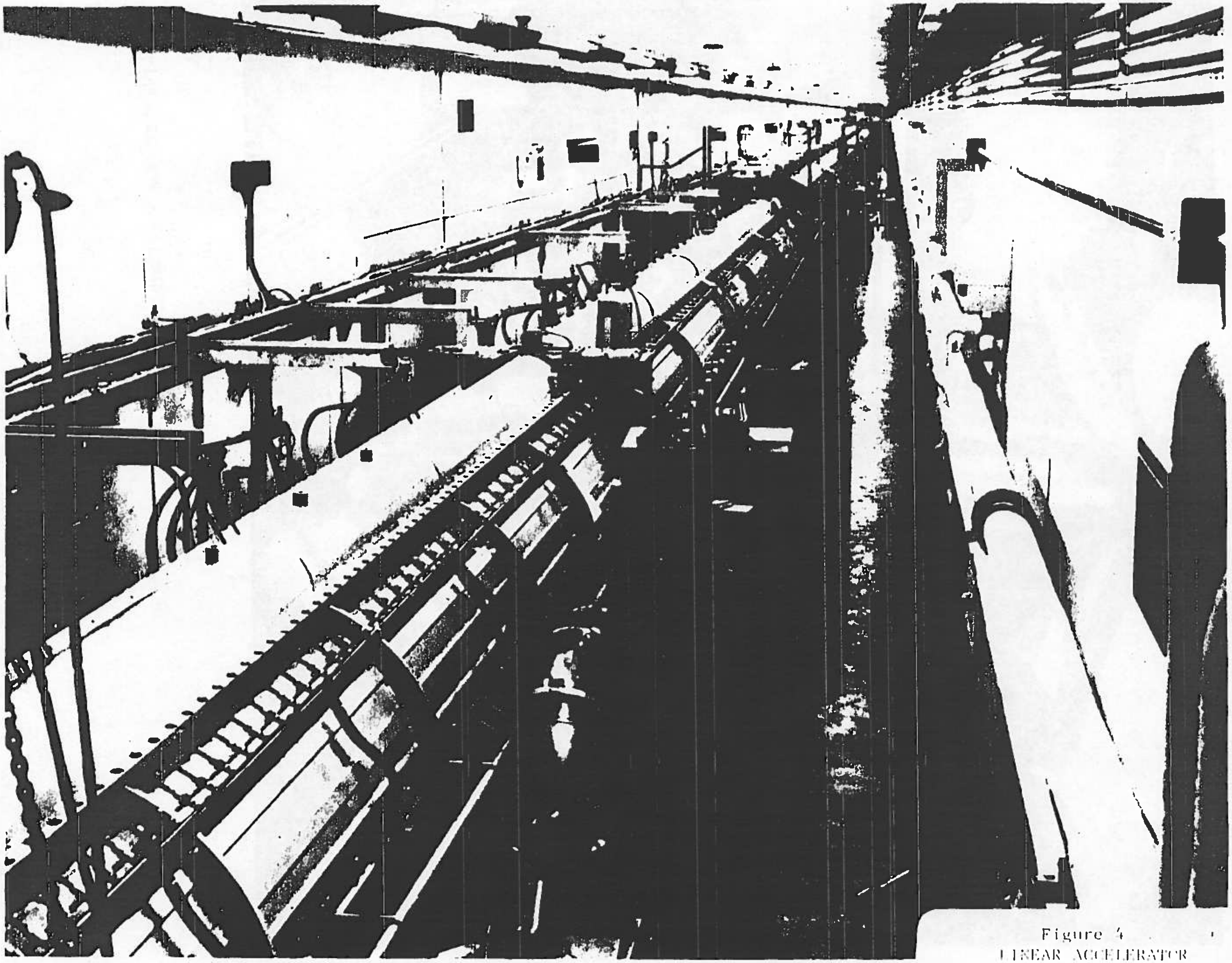


Figure 4
LINEAR ACCELERATOR

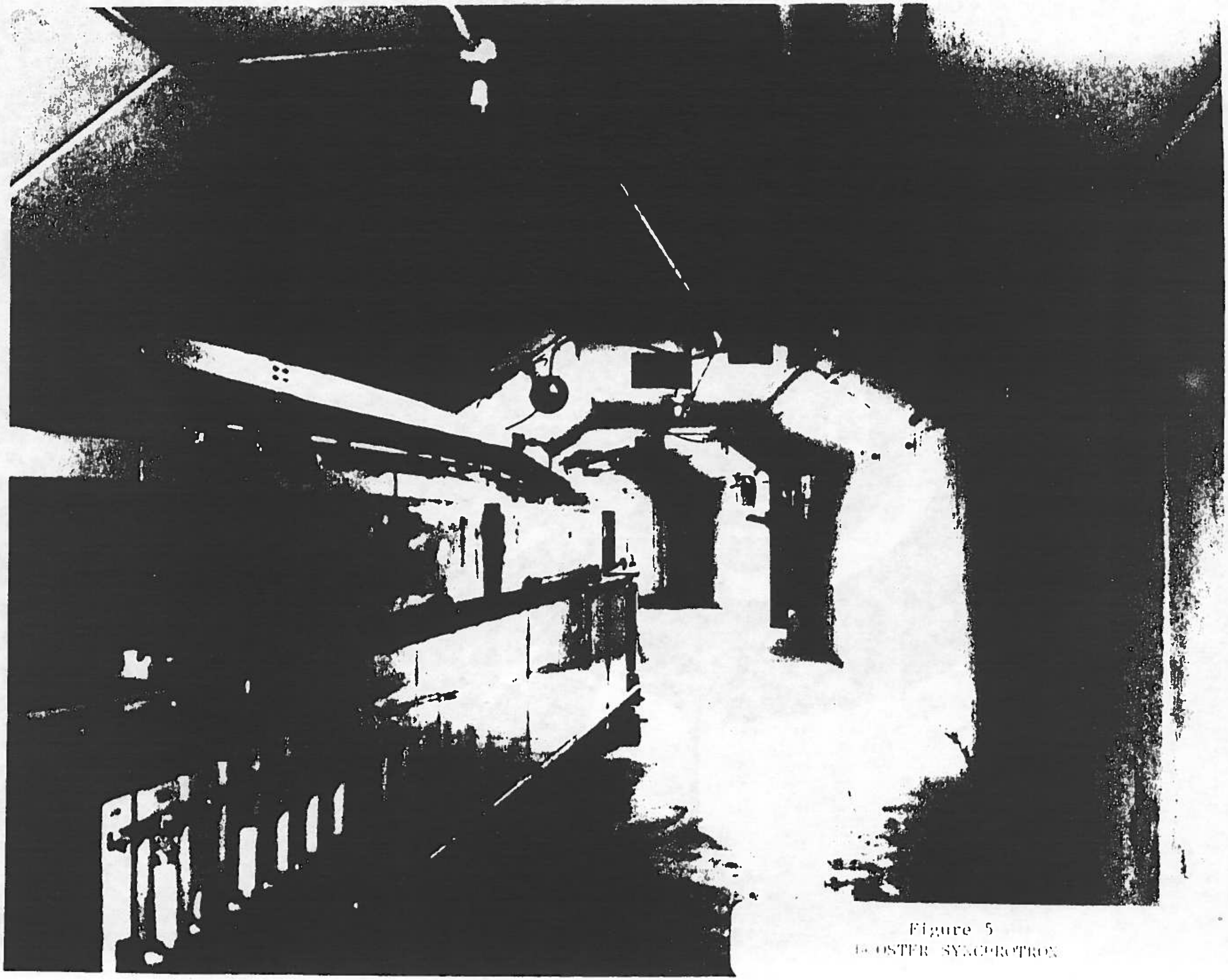


Figure 5
BOOSTER SYNCHROTRON

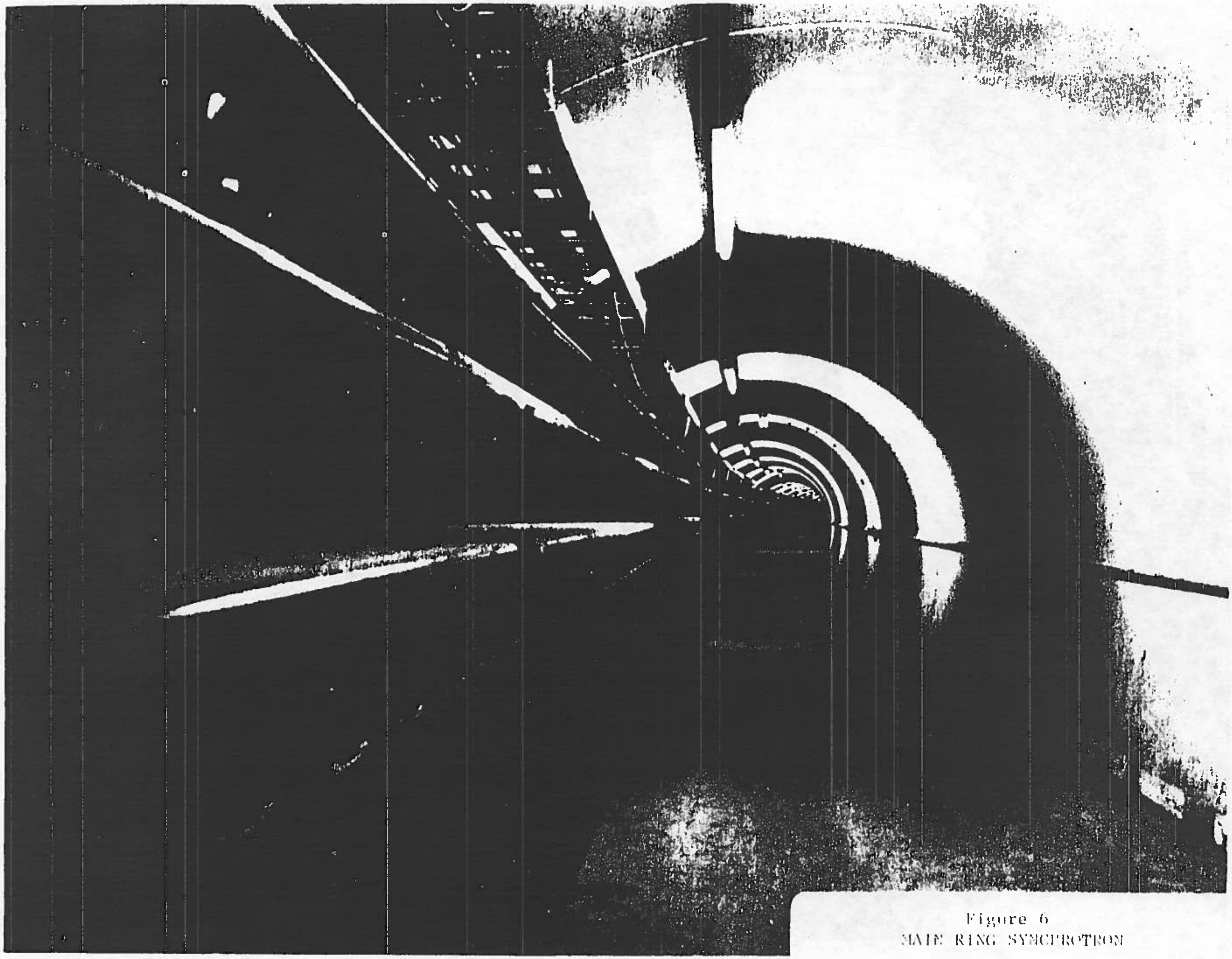
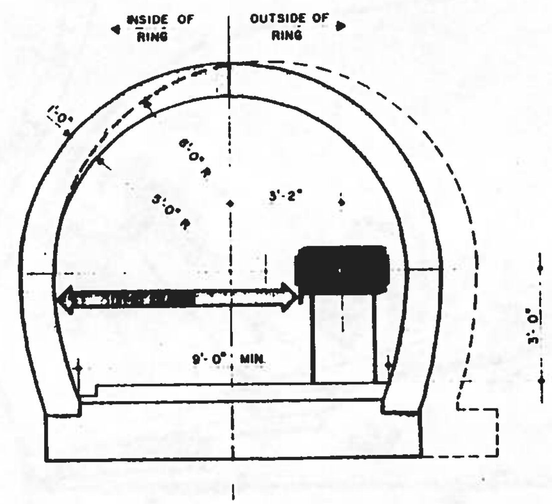


