DOE/EA-1267

ENVIRONMENTAL ASSESSMENT
for the
PROPOSED
8 GeV FIXED TARGET FACILITY
at the
FERMILAB BOOSTER
and for the
BOOSTER NEUTRINO DETECTORS

March 26, 1999

http://tis.eh.doe.gov/nepa/
http://www-boone.fnal.gov/

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1 PURPOSE AND NEED

1.1 Introduction

The U.S. Department of Energy (DOE) proposes to build a high intensity, 8 GeV Fixed-Target Facility and associated detectors at the Fermi National Accelerator Laboratory (Fermilab). Fermilab is a federal high-energy physics research laboratory in Batavia, Illinois operated on behalf of the DOE by Universities Research Association, Inc., a consortium of 87 research universities.

Fermilab is located 38 miles (61 kilometers) west of downtown Chicago, Illinois. Its 6800 acres (2750 hectares) straddle the boundary between eastern Kane and western DuPage counties in an area of mixed residential, commercial, and agricultural land use. Immediately to the east is the town of Warrenville (11,220 population), to the west is Batavia (17,076 population), to the north is West Chicago (14,796 population), and to the south is Aurora (99,581 population). Fig. 1 shows the location of Fermilab in the greater Chicago area. Fermilab has approximately 1900 employees, and 1400 experimenters from all over the world working at the Laboratory. On an annual basis, the Laboratory typically has approximately 50,000 day visitors who visit Wilson Hall to attend cultural activities, to take self-guided tours, to participate in activities at Fermilab's science education center, and to conduct business with the Laboratory. The closest residences to the proposed action are approximately 1.6 km (one mile) from the proposed site.

The 8 GeV Fixed Target Facility and associated detectors (Detector 1 and Detector 2) are shown schematically in Figs. 2, 3. The 8 GeV Fixed Target Facility will be a general purpose facility built to carry out a variety of particle physics and accelerator physics experiments. The first experiment that would be done at this facility will be the Booster Neutrino Experiment (BooNE) [1], which would use Detector 1. Construction for the 8 GeV Fixed Target Facility and Detector 1 would be begin in FY00, or as soon as funding will become available. Detector 2 would be built at a later time, depending on the result of the measurements carried out with Detector 1.

This Environmental Assessment documents DOE's evaluation of potential environmental impacts associated with the construction, operation and eventual decommissioning of this proposed action, as described in Section 2. Future uses of the facilities built as a result of this proposed action, not covered in the scope of this Assessment, would require the administrative approval of the Director of Fermilab and would undergo an appropriate level NEPA review.