Figure 6
MAIN RING SYNCHROTRON

NAL Accelerator Housing



NATIONAL ACCELERATOR LAB

Figure 7
CROSS-SECTION - MAIN RING TUNNEL

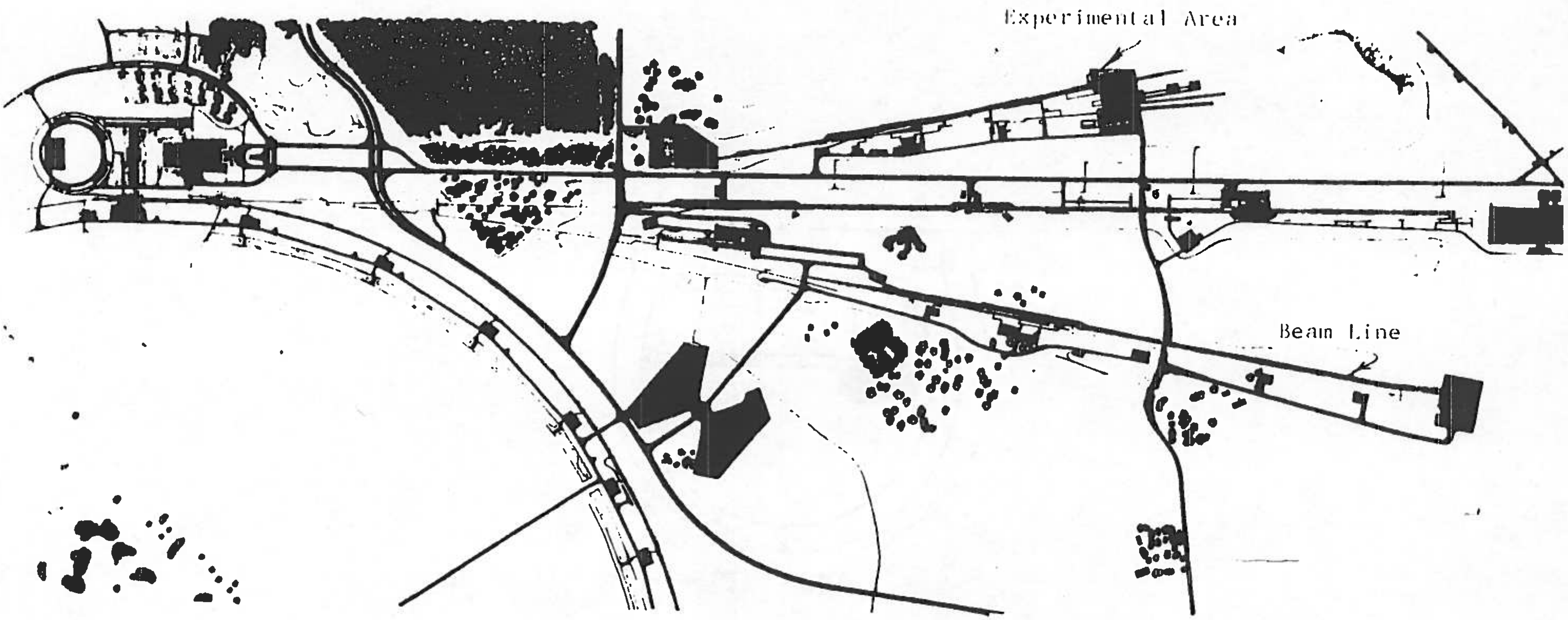


Figure 8
EXPERIMENTAL AREA - SITE PLAN

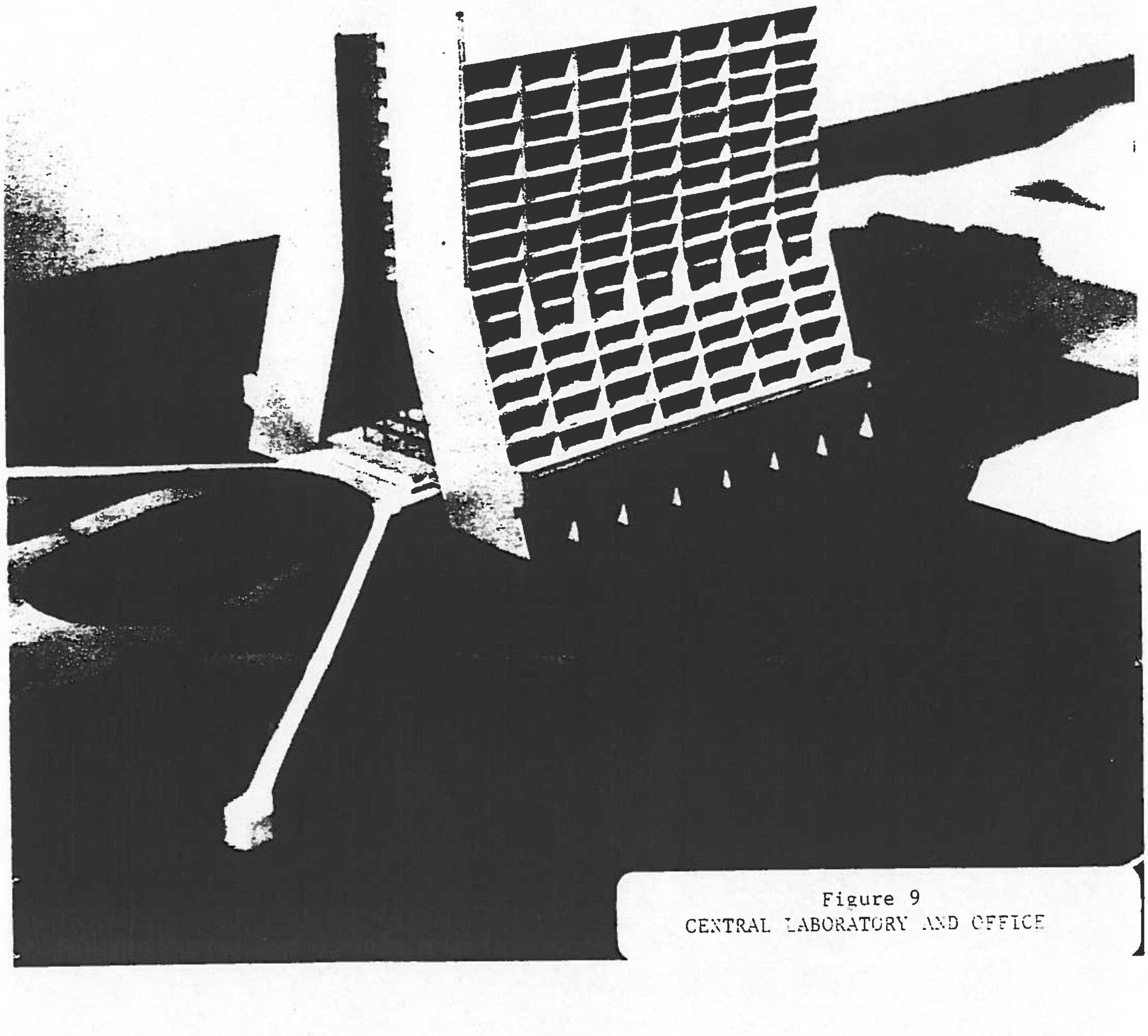


Figure 9
CENTRAL LABORATORY AND OFFICE

RADIATION SAFETY PROGRAM

1.0 Policy

1.1 Protons shall not be accelerated unless there is a good use for them.

1.2 No person shall be exposed to radiation unnecessarily.

1.3 Radiation doses to individuals in controlled areas shall be limited to those maximum permissible doses set by the Federal Government.

1.4 The radiation levels in off-site areas and on-site areas open to the public, as well as in general offices, shall not be greater than the limits set by the Federal Government for uncontrolled areas.

1.5 The beam dumps, accelerator, and external proton beam enclosures shall be so designed that normal radioactivation of the soil, taking into account known hydrology of the site and forseeable rainfall, will not contaminate water leaving the site above the permissible levels set by the Federal Government.

1.6 Proton beam losses shall be limited so that the remanent exposure rate inside the accelerator enclosures, including the external proton beam, shall safely permit all necessary maintenance.

1.7 Each person in the Laboratory is responsible for safety aspects of activities under his supervision.

2.0 Responsibilities

2.1 The overall responsibility for radiation safety and compliance with all applicable laws and regulations rests with the Director of NAL.

2.2 The Radiation Safety Officer will be charged with representing the Director for the implementation of all applicable laws and regulations as well as for the NAL Radiation Safety Program.

2.3 On behalf of the Director, the Radiation Safety Officer or his delegate shall stop any activity which, in his judgment, may violate Radiation Safety Policy.

2.4 Included in the Radiation Safety Program are:

2.4.1 Organization and direction of a radiation safety group of sufficient size to spot check the Laboratory's safety program, to insure that equipment being used to monitor radiation is properly placed and calibrated, and to supply personnel to conduct special surveys upon request.

2.4.2 Maintenance of appropriate radiation records.

2.4.3 Acquisition, distribution, and maintenance of suitable radiation safety equipment.

2.4.4 Acquisition and maintenance of radioactive sources for loan to NAL personnel and visiting experimenters.

2.4.5 Development of radiation safety procedures in conjunction with the various section heads.

2.4.6 Inspections and surveys to ascertain that established procedures and regulations are being observed.

2.4.7 Supervision of the acquisition, handling, storing, and disposal of radioactive materials.

2.5 The Radiation Safety Officer shall be readily available for consultation on all radiation safety matters. He shall be called upon for consultation by all groups planning or involved in activities where nuclear and/or X-ray radiations may be hazardous to health.

2.6 The Radiation Safety Officer shall maintain active programs for the development and refinement of radiation detectors, dosimeters, measurements of shielding characteristics, etc., and for the development of methods of calculating shielding, radioactivation, doses, etc.

2.7 With regard to radiation safety, each Section Head, in cooperation with and with the concurrence of the Radiation Safety Officer, is responsible within his section for:

2.7.1 Establishing and maintaining radiation safety in all areas in which members of his Section are active.

2.7.2 The installation and implementation of the radiation safety program.

2.7.3 Development of operating procedures which include adequate provisions for radiation safety.

2.7.4 Supervision of the appropriate electrical, electronic, and other groups in the design, installation, maintenance, and periodic inspection of interlock and warning systems pertinent to radiation safety.

2.7.5 Supervision of operation of doors, gates, etc., leading to high level radiation areas, and of radiation area warning signs as required.

2.7.6 Training of his Section's personnel in radiation safety procedures, including the training of engineers and technicians assigned to operating and controls crews.

2.7.7 Monitoring of radiation areas before personnel re-entries following operations and providing appropriate warnings and signals of dangerous levels of radioactivity.

2.7.8 Preparing detailed operating instructions for the radiation safety equipment and for the conduct of the safety program to guide the personnel.

2.7.9 Keeping records of radiation intensities in critical locations as instructed by the Radiation Safety Officer.

2.7.10 Accomplishing either directly or with the assistance of the Radiation Safety Officer surveys of radioactive areas and devices, and establishing appropriate time of occupancy for maintenance personnel.

2.7.11 Keeping appropriate records of doses received by operating and maintenance personnel, for guidance in establishing personnel rotation.

2.7.12 Ascertaining that no materials, tools, accelerator components, instrumentation, or any other item that may have become radioactive above limits set by the Radiation Safety Officer, leave the accelerator area which is directly under his supervision.

3.0 The Radiation Safety Committee

3.1 Purposes: The Radiation Safety Committee shall meet as needed to deal with extraordinary matters. Meetings shall be called by the Chairman at the request of any of its members.

3.2 Membership: The Radiation Safety Officer shall be the Chairman of the Radiation Safety Committee. The Chairman of the Laboratory Safety Committee shall be an *ex officio* member of this Committee. Other members shall be appointed by the Director of NAL at his discretion.

national accelerator laboratory

TM-306
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NAL OFF-SITE DOSE-EQUIVALENT RATES DUE TO ACCELERATOR-CAUSED RADIATION

M. Awschalom, D. Theriot, and A. Van Ginneken

May 25, 1971

Three examples of dose-equivalent rates off the NAL site are presented. The first estimate is for neutrons from the main accelerator to Butterfield Road, which forms the southern boundary of the site. The other two are for muons from the Meson Laboratory and the Neutrino Laboratory at the site boundary.

A. Main Accelerator

1. Dose Rate at Butterfield Road. The dose equivalent (DE) rate at Butterfield Road will be calculated using the neutron flux emanating from the shielding berm over the main accelerator. Typical cross sections of the berm over the main-accelerator enclosure are shown in Fig. 1. The dose rate at the surface of the berm has been estimated in a previous note[1] to be 4×10^{-4} rem/hr. This estimate already includes a safety factor of ten in beam loss. One may estimate the dose rate at points on the berm to be between 0.4 and 0.6 m rem/hr, using a relaxation length[2] of 120 G/cm^2 and a geometric factor of 1/R. We shall therefore use a mean value of 0.5 mrem/hr.

Using a flux-to-dose conversion factor[2] of 4.9×10^{-8} rem/(n/cm^2), the neutron flux at the surface of the berm is them 10^4 n/(cm^2 hr).

There are two types of contributions to the neutron flux at the site boundary: direct radiation from the side of the berm and "sky-shine," i.e. neutrons reaching the detector via scattering or production processes in the atmosphere.

2. Direct Radiation. Of the flux emanating from the berm side, only the low-energy component ($E \lesssim 200$ MeV) is expected to exit at an angle proper to contribute to the dose at the site boundary. Hence only about[3] 0.5 of the exiting flux should be used to calculate the direct radiation contribution to that off-site area.

To simplify the calculation, we will replace the accelerator by an infinite line source at the distance of closest approach. Then the flux at the site boundary is (for a small spherical detector)

$$\phi_d = \frac{S}{2\pi} \int_{-\infty}^{+\infty} dz \, \exp\left(-\sqrt{R^2 + z^2}/\ell\right) \Big/ (R^2 + z^2), \qquad (1)$$

where S ≡ linear source strength density (neutrons emitted per unit time and per unit length of the line source)

$= 3.8 \times 10^6$ n/(hr · cm) (based on a berm slope length of 25 feet)

R ≡ distance of closest approach between the main accelerator and Butterfield Road

$= 6.25 \times 10^4$ cm

ℓ ≡ neutron interaction length in air

$= 5.4 \times 10^4$ cm.

In Eq. (1) a factor of 2 appears instead of 4 since the estimated flux is the outgoing one. Evaluation of Eq. (1) yields a flux of 5.5 $n/(cm^2\ hr)$ and hence a direct dose rate of 0.22 microrem/hr. A conversion factor of 4×10^{-8} rem/(n/cm^2) is used here since the expected average energy of the neutrons is 2 MeV.

3. Skyshine. Here, the source includes both sides and the top of the berm (25 ft for each side, 13 ft of top). This outgoing flux is assumed to interact with air nuclei and produce evaporation neutrons. The interaction length was assumed to be 5.4×10^{4} cm. Using a crude model, the average number of evaporation neutrons per interaction is estimated to be 1.3 with an average energy of 2 MeV. These evaporation neutrons are assumed to be emitted isotropically. Elastic scattering, cascade particles, charged evaporation particles, and cascade development in air are neglected.

Based on these considerations (and again replacing the accelerator by an infinite line source) the skyshine flux becomes

$$\phi_{SS} = \frac{Sm_n}{2\pi^2 \ell} \int_{r_1=0}^{\infty} \int_{\theta=0}^{\pi} F(r_1)\, F(r_2)\, r_1 dr_1 d\theta. \qquad (2)$$

Here $S = 2\times10^{7}$ n/(hr cm)

$m_n \equiv$ average neutron multiplicity

$= 1.3$

$\ell \equiv$ interaction length in air

$= 5.40\times10^{4}$ cm.

$$F(r) = \int_0^\infty dz \exp\left(-\sqrt{r^2 + z^2}/\ell\right)\Big/(r^2 + z^2).$$

$r_1, \theta \equiv$ polar coordinates measured from the detector in a plane perpendicular to the line source.

$r^2 = \sqrt{r_1^2 + R^2 - 2rR\cos\theta}$, where $R \equiv$ distance of closest approach.

Numerical evaluation of Eq. (2) yields a flux of 21 n/(cm^2 hr) or a corresponding skyshine dose rate of 0.84 microrem/hr.

4. Total Dose Rate. Hence, at Butterfield Road, the total neutron dose rate due to operation of the main accelerator is expected to be less than (0.22 + 0.84 =) 1.1 μrem/hr or 9.6 mrem/yr. This may be compared with the 110 mrem/yr of the natural environmental background and the 170 mrem/yr permitted by the AEC Manual, Chapter 0524. Thus we estimate that the accelerator will produce approximately 8% above the natural background and approximately 6% of the AEC Manual maximum permissible dose rate for the population at large.

It is very important to note that the estimate is extremely conservative. We have assumed full operation at full intensity throughout the year, and we have assumed beam losses ten times higher than we expect.

For off-site neutron doses, the main accelerator is the worst offender; however, the above estimates show that the worst offender is a very tame one.

B. Experimental Areas

1. Muon Dose Rate. Here we shall discuss the cases of the two laboratories that have been designed up to this time for high-energy physics research, the Meson Laboratory and the Neutrino Laboratory. These two laboratories are very different from the point of view of muon-shielding design, because the former tries to minimize muon production while the latter enhances it in order to maximize neutrino fluxes.

The techniques used for the muon dose-rate estimates have been previously described.[5-13] Therefore, only the results will be given summarily.

2. Meson Laboratory. The discussion refers to full beam intensity into the target box: 10^{13} protons/sec at 200 GeV, on a one nonelastic mean-free-path long Be target, at 100% duty cycle. The shield is 1300 ft long. At the far end, a muon flux of 10^{-13} μ/cm^2 incident proton is expected.[5] At the site boundary, 7000 ft further away, we estimate

$$\phi(\mu) \sim 10^{13} \frac{\text{p}}{\text{sec}} * 10^{-13} \frac{\mu/\text{cm}^2}{\text{p}} * \left(\frac{1.3}{8.3}\right)^2 = 2.4\times10^{-2} \frac{\mu}{\text{cm}^2\,\text{sec}}$$

$$\text{DE} = 2.4\times10^{-2} \times \frac{1}{7.8} \frac{\text{mrem/hr}}{\mu/\text{cm}^2\,\text{sec}} = 3\ \mu\text{rem/hr} = 26\,\text{mrem/yr}.$$

The conversion factor of 7.8 $(\mu/\text{cm}^2)/\text{sec}$ = 1 mrem/hr has been used because not all muons are minimum ionizing muons.[14]

3. Neutrino Laboratory. The discussion is for 10^{13} protons/second at 400-500 GeV, on a Be target one nonelastic mean free path long, 100%

duty cycle and broadband neutrino beam operation. The shield is 5000 ft long. The site boundary is a further 5000 ft distant. We take the muon fluxes from Ref. 5 and calculate as above.

$$\text{Off-site DE} \simeq 4 \text{ mrem/yr @ 400 GeV}$$
$$\simeq 40 \text{ mrem/yr @ 450 GeV}$$
$$\simeq 260 \text{ mrem/yr @ 500 GeV.}$$

In fact, the original shield as described here is not adequate for bubble-chamber operation with 500-GeV protons. The bubble chamber would be swamped with muon tracks. It has therefore been decided to add a steel plug and a steel magnetic lens to deflect muons away from the chamber, as described in Ref. 12. The effect of this system on direct radiation at the site boundary has not yet been completely calculated, but it will certainly be in the direction of diffusing the muons over a larger area and therefore will reduce the muon intensity at a given point and resulting off-site DE rate.

C. Conclusions

The dose-equivalent rates just outside the NAL boundaries as estimated in this note are small even with the worst-case assumptions used. We expect that the accelerator will never be operated at full energy, intensity, and duty cycle into the Neutrino Laboratory for any considerable period because there will always be other competing demands of the research program.

During the first year of operation, the accelerator will operate at considerably less than 10% of its full product of energy and intensity and the muon flux will be correspondingly reduced. During this time, measurements will be made from which to predict the dose rates with greater certainty. If extrapolation of these data to full energy and intensity would give rise to any significant increase in radiation over the estimates here, additional shielding will be added. The 5000 ft from the present termination of the shield at the bubble chamber has been purposely left undeveloped to provide space for this shield.

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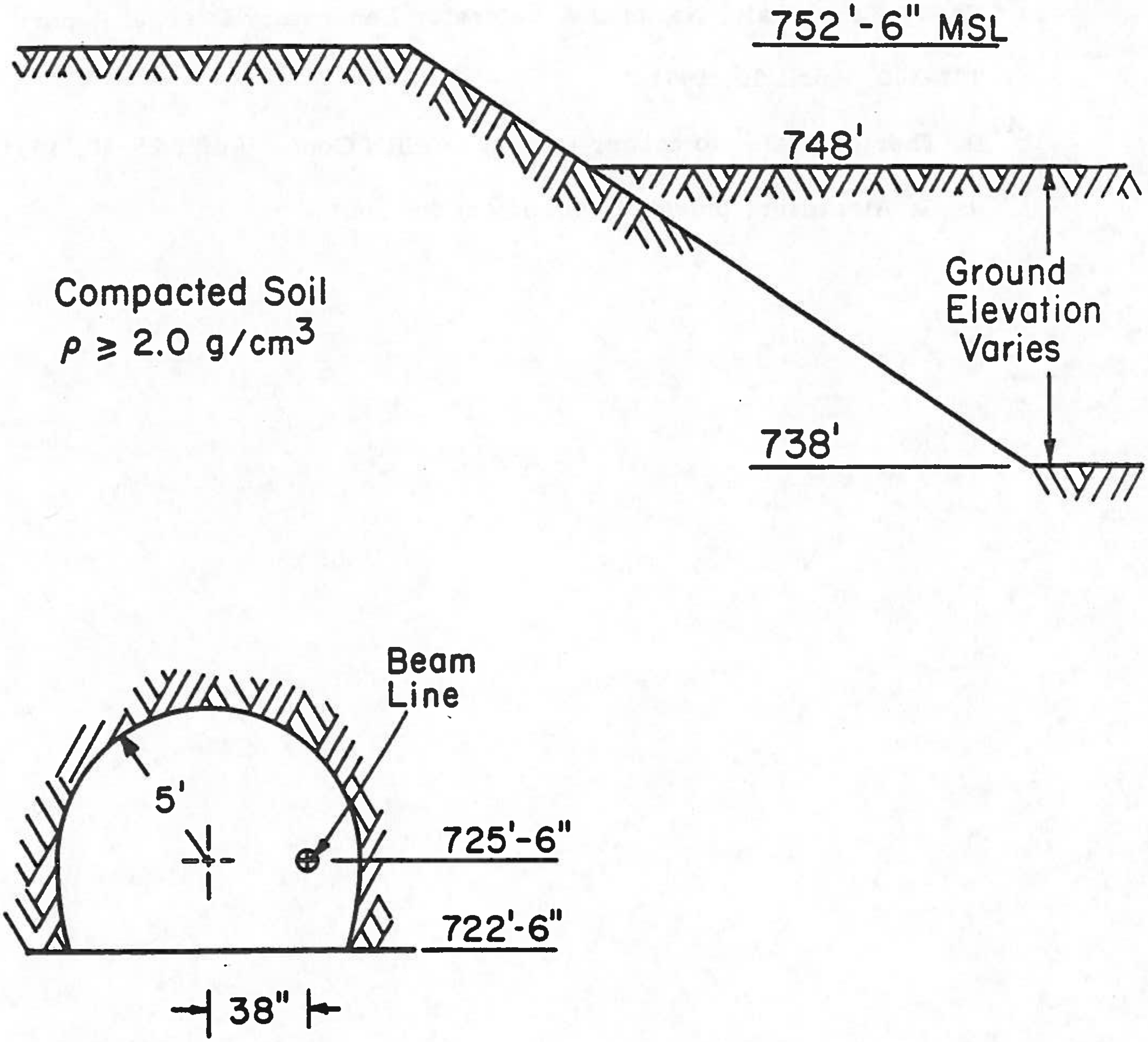

Fig. 1. Cross section of the Main-Accelerator shielding.

CALCULATION OF THE RADIONUCLIDE PRODUCTION IN THE SURROUNDINGS OF THE NAL NEUTRINO LABORATORY

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ABSTRACT

For the design of beam dumps, target stations, and the Neutrino-Laboratory decay tunnel, it was necessary to gather previously unavailable data, to calculate the maximum amount of leachable radioactivity that may be produced annually in the surrounding soil, and to estimate that fraction of the radioactivity which may leave the site via the underground waters. This paper describes the calculations.

The Neutrino-Laboratory decay tunnel is discussed as an example. Making very conservative assumptions about underground water velocities, large average proton-beam currents (10^{13} p/sec, at 400 GeV, 100% of the time) and broad band neutrino beam operation (maximum beam power into the soil), it is shown that rather small amounts of H^3 (55 mCi/yr) and Na^{22} (31 μCi/yr) may leave the site.

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The NAL accelerator will have more than one order of magnitude greater beam power than any other proton accelerator now in operation. Hence, it was necessary to study with some care the problem of soil radioactivation when high-energy protons interact with accelerator components and the secondary hadrons continue the development of the extranuclear cascade in the accelerator itself, enclosure, and surrounding soil. The concern with the radioactivation of the soil arises from the fact that some of the radioactivity so created may be leached away by the underground waters and be carried to off-site domestic water systems.

The problem may be divided into several parts:

1. The extranuclear cascade, activation, and spatial distribution of radionuclides;

2. Leachability of radionuclides from NAL soils;

3. Calculation of the leachable and non-leachable radioactivity created annually in the NAL soils; and

4. Transport of the radionuclides by the underground waters to the site boundaries.

Once the radioactivity leaving the site is estimated, it can be compared with the pertinent rules and regulations.[1]

In the treatment that follows, different approaches for solving a problem are discussed when possible. This makes the presentation longer, but it may give a better feeling for the uncertainties involved in these calculations.

1. The Extranuclear Cascade

There is some uncertainty in the extranuclear cascade calculations because the most important input data, the source term, will only be known after the accelerator has become operational.

When a high-energy hadron undergoes a nonelastic event with a nucleus of the medium under consideration, it is said that a "star" has been created even if there is only one outgoing hadron. In the case of incident hadrons with energies of tens of GeV or greater, about 1 to 4 stars are produced per incident GeV of hadron kinetic energy.[2-4]

For any calculations involving stars and activations, nonelastic cross sections as well as activation cross sections are needed. The nonelastic cross sections of Belletini[5] are used, and they are assumed to be energy independent from about 30 MeV to the highest energy considered. For the sodium-22 activation, the cross-section calculations of Van Ginneken[6] are used. They are in excellent agreement with experimental results.[7-8] For the H-3 activation, experimental results are used exclusively.[7]

While studying the extranuclear cascade, we shall be interested in two of its characteristics:

1. The total number of radionuclides of a given type that are created per incident proton;

2. The spatial distribution of these radionuclides.

To calculate the quantity of nuclides and their distribution, two different but consistent approaches will be discussed below. They are:

(a) Some experimental results and Monte Carlo calculations

(b) Some other experimental results plus physical arguments.

a. The Monte Carlo Calculation

The calculation consists in picking random numbers to select polar and azimuthal angles as well as track lengths for the various hadrons produced in a collision, using energy-dependent mean free paths. Hadron momenta are chosen using random numbers and either Trilling's formula[9] for pions and or a modification of it for protons and neutrons. Energy is conserved at each interaction. Inelasticities are taken from cosmic-ray data when available and from R. G. Alsmiller's calculations[10] otherwise.

As the extranuclear cascade develops in configuration space, the star density and the energy spectra of the various components (p, n, and $\pi^{\pm}$) vary as functions of r and z, where r and z are cylindrical co-ordinates, with the incident primary hadron moving along the z-axis and the target-dump starting at $z = 0$.

There are three large Monte-Carlo programs to calculate extra nuclear cascades. The first one, TRANSK, written by J. Ranft,[11] was later modified and improved at NAL by Ranft and Borak.[9]

J. Ranft used this more modern version to write a new program called FLUTRA.[12]

There is presently at NAL a greatly improved version of FLUTRA that has great versatility and that can reproduce all published shielding experiments carried out at 28 GeV within factors of two to three[13] over a range of fluxes of $10^5:1$.

Figures 1 and 2 show the geometries of the Brookhaven experiment.[14,15] FLUTRA has been very successful in reproducing these results, as may be seen in Figs. 3-5. Figure 3 shows the prediction of the results for the side-shielding experiment of Bennett et al.[15] and actual results. Figure 4 is a prediction of the $C^{12} \rightarrow C^{11}$ activation in the beam-dump experiment[14] and actual results. Figure 5 is a prediction of the $Al^{27} \rightarrow F^{18}$ activation in the same dump[13] and the actual results. We can see that at 28 GeV the calculations are quite good for their intended use.

A virtue of FLUTRA is its simplicity. A much more elegant and accurate but slower program for similar calculations has been developed by R. G. Alsmiller and his group[10] at ORNL. In Alsmiller's model, the source function, i.e., the yield term, is the "extrapolation model,"[16] which is based on Bertini's nuclear model[17] for intranuclear cascades up to 3-GeV incident proton energy.[18] Figure 5 also shows Alsmiller's[19] prediction for the $Al^{27} \rightarrow F^{18}$ activation in the beam stop of the BNL experiment. This model makes more accurate predictions than

FLUTRA at 28 GeV. Other examples of this type of calculations may be found in Refs. 20 and 21.

Hence, we see that for energies up to 28 GeV, there are at least two independent programs that make absolute predictions very close to actual measurements. One should therefore consider their predictions for incident energies in the 200 to 500 GeV range to be probably as good as our ability to conceive source terms and so to predict particle production at higher energies. In particular, one should have additional confidence in Alsmiller's extrapolation model,[16] since it gives very good predictions of the π^- production at 75 GeV.

In practice, it is very difficult to separate the different components of the cascade in the midst of a thick shield. This is a consequence of the use of activation detectors for flux integration. Hence, it is customary to add all the components of the cascade into an undifferentiated hadronic flux. It is also customary to use the proton activation cross sections to estimate the magnitude of the undifferentiated hadron flux. Finally, it has also been customary to adopt an energy-independent value for the activation cross sections from threshold to maximum energy. Figure 6 shows, as an example, the C^{12} (n, 2n) C^{11} cross section as commonly used and the C^{12} (p, pn) C^{11} and C^{12} (p, pn)C^{11} as measured.[22] Figure 7 shows the measured Al^{27} (p, x) Na^{22} cross section as well as the macroscopic cross section for Na^{22}

activation in NAL soil. The present calculation, like many others,[6,23-25] recognizes that Na^{22} is produced by the spallation of Si, Fe, Ca, Mg, Na^{23}, K, etc.

In Table I, the macroscopic cross sections at 500 MeV for two types of NAL soils are presented. They show very similar nuclear characteristics in spite of their different natures. One is a composite of various NAL soils[26] and labeled "average NAL soil." The other one is from the glacial till at a location near the main accelerator.[7]

The results of the Monte-Carlo calculations may be used in various manners to calculate the production of a given nuclide.

For example, Armstrong[19,20,21,27] and Gabriel[20,27] use a complete intranuclear cascade at the site of a non-elastic event in order to determine the residual nucleus. In the NAL version of FLUTRA, the macroscopic activation cross section is entered as a dimensional array. In the program TRANSK the energy-dependent cross section is calculated using Rudstam's formula.[28]

In all cases, the quantity sought is

$$A_i = \int_V dV\, A_i(r,z) = \int_V dV \int_0^E \Sigma_i(E')\phi(E',r,z)dE', \qquad (1)$$

where $A_i(r,z)$ is the production of the i-th nuclide per incident hadron at a point (r,z) of the medium. Sometimes A_i is expressed in curies for a given incident current and energy and after a certain irradiation

Table I. ^{22}Na Macroscopic Cross Sections at E_h = 500 MeV For NAL's Average Soils and Glacial Till.