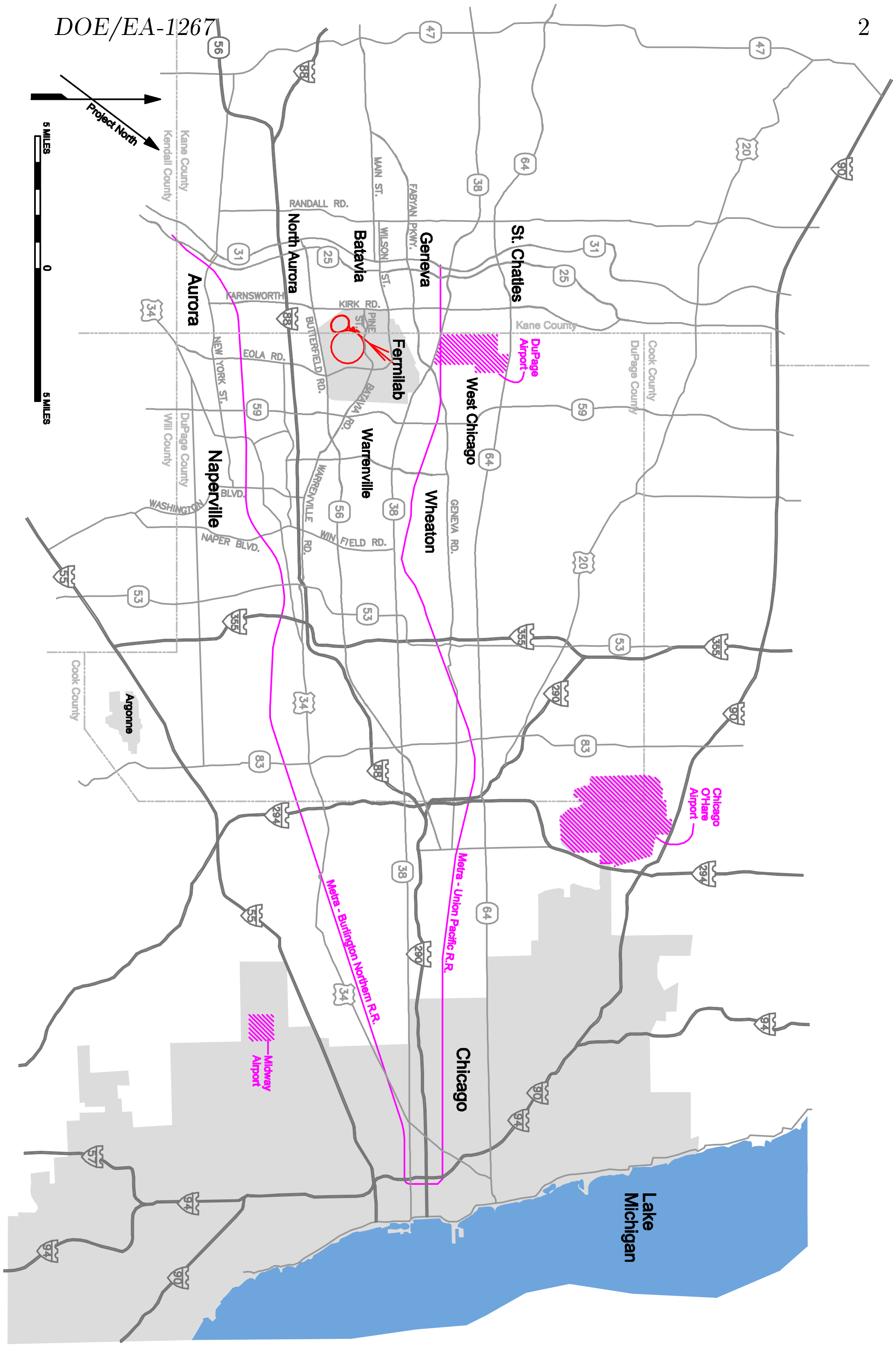

Figure 1: Map of the Chicago area showing Fermilab and its proximity to local communities.

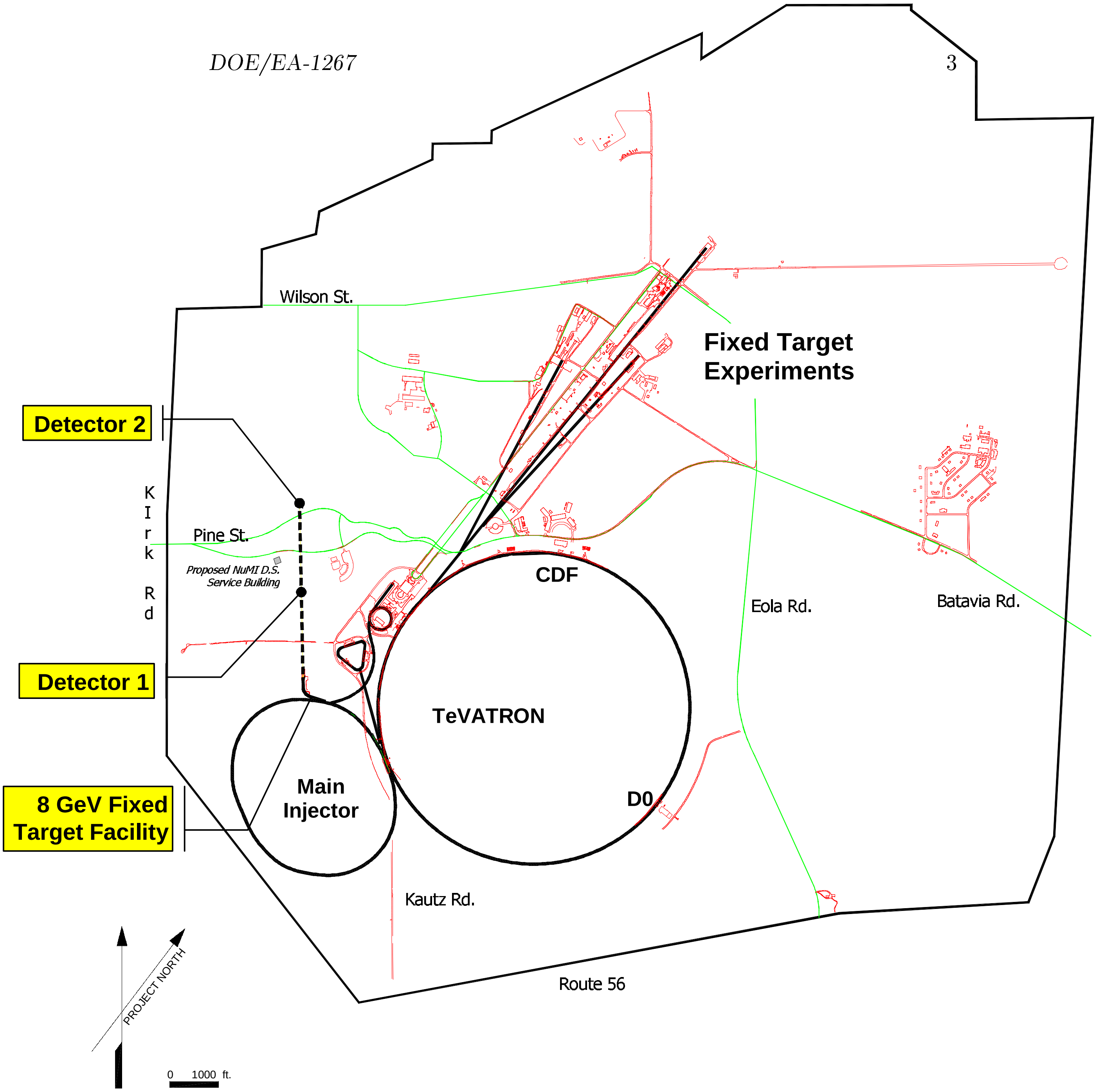

Figure 2: A schematic representation of the site showing the main features of the site relative to the proposed 8 GeV Fixed Target Facility and the associated detectors.