		Average Soil						Glacial Till				
A	Element	% by Weight	N (a)	σ_{Na} (b)	$N\sigma_{Na}$ (c)	σ_{ne} (b)	$N\sigma_{ne}$ (c)	% by Weight dry	% by Weight moist	N (a)	$N\sigma_{Na}$ (b)	$N\sigma_{ne}$ (c)
16	O	55.0	2.07E22	0	0	0.31	0.642E22	50.8	56.5	2.13E22	0	0.660E22
28	Si	22.8	0.49	0.017	0.00833E22	0.47	0.230	25.7	21.8	0.47	0.0080E22	0.221
27	Al	5.51	0.123	0.013	0.00160	0.46	0.057	6.2	5.3	0.12	0.0016	0.0552
12	C	3.32	0.166	0	0	0.195	0.032	3.7	3.2	0.15	0	0.0292
1	H	1.23	0.737	0	0	0.025	0.018	-	1.67	1.01	0	0.0252
56	Fe	2.91	0.0314	0.0002	-	0.800	0.025	3.3	2.8	0.031	-	0.0248
40	Ca	6.08	0.0914	0.004	0.0037	0.62	0.057	6.8	5.8	0.087	0.00035	0.0539
25	Mg	2.09	0.0518	0.028	0.00145	0.43	0.022	2.4	2.0	0.050	0.0014	0.0215
23	Na	0.40	0.0104	0.036	0.00037	0.40	0.004	0.45	0.38	0.010	0.00036	0.0040
39	K	0.52	0.0080	0.004	0.00003	0.62	0.005	0.58	0.49	0.0077	0.00003	0.00471

Average Soil: $\Sigma N_i\sigma_{i,Na}$ = 0.012E22 $\Sigma N_i\sigma_{i,ne}$ = 1.09E22

Glacial Till: $\Sigma N_i\sigma_{i,Na}$ = 0.012E22 $\Sigma N_i\sigma_{i,ne}$ = 1.10E22

[a] atom/gram, moist soil
[b] barns
[c] barns/gram

time; E is the energy of the primary incident hadron, usually a proton; $\Sigma_i(E')$ is the macroscopic cross section for the formation of the i-th nuclide in the given medium by an undifferentiated hadron of energy E'; and $\phi(E',r,z)$ is the number of undifferentiated hadrons of energy E' per cm^2, per MeV per incident primary hadron, at a point (r,z) in the shield.

b. Experimental Results and Physical Arguments

The spatial distribution of the activity may be inferred from the measurements at CERN[29] and at BNL,[15] remembering that $p_\perp$ remains essentially unchanged as the energy of the incident hadron increases, while $p_\parallel$ increases monotonically with $p_{incident}$.

T. Toohig[30] has estimated that about one-third of all the activity is created in the soil surrounding the decay pipe of the neutrino-beam facility and two-thirds is created in the beam stop at the end of the pipe. This fractionation is in good agreement with the Monte Carlo calculations of Gabriel.[27]

In order to calculate the number of atoms of some nuclide, some manipulation of the cross sections and assumptions regarding the energy spectrum of the hadrons must be made.

If the total number S of "stars" has been obtained by calculation or estimation from experimental results, the ratio A_i/S (nuclides of the i-th type to all stars) can be calculated from

$$\frac{A_i}{S} = \int_v dV \int_0^E \Sigma_i(x)\phi(x,r,z)\,dx \Big/ \int_v dV \int_0^E \Sigma(x)\phi(x,r,z)\,dx, \quad (2)$$

where $\Sigma(E)$ is the energy-dependent macroscopic nonelastic cross section for the given medium.

The distribution of the radionuclides is commonly assumed to be the same as that for all the stars, unless the activation cross section for the particular radionuclide is used as part of the calculation.

Certain simplifying assumptions are commonly made such as

1. A single energy spectrum is used throughout; then the flux term can be split into a product of an energy-dependent term and a spatially dependent term. That is,

$$\phi(E,r,z) \rightarrow N(E)\phi'(r,z). \quad (3)$$

This may underestimate the Na^{22} production by not more than 10-15% in some regions.

2. In such geometries as the Neutrino-Laboratory decay tunnel ϕ' is assumed to be independent of z, which is a good first approximation.[4,27] Using the activities at the maximum of the distribution, the total Na^{22} is overestimated by less than a factor of three.

The change of the constant-flux cardioids of revolution[4,14,31] into spheres makes no difference in practical applications such as target boxes, because the forward shielding is dictated by considerations other than soil activities and usually is greater than that needed for soil protection.

Accepting the assumptions (a) and (b) above and that of energy-independent cross sections, then formula (1) becomes

$$A_i = \Sigma_i \int_V \phi\,(r,z)\,dV \int_{E_{th}}^{E} N(x)\,dx, \qquad (4)$$

where E_{th} is the threshold energy for the macroscopic cross section Σ_i.

If a flux has been evaluated with a detector having a macroscopic cross section Σ_d and threshold energy E_{th} (d), the two activities may be related by

$$A_i = A_d * (\Sigma_i/\Sigma_d) * \left[\int_{E_{th}(i)}^{E} N(x)\,dx \Big/ \int_{E_{th}(d)}^{E} N(x)\,dx \right] \qquad (5)$$

where the subscripts i and d refer respectively to the nuclide under consideration and the monitoring detector used for flux evaluation in either a calculation or an experiment. Effectively, Eq. (5) is a re-written Eq. (1).

Figures 8 and 9 show graphs of the integral $\int_{E'}^{E} N(x)\,dx$ as a function of E' (the threshold energy) for incident protons of 200 and 500 GeV and soil as a moderating medium. They are taken from Ref. 8.

It is obvious that if a number S (total stars per incident hadron produced by hadrons with energy greater than a given threshold) is known from some source, then the number of nuclides may be found by substituting A_d by S.

The number S may be calculated using the expression

$$S = kE_0, \tag{6}$$

where S is the total number of stars created in a given semi-infinite medium, by incident protons of kinetic energy E_0, by all secondaries with energy greater than or equal to E', and k is the proportionality constant that depends on the medium and E'.

The value of k may be obtained from experimental results by studying the activation of foils through beam stops or other geometries. The value of k given in Ref. 2 is of experimental origin. It is very comforting that the values of k agree so well.

For our calculations, we have adopted the value k = 4, because FLUTRA tends to underestimate the flux at large radii by a factor of approximately 3. Hence, k = 4 should be conservative.

Table II. Values of the Proportionality Constant k.

Medium	E'(MeV)	k	Source
steel	100	1.68	3
steel	15	4.36[a]	3
steel	47	0.8	4
soil	15	1.4	4
steel-soil	"?"	~1-2	2

[a] A proper fit in the 40 to 1000 GeV range requires $S = kE_0 + 75$

2. Measurements of the Macroscopic Cross Sections and Leachability of Various Radionuclides for NAL Soils

In order to calculate the production of radionuclides in the soil, one needs: (a) the distribution of the components of the hadronic cascade in the phase-space of the generalized target (dump, shield, etc.) and (b) the energy-dependent macroscopic cross sections for the production of the radionuclides of interest in the medium under consideration.

In Section 1 a discussion of methods for flux estimation were given. To obtain the activation macroscopic cross section for NAL soil, one may refer to published activation cross sections and calculate them. This is possible to do for Na^{22} and an example of such a calculation at one energy was given in Table I. In Ref. 6 the energy-dependent macroscopic cross section is calculated and plotted. Figure 9 is a reproduction of Fig. 7 of Ref. 6 of the macroscopic cross section versus energy.

From Table I, we get the ratio of the macroscopic cross section, $\Sigma(Na^{22})$ to Σ (nonelastic) to be approximately equal to 0.011.

A second method consists of taking samples of NAL soils and exposing them at the Argonne ZGS and Brookhaven AGS, near internal targets and behind one foot of concrete. The results of such measurements are given in Ref. 7.

The agreement between the measured macroscopic cross sections for Na^{22} and the calculated ones is excellent. From Ref. 7 we have

$$\Sigma_{meas}(Na^{22}) = 1.5 - 2.2 \times 10^{-4}\ cm^2 g^{-1}$$

$$\Sigma_{calc}(Na^{22}, 500\ MeV) = 1.2 \times 10^{-4}\ cm^2 g^{-1}.$$

Note that the calculated Σ has a broad maximum at $1.7 \times 10^{-4}\ cm^2 g^{-1}$.

A quantity that would be difficult to calculate is the fraction of the created activity of each radionuclide which would leach out in a first water pass and in subsequent water passes. Experimental results are given in Table III.

The importance of the fraction leached during subsequent washings of the soil is that it provides a means to calculate the relative ion velocity of the radionuclide in question with respect to the water velocity.

From the leachings following the first one, one can calculate the ion drift velocity using the expression[32]

$$Kd = \frac{q_A}{C_A} = \frac{(\mu Ci/g)\text{ in dry soil}}{(\mu Ci/ml)\text{ in solution}} = \left(\frac{ml}{g}\right), \qquad (7)$$

where Kd is the distribution coefficient, q_A is the radionuclide activity per gram of dry soil, and C_A is the radionuclide activity per ml of solution.

In actual practice, one can use the approximate relation

$$Kd = \frac{Co - C_E}{C_E} \times \frac{\text{volume of solution (ml)}}{\text{mass of dry soil (g)}}, \qquad (8)$$

where Co is the initial concentration of radioactivity ($\mu Ci/ml$) in the solution, and C_E is the activity of the solution ($\mu Ci/g$) after contact with the solution.

The diffusion coefficient Kd may then be used to calculate the relative velocity of the radionuclide with respect to the water carrying it.

$$\text{Relative velocity} = \frac{v(\text{radionuclide})}{v(H_2O)} = \frac{1}{1 + D}, \qquad (9)$$

where $D = Kd * (\rho_b/\epsilon)$ is a dimensionless quantity, p_b is the density of the dry soil (g/cm^3) and ϵ is the porosity (the fraction of the volume of dry soil occupied by the voids).

Formulas 7 and 9 were used in evaluating Kd for H^3 and Na^{22} in NAL's glacial fill. The results are given below:

Table III. Leachability of Sodium and Tritium.

Radionuclide	Na^{22}	H^3
Leachable Fraction, first wash	0.20	1.0
Leachable Fraction, other washes		
Kd	0.204	~O
Relative Velocity	0.44	1

The results of the batch work done at NAL are reported elsewhere.[7,33]

3. Calculation of Radionuclide Production

The beam parameters used in the calculations are

Table IV. Beam Parameters

Incident Proton Energy	= 400 GeV
Average Incident Proton Current	= 10^{13} protons/sec
Irradiation Time	>>half life of any one radio-nuclide under consideration.

All secondaries interact in the soil surrounding the point of interaction.

Note that the use of an average beam current implies some combination of actual beam current and duty cycle. In addition irradiation times much longer than the half-life of the radionuclide under consideration imply a condition of dynamic equilibrium between the number of radionuclides produced per second and the number of radionuclides decaying per second.

The calculations are summarized in Table V. Comparisons with calculations of other authors are also shown. The k's used are those of Table II, and for this work K = 4. The ratio of all Na^{22} stars to all stars is taken as 0.011, from Table I.

The activities derived from Ref. 27 were calculated averaging over all radii for the Z-interval 50 m to 100 m, and multiplying the activities is given by the ratio (400/500) to convert them to 400 GeV.

The calculations given below in Table V assume that all the beam power is dissipated in the soil. In Table VI, the geometry is taken into account.

The quantities given are total and leachable activity created per year. This rate of production is convenient for the calculation of the yearly activity leaving the site.

Table V. Comparison of Various Calculations for Yearly Radioactivity Production and Leaching from NAL Soils by a Proton Current of 10^{13} p/sec at 400 GeV.

Radio-nuclide	Radioactivity Production Rate(1) kCi/yr	Leachable Fraction	Leachable Radio-activity Production(1) kCi/yr	Reference
Na^{22}	3.04	0.20	0.608	2
Na^{22}	0.029	0.10	0.0029	30
Na^{22}	1.9	0.20	0.38	See a
Na^{22}	1.1	0.20	0.22	This work
Na^{22}	0.74	-	-	27
Na^{22}	0.41	-	-	34
H^3	0.34	-	-	27
H^3	1.1	1.0	1.1	This work
Ca^{45}	0.76	-	-	27
Ca^{45}	0.25	0.05-0.10	0.013	This work
Mn^{54}	0.40	-	-	27
Mn^{54}	0.054	0.003	-	This work

[a] The activity estimated in Ref. 30 was changed by the author of this note as follows:

1. Correction for Na^{22} macroscopic cross section. The macroscopic cross section given by Van Ginneken[6] at 100 MeV is used instead of only the aluminum spallation cross section. This gives an increase of 20 in the expected activity.
2. The energy scaling factor is taken as E^{+1}, instead of $E^{\frac{1}{2}}$, this gives an additional factor of $(400/30)^{\frac{1}{2}} = 3.65$.

3. The correction for threshold energy using the curves in Ref. 8, gives a factor of 0.90. Then, the activity created per year becomes

activity/year (corrected) = 0.029 Ci/yr * 20 * 3.65 * 0.90
= 1.9 k Ci/yr.

The Na^{22} activity created per year that has been estimated in this paper is just below the geometric mean of the maximum and minimum activities, $\sqrt{5 \times 7 * 0.41}$ = 1.5 k Ci/yr.

To estimate the activity that may be leached annually to the aquifer, it is imperative to examine a drawing of the cross section of the neutrino laboratory meson decay pipe. This is shown in Fig. 10.

The cross-sectional area has been divided in sections for ease of calculations and for reasons of expected water flow. Sections 1 and 4 are backfilled with sand and gravel. Sections 3 and 3 are backfilled with compacted clay-like materials. Sections 5 and 6 are essentially undisturbed soils.

The significance of these sections is as follows. All radionuclides produced in Sections 1, 2, and 4 are assumed to be caught with 95% efficiency or greater by the imperious blanket.

Whatever escapes this "bathtub" is caught by the underdrains A and B. In addition, underdrains dry up a region determined, very approximately, by slopes of 5 in 1, near the tiles. These "draw-downs" form the lower boundaries of Section 5. It is also assumed that the activity created in Sections 3 and 5 is collected. Then, only the activity created in Section 6 escapes to the aquifer.

To calculate the fraction of the stars created in each section, a radial dependence of the star density of the form

$$\phi(r) = \phi(r_0) r_0 \exp[-(r - r_0)\rho/\ell]/r, \quad (7)$$

is assumed. Here, $r_0 = 45$ cm, $\rho = 2.0$ g/cm^3, and $\ell = 100$ g/cm^2.

A cylindrical geometry is assumed and all matter is clay. Then, the relative fractions are given in Table VI.

Table VI. Distribution of Stars by Soil Section Perpendicular to Decay Pipe of Neutrino Laboratory.

Section	Fraction of All Stars
1	0.495
2	0.00402
3	0.000577
4	0.495
5	0.00500
6	1.14×10^{-4}

Now, we can calculate the maximum and minimum leachable radioactivity created in the vicinity of the decay pipe. Three sets of numbers will be calculated: maximum (Ref. 2), and minimum (Ref. 34).

Table VII. Annual Na^{22} Radioactivity Produced in the Soil.

	Minimum	This TM	Maximum	
Total	0.41	1.1	3.0	k Ci/yr
In Dump (2/3)	0.28	0.74	2.0	k Ci/yr
In Soil (1/3)	0.13	0.37	1.0	k Ci/yr
In zones 1, 2, and 4 (0.994)	0.13	0.37	1.0	k Ci/yr
In zones 3 and 5 (0.0056)	0.73	2.1	5.6	Ci/yr
In zone 6	0.015	0.042	0.11	Ci/yr
Leachable in zone 6	3.0	8.4	22.	m Ci/yr

Similar calculations may be carried out for H^3.

Table VIII. Annual H^3 Radioactivity Produced in the Soil.

	Minimum	This TM	Maximum	
Total	0.41	1.1	3.0	k Ci/yr
In Dump (2/3)	0.28	0.74	2.0	k Ci/yr
In Soil (1/3)	0.13	0.37	1.0	k Ci/yr
In zone 6	15	42	110	m Ci/yr
Leachable in zone 6	15	42	110	m Ci/yr

The concept of the gravel and the "bathtub" as well as that of the underdrains and creation of "draw-down" surfaces were discussed with representatives of the Illinois State Water Survey.[35] It was considered adequate by them.

4. Transport of Radionuclides.

We now have to estimate the travel time for the Na^{22} and H^3 from the vicinity of the decay pipe to the aquifer and along the aquifer to the site boundary.

The vertical velocity of the water in the glacial till is estimated to be 8 ft/yr,[36] and 3.6 to 7.2 ft/yr.[37] Here, a conservative value of

7.2 ft/yr will be used. Now the Na ion velocity[33] is about 0.44 that of water, because of ion-exchange processes taking place. Hence, the Na^{22} ion velocity is taken to be 3.2 ft/yr. For H^3, the ion velocity and the water velocity are the same.

It is now possible to estimate the transit times to the aquifer for Na^{22} and H^3:

Vertical distance = 70 ft
Na^{22} transit time = 70/3.2 = 21.9 years
H^3 transit time = 70/7.2 = 9.72 years.

Since the respective half-lives are 2.6 and 12.3 years, the surviving fractions are

$$Na^{22} \text{ surviving fraction} = \exp(-21.9 \ln 2/2.6) = 2.91 \times 10^{-3}$$

$$H^3 \text{ surviving fraction} = \exp(-9.72 \ln 2/12.3) = 0.58.$$

The horizontal velocity of water in the aquifer is relatively large. Hence it is now assumed that all ions travel with the velocity of water.

The horizontal velocity is estimated at 3-6 ft/day, with a maximum of 13 ft/day.[36] The distance from the decay pipe to the site boundary in a southeasterly direction, as it is expected to flow from measured gradients,[37] is about 4 km. Then the horizontal transit time becomes,

$$T_h = 4 \times 10^3 \text{ m}/(13 \text{ ft/day} \times 365 \text{ day/year} \times 0.304 \text{ m/ft}) = 2.7 \text{ years}.$$

Surviving fractions,

$$Na^{22} \text{ fraction} = \exp(-2.7 \ln 2/2.6) = 0.49$$

$$H^{3} \text{ fraction} = \exp(-2.7 \ln 2/12.3) = 0.86.$$

Finally, it is possible to estimate the radioactivity reaching the aquifer and the site boundaries.

Table IX. Production of Annual Radioactivity Reaching the Aquifer.

	Na^{22}	H^{3}	
Leachable, zone 6	3.0-8.4-22.	15.-42.-110.	m Ci/yr
Reaching aquifer	0.0087-0.024-0.064	8.7-24.-64	m Ci/yr
Reaching site boundary	0.004-0.012-0.031	7.5-21.-55	m Ci/yr

5. Conclusions

The present estimates of the annual amounts of radioactivity leaving the site are quite conservative since they include the maximum reasonable ion velocity both vertically and horizontally.

In addition, the leachable fraction of the total activity was mesured by the batch process. This certainly gives an upper limit to the leachability.

Finally, both a high beam power and 100% duty cycle of the broad band neutrino facility have been assumed. This is certainly a gross overestimate. It is, therefore, felt that the estimates of the annual radioactivities leaving the site as given in Table IX are very cautious and conservative.

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FIGURE CAPTIONS

Fig. 1. Geometry of the beam-stop equipment. The steel and air gap width, used in the calculations, are given.

Fig. 2. Geometry of the side shield experiment.

Fig. 3. Comparison of predictions[34] and measurements[15] in the BNL side shield experiment.

Fig. 4. Comparison of carbon activation results[14] and predictions[34] in the BNL beam-stop experiment.

Fig. 5. Comparison of the Al^{27} (hadron ?) F^{18} results[13] and predictions by the NAL group[34] as well as those of Alsmiller's.[10]

Fig. 6. The C^{12} (p, pn) C^{11} and C^{12} (n, Zn) C^{11} measured cross sections[22] (solid lines) and its energy-independent approximation[29] (dashed lines).

Fig. 7. The Al^{27} (p, x) Na^{22} measured cross section[22] as well as the macroscopic activation cross section for Na^{22} in NAL soil.[6]

Fig. 8. Graph of the function $\phi(E') = \int_{E'}^{E} N(x)\,dx$ where E' = threshold energy and N(x) is the undifferentiated hadron flux. Case: lateral shielding of 200-GeV protons lost on steel (200 g/cm^2) and soil to a total thickness of 1500 g/cm^2.[29]

Fig. 9. Same as Fig. 8, but for 500 GeV protons and secondaries. Data from spectrum given in Ref. 27.

Fig. 10. Cross section through the decay pipe of the neutrino laboratory showing the different types of fill and the undisturb soils.

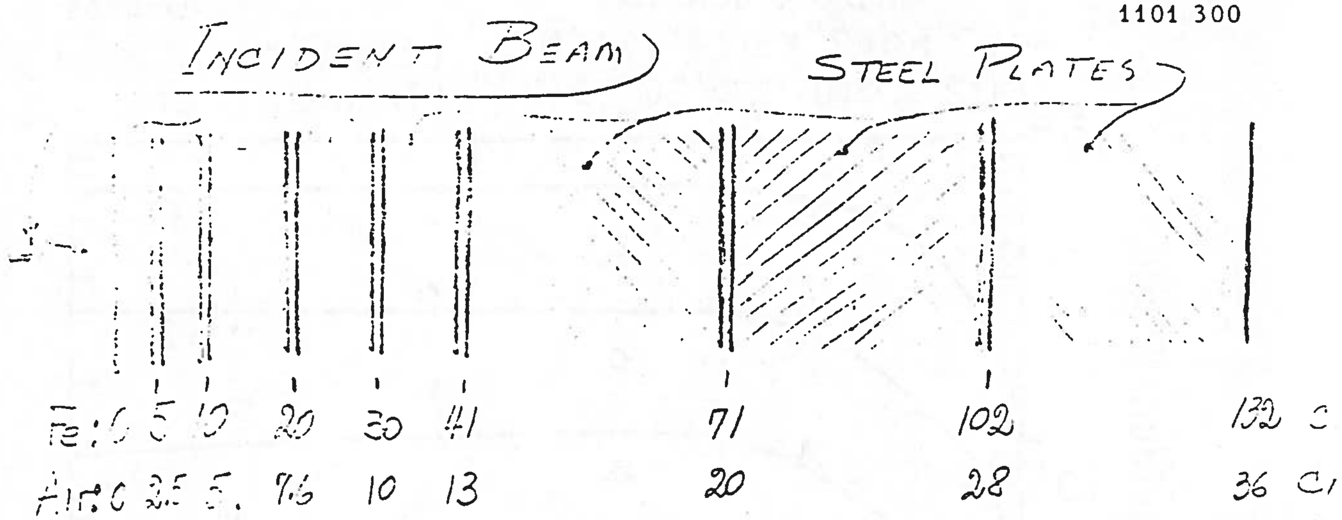

INCIDENT BEAM
STEEL PLATES
Fe: 0 5 10 20 30 41 71 102 132
Air: 0 2.5 5. 7.6 10 13 20 28 36

Fig. 1

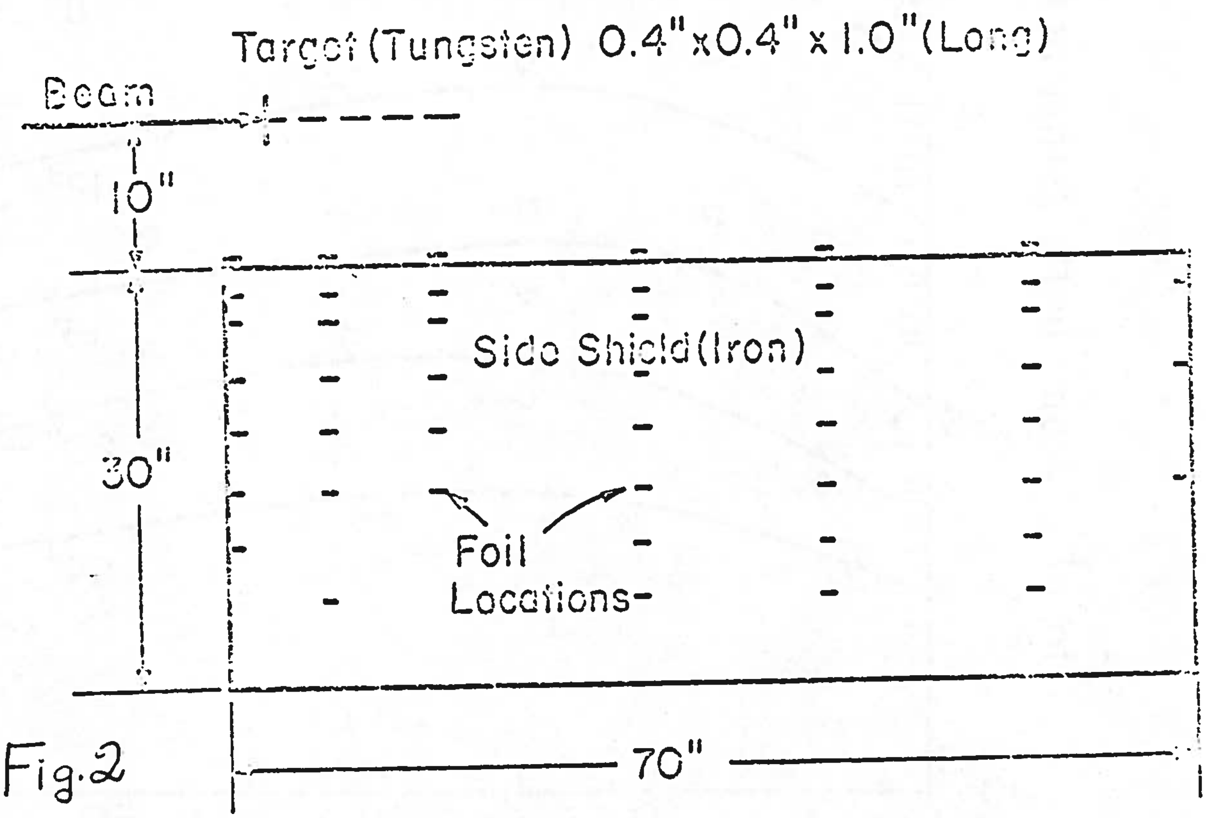

Target (Tungsten) 0.4"x0.4"x1.0"(Long)
Beam
10"
30"
Side Shield (Iron)
Foil Locations
70"

Fig. 2

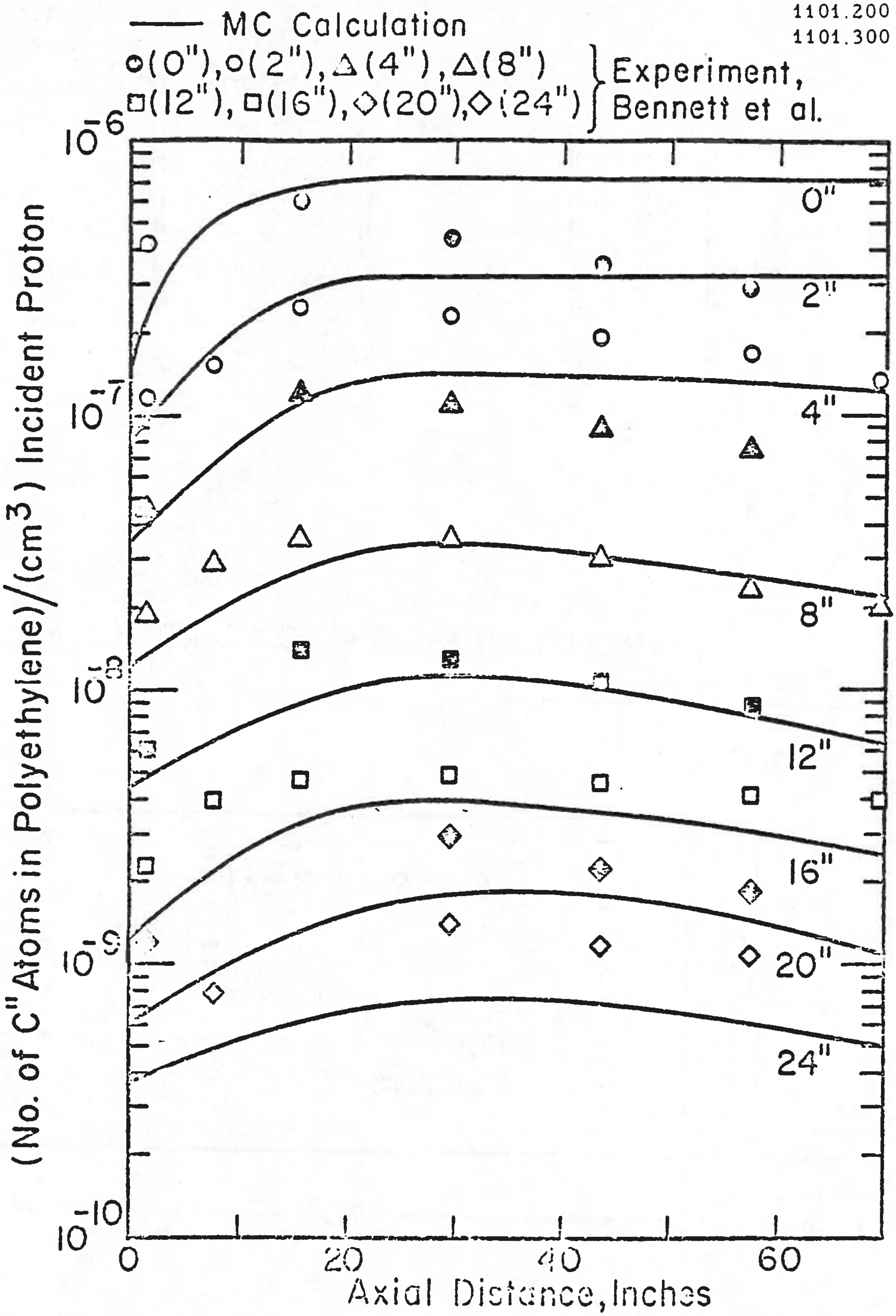

MC Calculation
○(0"), ○(2"), △(4"), △(8")
□(12"), □(16"), ◇(20"), ◇(24")
Experiment, Bennett et al.
(No. of C" Atoms in Polyethylene)/(cm³) Incident Proton
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
0"
2"
4"
8"
12"
16"
20"
24"
0
20
40
60
Axial Distance, Inches

Fig. 3

FIG. 4

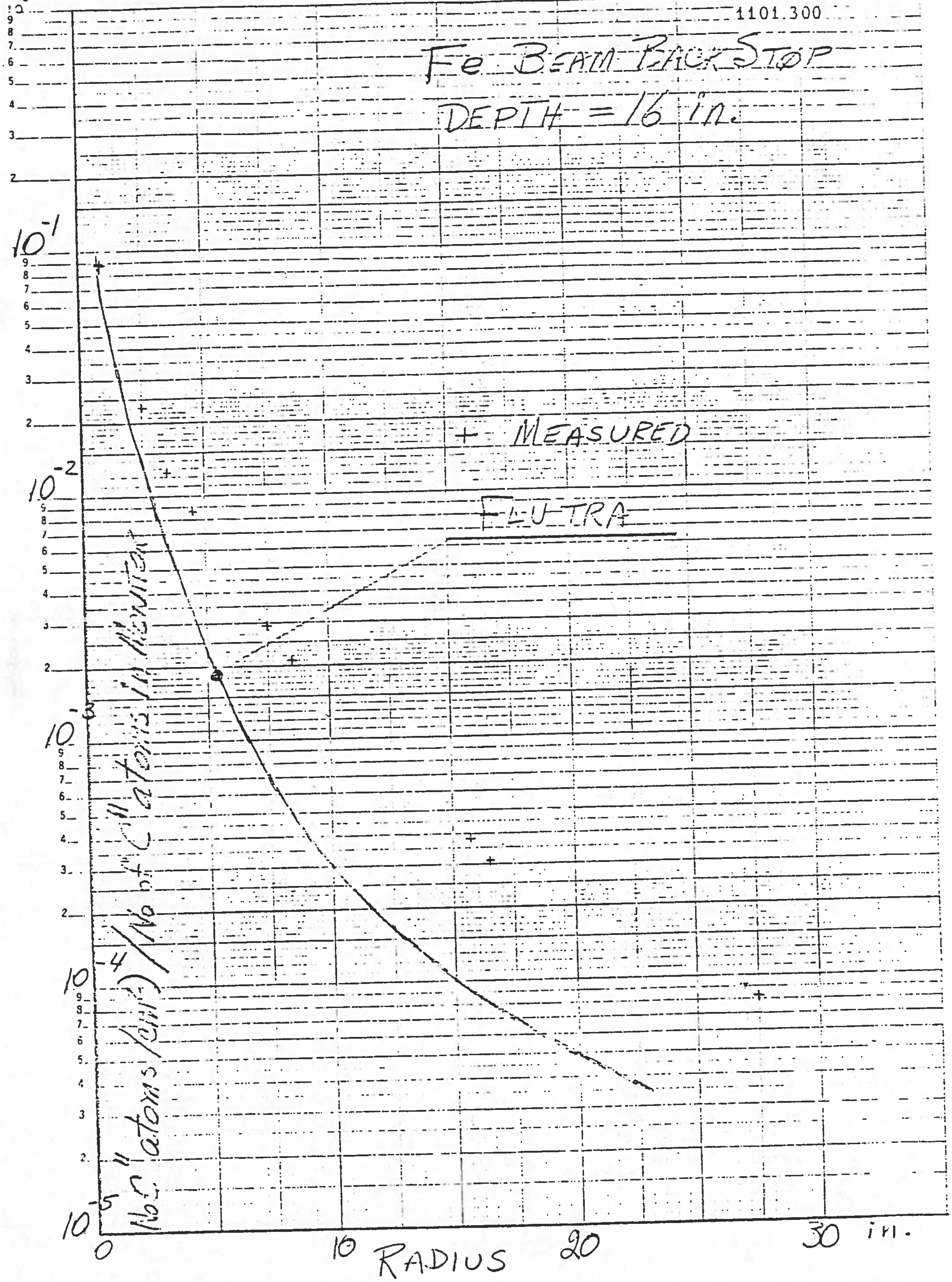
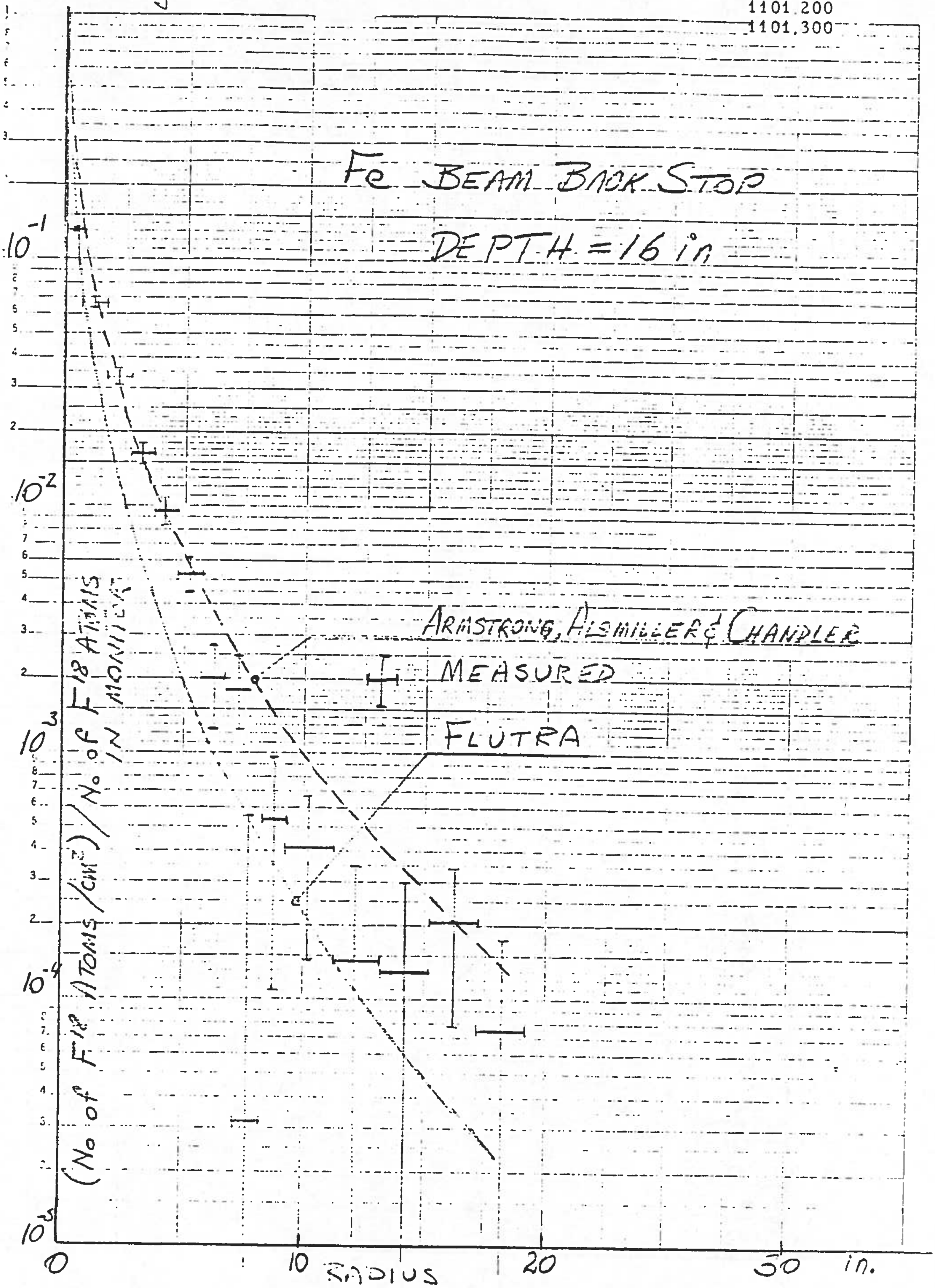

Fe BEAM BACK STOP
DEPTH = 16 in.
+ MEASURED
FLUTRA
No. "C" atoms/cm³ / No. of "C" atoms in Monitor
RADIUS
0
10
20
30 in.
10^-1
10^-2
10^-3
10^-4
10^-5

Fig. 5


Fe BEAM BACK STOP
DEPTH = 16 in
ARMSTRONG, ALSMILLER & CHANDLER
MEASURED
FLUTRA
(No of F18 Atoms/cm2)/No of F18 Atoms IN MONITOR
RADIUS
in.

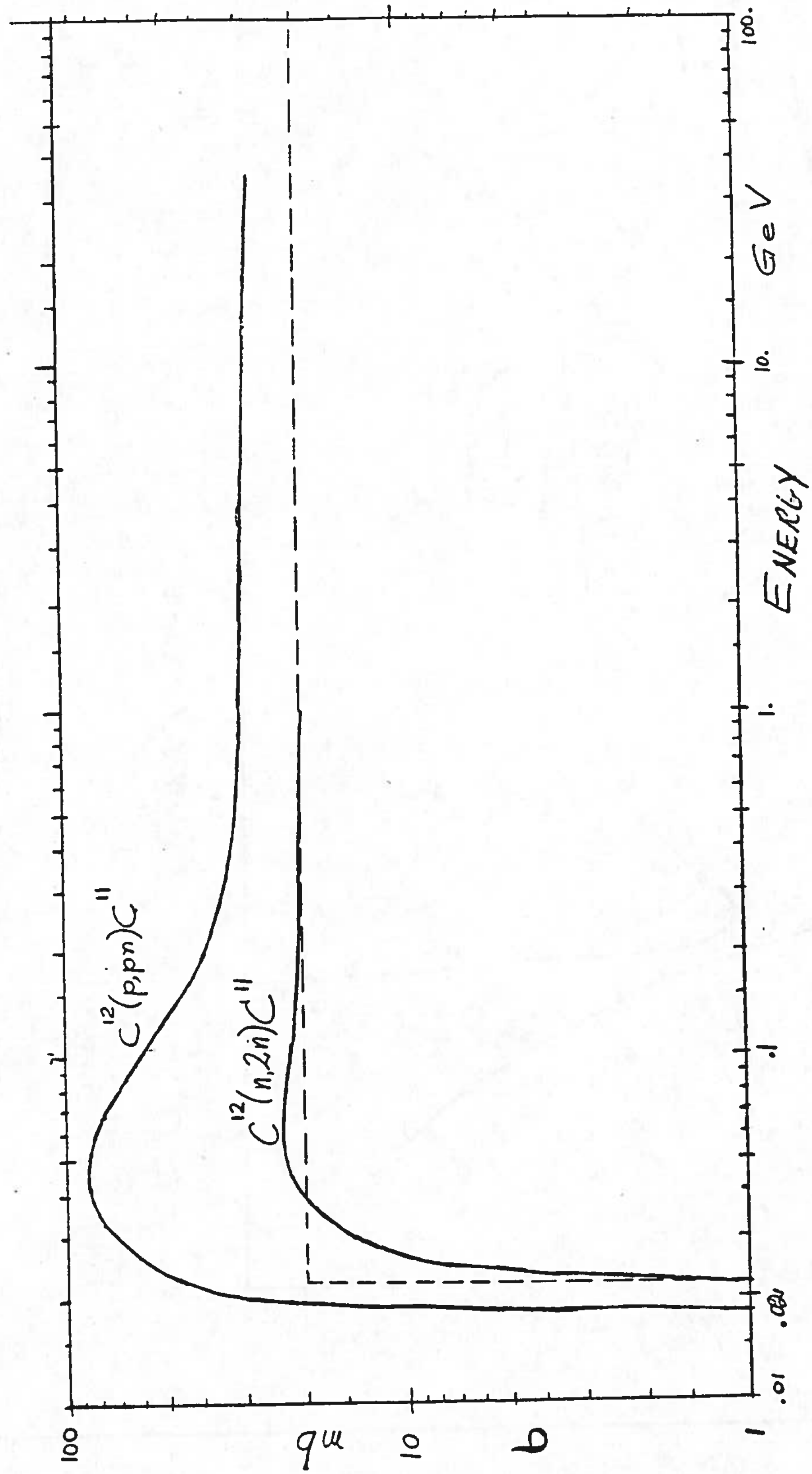


Fig 6

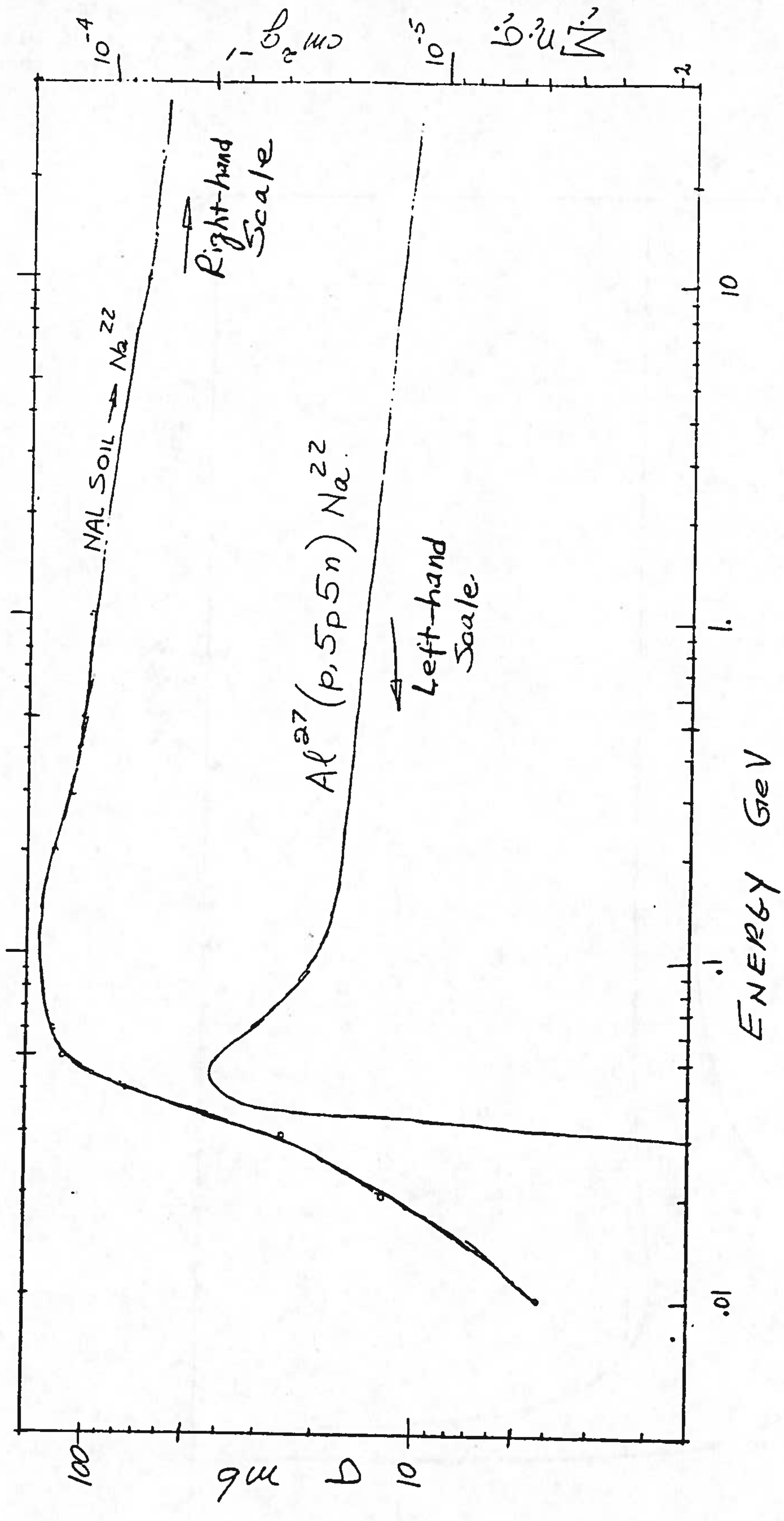

NAL SOIL → Na^{22}
$Al^{27}(p,5p5n)$ Na^{22}
Right-hand Scale
Left-hand Scale
ENERGY GeV
.01
.1
1.
10
100
10
mb
10^{-4}
10^{-5}

Fig 7

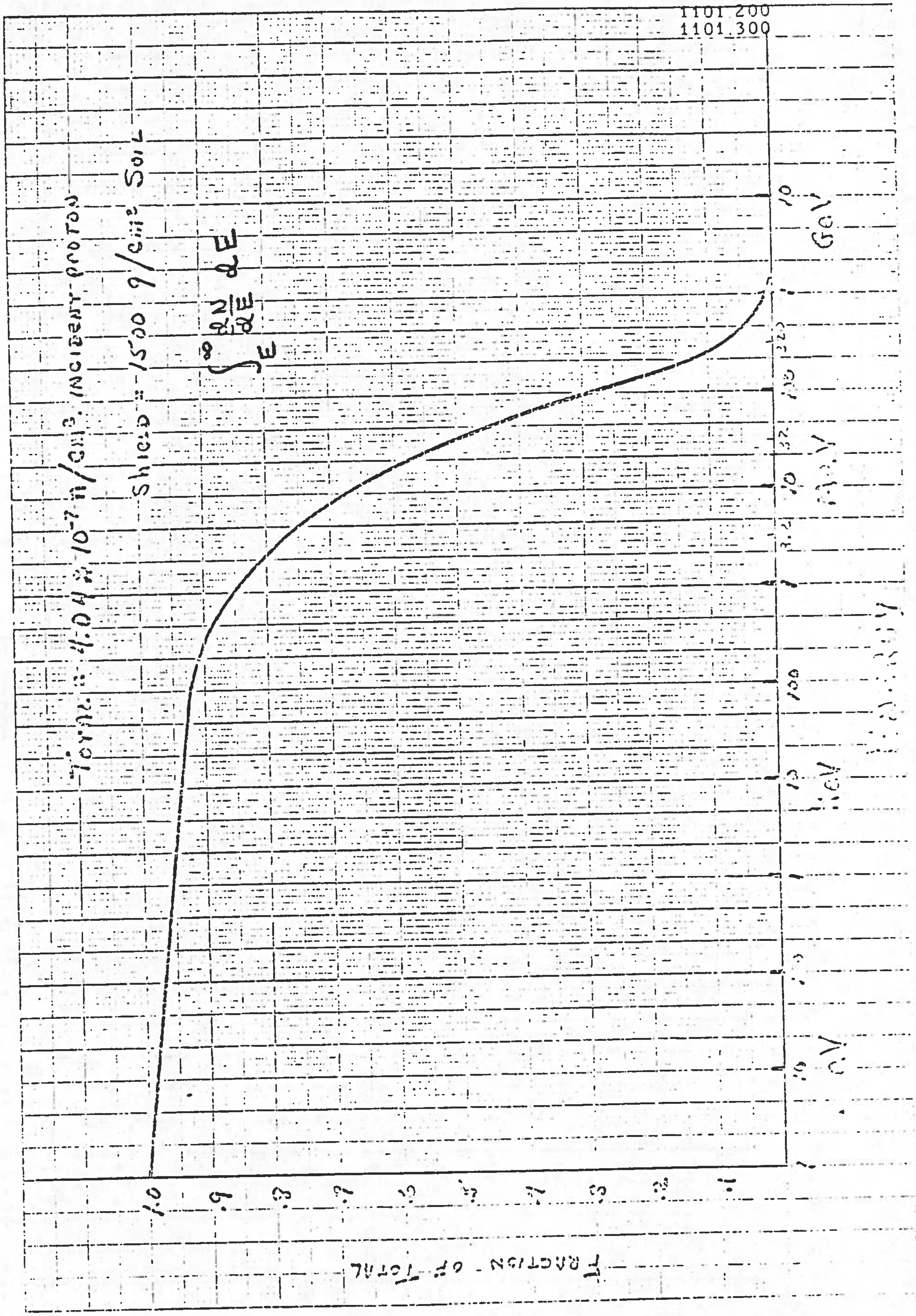


Fig. 8

Gabriel et al.

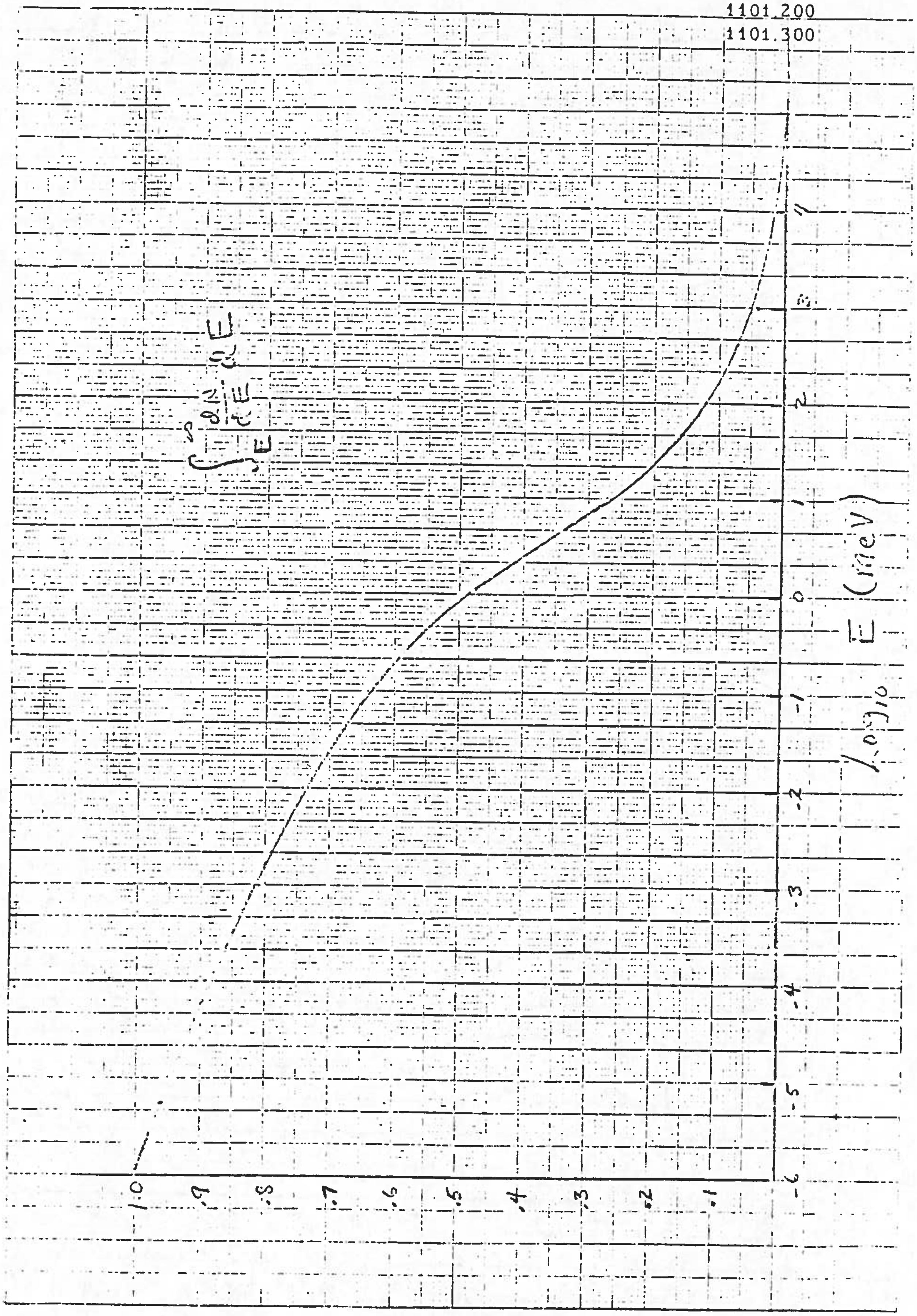


Fig. 9

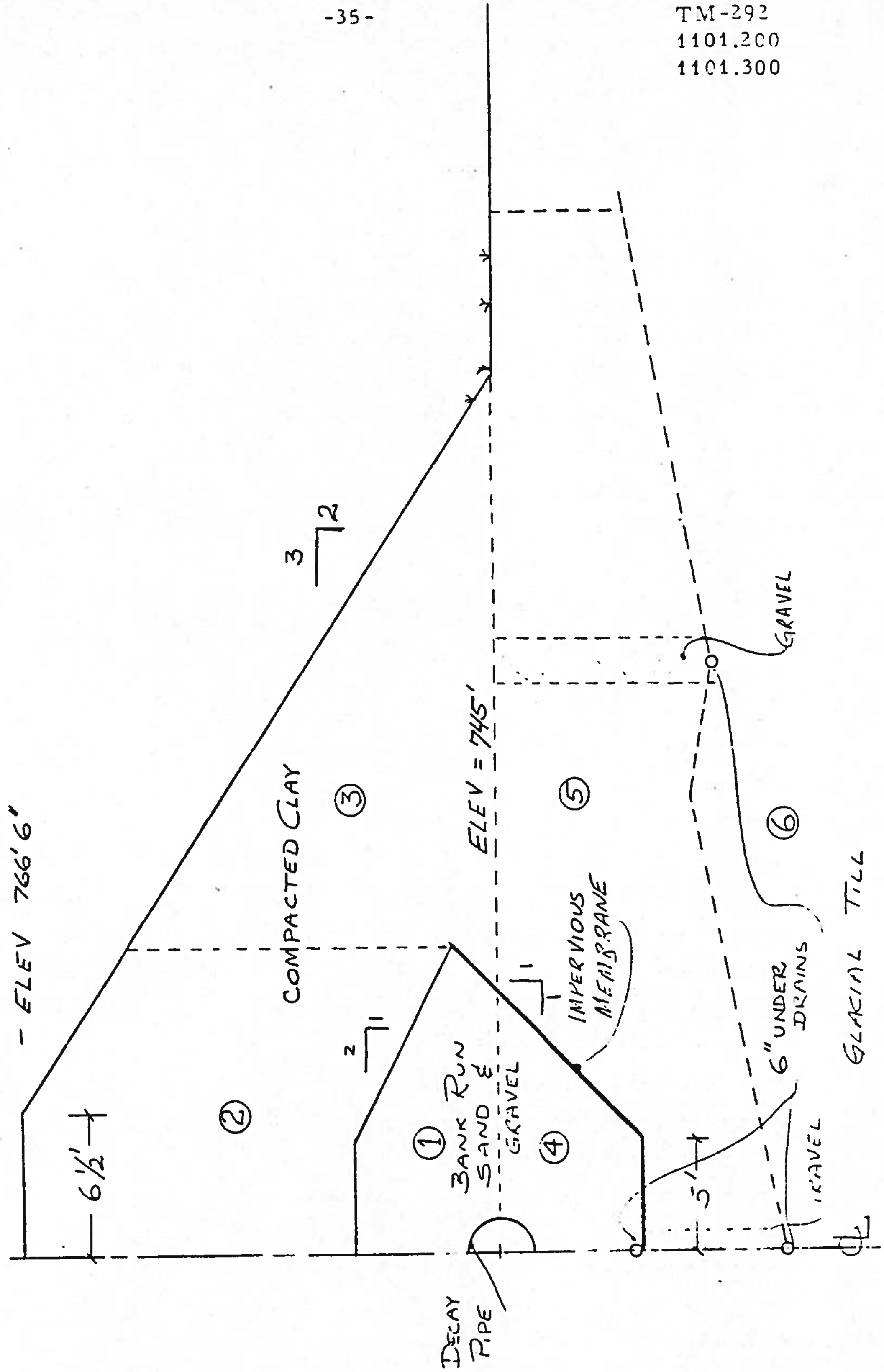

ELEV 766'6"
COMPACTED CLAY
ELEV = 745'
BANK RUN SAND & GRAVEL
IMPERVIOUS MEMBRANE
GRAVEL
6" UNDER DRAINS
GLACIAL TILL
DECAY PIPE
6½'
5'
1
2
3
4
5
6

Fig 10

APPENDIX D

COMMENTS RECEIVED ON DRAFT ENVIRONMENTAL STATEMENT AND AEC RESPONSES

UNITED STATES
ATOMIC ENERGY COMMISSION
WASHINGTON, D.C. 20545

DEC 30 1971

Dr. Roger O. Egeberg
Assistant Secretary for Health
and Scientific Affairs
Department of Health, Education,
and Welfare
Washington, D. C. 20201

Dear Dr. Egeberg:

This is in response to your letter of March 22, 1971, concerning the "Draft Environmental Statement for the National Accelerator Laboratory (NAL), Batavia, Illinois." At the time you indicated concern about the adequacy of the information in support of the conclusions reflected in the Environmental Statement on expected radiation levels at NAL. In the past couple of months, the Statement has been revised and strengthened, primarily in the Physical Impact - Part IVA. The final environmental statement is enclosed. In addition, the assumptions and calculations supporting the conclusions in the Statement have been formalized in TM-306, entitled, "NAL Off-Site Dose-Equivalent Rates Due to Accelerator-Caused Radiation," dated May 25, 1971; and TM-292-A, entitled, "Calculation of the Radionuclide Production in the Surroundings of the NAL Neutrino Laboratory," dated March 11, 1971. These documents are also enclosed.

Thank you for your review and comments.

Sincerely,

John A. Erlewine

John A. Erlewine
Assistant General Manager
for Operations

Enclosures:
1. Final Environmental Statement - NAL (4 cys)
2. Report TM-306
3. Report TM-292-A

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
WASHINGTON, D.C. 20201

OFFICE OF THE SECRETARY

John A. Erlewine
Assistant General Manager
for Operations
U.S. Atomic Energy Commission
Washington, D.C. 20545

Dear Mr. Erlewine:

Thank you for your letter of February 1, 1971, to Mr. Roger Strelow transmitting the "Draft Environmental Statement for the National Accelerator Laboratory, Batavia, Illinois," dated January 1971. The staffs of our Bureaus of Radiological Health and Community Environmental Management have reviewed this statement as required by the provisions of the National Environmental Policy Act of 1969. Their report is enclosed.

The "Environmental Statement" indicates that the National Accelerator Laboratory can be built and operated at the Batavia, Illinois, site without adverse environmental effects or unacceptable radiation exposure of the surrounding population. While this may in fact be possible, it was the opinion of the reviewing staff that the general nature of the statement made it impossible to adequately evaluate the acceptability of the site or facility nor to assess the adequacy of the studies made by the AEC and the conclusions summarized in the "Environmental Statement." For instance, the maximum dose rate of 30 mrem/yr at the site boundary is well within the standards for exposure of the public; however, the acceptability of this calculated exposure is dependent on the data and assumptions made. Such information is not presented. Further, this level would be considered unacceptable for a reactor installation.

Based upon the information presented, the proposed facility should not represent an unacceptable hazard to the public or the environment. However, it has not been possible to evaluate the adequacy and completeness of the data and assumptions used in formulating the statement's conclusions on the basis of data provided.

Sincerely yours,

Roger O. Egeberg, M.D.
Assistant Secretary
for Health and Scientific Affairs

Enclosure

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE
Bureau of Radiological Health

Date: March 11, 1971

Reply to Attn of:

Subject: Comments on the Environmental Statement for the National Accelerator Laboratory

To: Deputy Director
Bureau of Radiological Health

1. The subject document has been reviewed by staff members of the Radioactive Materials Branch, DMRE and the Product Testing and Evaluation Branch, DEP. The following statement summarizes the information presented which indicates that there is no unacceptable radiation hazard to the general public or the environment from the operation of the facility.

a. External Radiation The main accelerator is contained in an underground tunnel which is covered with the equivalent of 20 or more feet of earth shielding. Peak radiation levels at the site boundary are calculated to be no greater than 0.009 mrem/hr above background at the northeast corner and no more than 0.003 mrem/hr at other points due primarily to neutron and muon radiation.

Allowing for operational variations in beam intensity, beam energy, and operating times, cumulative levels are expected to be less than 10 mrem/yr at the major fraction of the site perimeter and less than 30 mrem/yr at the northeast corner.

b. Residual Radioactivity will be produced in the tunnel walls, components, cooling water, tunnel air and ground water. The beam tunnel enclosures will be sealed during operation and for a period of time after shutdown to allow decay of the radioactive air. The primary cooling is a completely closed system and the radioactive water will be contained.

c. Ground Water The irradiation of soil adjacent to the external target areas can be expected to produce ^{55}Fe, ^{39}Ar, ^{14}C, and ^{22}Na. To prevent the majority of these activation products from reaching the ground water a collection system will drain the target areas into a holding pond for monitoring prior to any release. Using hypothetical assumptions it was calculated that the concentration of ^{22}Na (the most significant radionuclide) in well water on the facility site would be less than 5% of the general public permissible concentration.

2. The document however is so limited in scope that it is impossible to make an evaluation of the radiation hazards of the facility or to assess the adequacy of studies made by the operator-contractor which are presented in the "Environmental Statement." It is highly questionable that a document of this nature serves any useful purpose in determining deleterious efforts on the environment from the construction and/or operation of this facility.

3. I discussed this "Environmental Statement" with Dave Harward, EPA, and he indicated that they felt it to be inadequate even though better than some they have received. He further noted that the estimate of 30 mrem/yr at the site boundary would be considered unacceptable for a reactor site. Without any data relating to the basis for this dose rate from neutron and muons and its fall off with distance or the area involved there may be a valid reason to hold this opinion. At the same time one should realize that by-product and x-ray facilities are generally accepted when it is shown that the dose at the site boundary does not exceed 500 mrem/yr.

4. This "Environmental Statement" was also referred to BCEM and has been discussed with Francis Jacocks. Mr. Jacocks stated that based on the statements made, the site and facility were acceptable from a community planning and management viewpoint. Again it was noted that insufficient data was presented to evaluate and assess the facility. Mr. Jacocks suggested that we respond directly (without a sign-off by BCEM) noting that they found the facility acceptable based on the statements made by the AEC.

Gail D. Schmidt
Chief, Radioactive Materials Branch
Division of Medical Radiation Exposure

cc: Mr. Gundaker
Mr. Jacocks

UNITED STATES
ATOMIC ENERGY COMMISSION
WASHINGTON, D.C. 20545

DEC 30 1971

Mr. Thomas E. Carroll
Assistant Administrator for
Planning and Management
Environmental Protection Agency
Washington, D. C. 20460

Dear Mr. Carroll:

This is in response to your letter of April 7, 1971, regarding the Draft Environmental Statement for the National Accelerator Laboratory (NAL), Batavia, Illinois. Your comments pertained primarily to expected radiation levels and control, and the handling of sewage wastes. In the past couple of months, the Environmental Statement has been revised and strengthened primarily in the Physical Impact - Part IVA. Copies of the final environmental statement are enclosed. In addition, the assumptions and calculations supporting the conclusions in the Statement have been formalized in TM-306, entitled, "NAL Off-Site Dose-Equivalent Rates Due to Accelerator-Caused Radiation," dated May 25, 1971; and TM-292-A, entitled, "Calculation of the Radionuclide Production in the Surroundings of the NAL Neutrino Laboratory," dated March 11, 1971. These documents are also enclosed.

It is noted that discussions are still underway with the City of Batavia for possible use of the City's sewage treatment plant, however, at this time an agreement has not been reached and we therefore must indicate alternate methods for handling of this waste.

Thank you for your review and comments.

Sincerely,

John A. Erlewine

John A. Erlewine
Assistant General Manager
for Operations

Enclosures:
1. Final Environmental Statement - NAL (7 cys)
2. Report TM-306
3. Report TM-292-A

ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

APR 7 1971

OFFICE OF THE ADMINISTRATOR

Mr. John A. Erlewine
Assistant General Manager
for Operations
U.S. Atomic Energy Commission
Washington, D. C. 20545

Dear Mr. Erlewine:

Thank you for your letter of February 2, 1971, requesting comments on the Draft Environmental Statement for the National Accelerator Laboratory to be located at Batavia, Illinois. The enclosed report constitutes a summary of the technical comments developed by the various operating offices of the Environmental Protection Agency.

We are of the opinion that the facility, as proposed, can be operated safely from an environmental point of view. It is quite important, however, to take all steps possible to minimize the radiation dose to the population from the secondary radiation produced when the accelerator is being operated. In this regard, it is essential to control movement of personnel onto the site exclusion area when the accelerator is being operated. It is also extremely important to have an off-site monitoring program to confirm that the facility is operating as anticipated and to insure that the general public is not being unduly exposed to radiation originating at the site. The control over the site boundary and the area within along with the details of the off-site environmental surveillance program should be included in the final environmental statement. The Atomic Energy Commission should make available at frequent intervals the results of this surveillance program so that a continuing evaluation can be made that population doses are at the lowest practicable levels from operating the facility.

We would be pleased to discuss any of our comments on the National Accelerator Laboratory. If we can assist you further in this matter, we will be happy to do so.

Sincerely yours,

Thomas E. Carroll

Assistant Administrator
for Planning and Management

Enclosure

ENVIRONMENTAL IMPACT REVIEW

NATIONAL ACCELERATOR LABORATORY

BATAVIA, ILLINOIS

Coordinated By
Radiation Office
ENVIRONMENTAL PROTECTION AGENCY
5600 Fisher's Lane
Rockville, Maryland 20852

March 1971

PREFACE

This report is one of a series designed to summarize the results of evaluations by the Environmental Protection Agency of the radiological effects of nuclear facilities on the environment. The evaluation is based on a detailed technical review of the "Draft Detailed Statement on Environmental Considerations" submitted by the Atomic Energy Commission pursuant to the requirements of the National Environmental Policy Act of 1969. The reviews are coordinated with the operating offices of the Environmental Protection Agency by the Division of Technology Assessment, Radiation Office. The Water Quality Office has the major role in developing comments on water quality; comments by other offices are included as appropriate for specific problem areas. As part of this review process, several technical documents have been developed and referenced to support the discussions presented.

The evaluation presented in this report is directly responsive to the requirements placed on Federal agencies by the National Environmental Policy Act and as such is intended to state the position of the Environmental Protection Agency on the environmental effects of carrying out the various nuclear activities. The report is also intended to provide information to the State involved for its use in developing and conducting environmental programs for the particular nuclear activity.

INTRODUCTION AND CONCLUSIONS

The purpose of this report is to summarize the results of an evaluation by the Environmental Protection Agency of the potential environmental effects of the National Acceleratory Laboratory (NAL) to be located at Batavia, Illinois. The laboratory is to be located on a tract of 6,800 acres approximately 30 miles west of the center of the city of Chicago and 15 miles northwest of the Argonne National Laboratory. The main research facility at the laboratory will be a 200 GeV proton synchrotron, with possible extensions to 500 GeV, which will be fed by a linear accelerator and booster synchrotron. The accelerator will be constructed underground in a circular ring about 4 miles in circumference.

The Atomic Energy Commission will operate the proposed facility and has submitted a draft environmental statement(1) which discusses the potential environmental impact. This review is based on this statement and has considered primarily radiological effects on the nearby environment and population. The principal conclusions are:

1) The draft environmental statement should include a presentation of the following: a) the control over the site boundary and exclusion areas within, b) the radionuclide inventory and discussion of operating procedures of the cooling water system, c) the method and assumptions used to determine the site boundary dose, and d) potential off-site radiation emergencies associated with the operation of the facility.

2) It appears that the facility can be operated such that public radiation exposures will be within the guidance of the Federal Radiation Council; however, consideration should be given to practicable means of reducing the dose in the public environs of the NAL either by additional shielding or extension of the restricted area.

3) Possible contamination of ground water could occur from percolation to the aquifers of sodium-22 produced by activation of soil by secondary radiation. The assumptions concerning the rates of production and percolation of radionuclides to the aquifer should be discussed relative to estimated radionuclide concentrations in domestic water supplies.

4) Environmental surveillance for the site should be established to monitor radiation levels in the environment especially for underground water supplies and external radiation doses outside the restricted area.

5) The probable volume and composition of sewage wastes as well as the ultimate disposal methods and sites to be used by the contractor should be indicated. Since the nearby Batavia treatment plant meets water quality standards and has additional capacity available, the Atomic Energy Commission is encouraged to utilize this facility.

6) If the considerations discussed here are carried out, we are of the opinion that the National Accelerator Laboratory can be built

and operated such that the environmental impact would be acceptable. The recommendations are, in our judgment, both prudent and reasonable in minimizing risk to the public.

SITE CONSIDERATIONS

It appears that the main public risk will be associated with secondary radiation produced when the accelerator is being operated. Secondary radiation refers to all radiation resulting from the interaction of the primary beam with matter other than the radiation from induced radioactivity. In this regard it was indicated that a private guard service will be employed at the site to control movement of personnel onto the site when tests are being conducted. It is extremely important for these control measures to be sufficient to enforce the site boundary and exclusion areas in order to protect the public from radiation. Detailed information should be provided describing access controls to the area and the distance of exclusion area fences from all critical portions of the facility from the standpoint of radiological protection of off-site areas.

The accelerator will use a cooling water system which is made up of three or four shallow basins on site to retain and cool the water. Radionuclide composition and activity levels of the cooling water in the basins should be presented along with the possible environmental effects since it was stated that the basins will be used as a natural preserve for fish and wildlife. Operational procedures for the cooling water system should also be discussed to verify that the cooling water is in a completely closed system and that the water in the basins will not mix with water outside the exclusion area before appropriate treatment to remove radioactive materials.

Expected radioactive waste discharges from the NAL ventilation systems should also be discussed in the final environmental statement. Radioactive materials which are powdered and those that tend to flake should be handled in hoods in which adequate ventilation is provided. The hood ventilation system should exhaust outside the building and include a high efficiency particulate air filter to limit radioactive airborne particulate emissions. There is also the possibility in the operation of an accelerator that gaseous and airborne particulate activity will be produced as the result of activation of air in rooms or cavities surrounding the target area. If this is to be potential source of radioactive waste, high efficiency particulate air filters should be provided to reduce discharges to the environment.

The draft environmental statement[1] indicates that waste from the industrial water treatment facility, solid wastes from the sewage treatment facility, and other sources will be disposed of by a contracted service in accordance with applicable Federal, State and local standards. The probable volume and composition of these wastes, as well as the ultimate disposal methods and sites to be used by the contractor should be indicated.

It is also indicated that sewage treatment will be accomplished by either a "full sewage-treatment plant" constructed on the site or by the City of Batavia treatment plant with either of these alternatives fully meeting Federal and State standards.[1] Additional information should be included regarding sewage treatment processes to be provided and a discussion of plans to be followed until waste treatment arrangements are completed. Since the nearby Batavia sewage treatment plant meets water quality standards and has additional capacity available, the Atomic Energy Commission is encouraged to utilize this facility.

ENVIRONMENTAL IMPACT

In our opinion, the most significant off-site radiological effect of the operation of the accelerator will be the population dose that results. It is stated that the external dose due to the operation of the accelerator will be kept below 170 mrem/yr, which is the standard for population groups in uncontrolled areas as expressed in chapter 0524 of the Atomic Energy Commission Manual.[2] The analysis of beam energies, and operating conditions led to the conclusion that "cumulative dose levels are expected to be less than 10 mrem/yr at the major fraction of the site perimeter and correspondingly less than 30 mrem/yr at the northeast corner."[1] Information is needed on the method of making these dose estimations; especially on the energy distribution and intensity of the neutron beam, the quality factors used, the accelerator "down time," and the dose as a function of distance from the multiple target stations. The dose estimates should also include contributions from bremsstrahlung. Even though the bremsstrahlung associated with a 100 GeV proton is approximately equivalent to that of a 30 KeV electron, it is conceivable that other bremsstrahlung which is more intense and energetic could originate from the interaction of the "shower" produced by the impact of the proton beam in the target area.

Even though these population dose estimates are less than the Federal Radiation Council's Radiation Guide of 170 mrems/yr for a suitable sample of the exposed population, their potential magnitude is sufficently high that every reasonable consideration of additional actions should be taken to keep them as low as practicable. Additional shielding and/or extension of the exclusion radius could be employed in order to reduce the maximum off-site doses well below the expected dose of 30 mrem/yr.

It is indicated that ^{22}Na will be produced as a result of soil activation by secondary radiation, and that through percolation, significant ground water concentrations could result. Estimates have been made of the maximum amount of radioactivity that could be produced, that could escape the drainage system, and that could migrate downward to the aquifer. The assumptions made in calculating the radioactivity produced and its migration rate were not presented in the draft environmental statement.(1) Levels of radionuclide production in the soil and assumptions concerning the percolation of radionuclides to the aquifer should be presented in the final environmental statement so that an independent estimate of radionuclide concentrations in domestic water supplies can be made.

ENVIRONMENTAL SURVEILLANCE

An environmental surveillance program is essential to confirm that the facility is operating as anticipated and to insure that the general public is not being unduly exposed to radiation originating at the site. Adequate surveillance should be done by the Atomic Energy Commission and the Illinois Department of Public Health to insure that there is no encroachment of radioactivity into drinking water supplies or other critical environmental pathways to man. Local wells should be sampled periodically, especially for sodium-22, to ensure that this potential pathway is not being contaminat d as a result of operating the facility.

The Radiation Physics Section of the Laborat ry will monitor the site boundaries continuously to ensure that the minimum radiation levels are maintained. In this regard, we recommend that integrating dosimeters changed at appropriate intervals be utilized. Besides the expected neutron and muon radiation at the site boundary there may be significant levels of gaseous radioactivity discharged into the atmosphere through the ventilation system and the vacuum pumps. The exhaust from the ventilation systems and vacuum pumps should be monitored at the points of discharge and off-site air samples taken and analyzed until it is shown that the potential environmental effect from these sources will not be significant. Shielding surveys should be performed periodically to determine if the escaping neutron flux is within acceptable limits and to determine the structural integrity of the shielding material. The final environmental statement should indicate that such procedures will be followed to provide maximum protection of the public.

REFERENCES

1. United States Atomic Energy Commission "Draft Environmental Statement for the National Accellerator Laboratory - Bativa, Illinois"- January 1971.

2. United States Atomic Energy Commission, "Standards for Radiation Protection," Atomic Energy Commission Manual, Atomic Energy Law Reports, Chapter 0524, pp. 12,024a - 12,026, Washington, D.C.

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