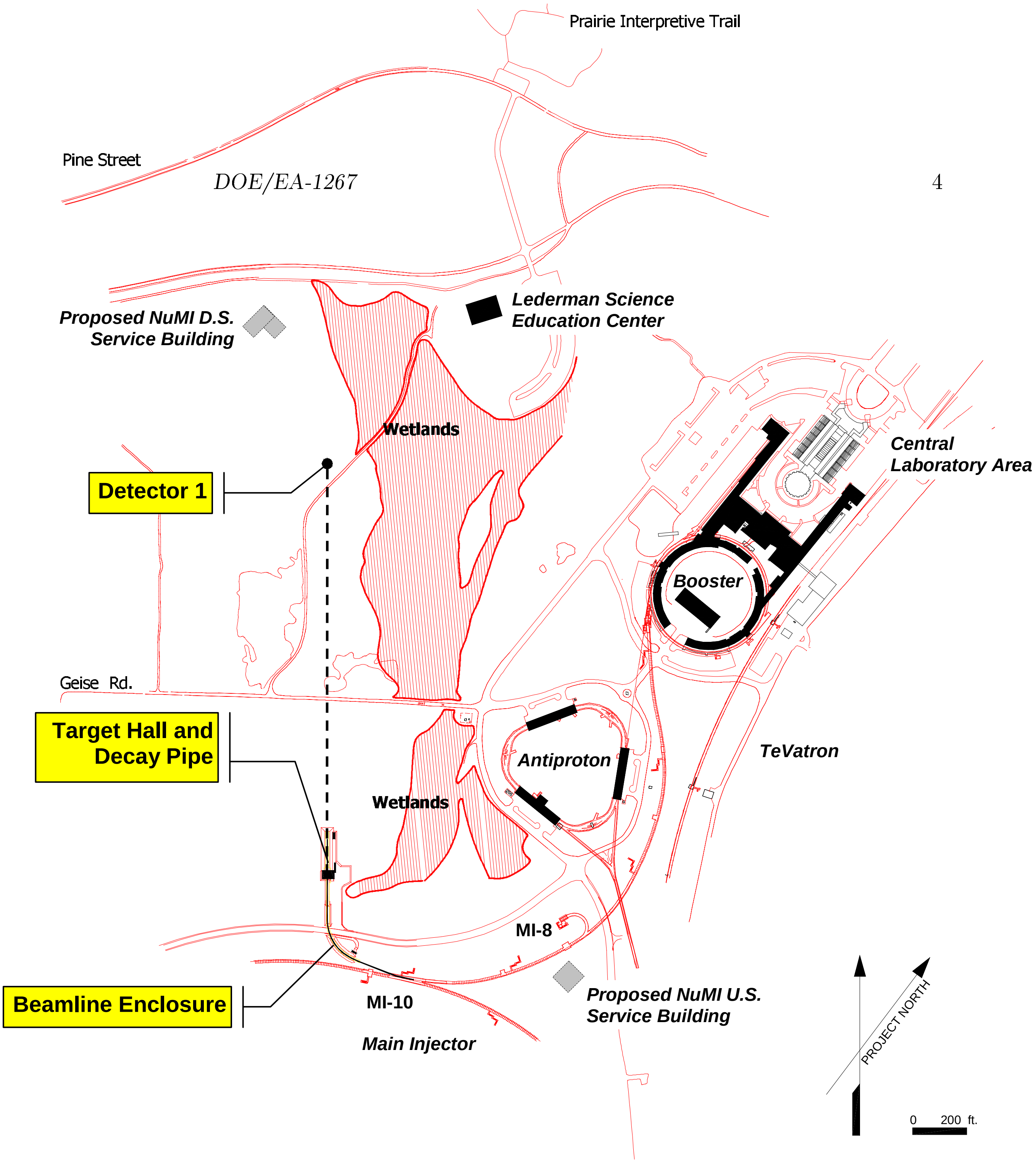

Figure 3: A schematic view of the 8 GeV Fixed Target Facility and associated detectors. The Target Hall, Decay Pipe and Beamline Enclosure are part of the 8 GeV Fixed Target Facility. See Fig. 4 for more detail.

1.2 Background Information

The proposed action would use the existing Fermilab Booster accelerator to explore an important issue in High Energy Physics, known as neutrino oscillations. BooNE[1] collaborators would build a detector to explore this physics issue.

1.2.1 The Fermilab Booster

The Fermilab Booster (See Fig. 3.) operates as a source of protons for the High Energy Physics program. It is a 15 Hz rapid cycling machine capable of delivering nearly 5×10^{12} protons per cycle at an energy of 8 GeV. [2] It has operated successfully and reliably to support the Fermilab program, since the early 1970's.

The current Fermilab program does not use all of the available Booster cycles – only the cycles extracted for experiments are filled with beam. The cycles not used by the existing program are available to support new high energy physics needs such as BooNE.

1.2.2 Neutrino Oscillations

In the Standard Model of elementary particle physics there are three types, or "families" of particles that do not interact strongly with matter. Collectively, they are called leptons. Each family is composed of a lepton having electric charge, and an associated neutrino. The three electrically charged leptons are: electrons, which are one of the building blocks of ordinary matter; muons, which are a major component of the cosmic rays; and taus, which so far have been observed only in experiments at high energy physics laboratories. The associated neutrinos are called electron neutrino, muon neutrino, and tau neutrino. To date, the electron neutrino and the muon neutrino have been observed in connection with electrons and muons, respectively. The tau neutrino has yet to be directly observed. Neutrinos have not been observed to change from one family to another. Such "oscillations" would imply that neutrinos, originally assumed to be without mass, have mass. There are compelling hints from both theoretical studies and experimental data that such

[1] Physicists from five or more American universities and three National Laboratories will collaborate to make the measurements associated with the experiment.

[2] To take advantage of the full machine capability, an upgrade to some of the magnets and power supplies is required. The BooNE proposal[1] includes an estimate of $728K for this upgrade.

family-changing, or oscillations, could be an explanation for several scientific puzzles. In particular, an observation of neutrino oscillations was made by the Liquid Scintillator Neutrino Detector (LSND) collaboration [2] carried out at the Los Alamos National Laboratory (LANL).

1.3 The Purpose and Need of the Proposed Action

The purpose of the 8 GeV Fixed Target Facility would be to utilize the high intensity, low energy proton beam to produce various subatomic particles for High Energy Physics experiments. The first experiment that would be done would be the Booster Neutrino Experiment (BooNE). The goal of the experiment would be to make a definitive measurement of the LSND neutrino oscillation signal.

2 PROPOSED ACTION and ALTERNATIVES

This proposed action provides for the construction, operation and eventual decommissioning of underground enclosures and an above ground service building that would be used for high-intensity, 8 GeV fixed target experiments, and the construction of associated detectors for BooNE.

2.1 Description of the Preferred Alternative

2.1.1 The 8 GeV Fixed Target Facility

The scope of the proposed 8 GeV Fixed Target Facility includes the following elements: (See Fig. 4.)

- Civil engineering design, construction, and installation of a buried beampipe, several underground enclosures, and an above ground service building.

- Technical design, fabrication and installation of the beamline components necessary for transporting a primary beam and producing a secondary beam.

The area between the Target Hall and the associated detectors would have only construction for a shallow buried PVC pipe that would be directed around any wetland area.

The proposed action would create a switch in the Main Injector Tunnel to deflect the primary beam outward. The construction would begin at the point where the beam exits the Main Injector Tunnel. There the beam would enter an evacuated buried beam pipe. The buried pipe would extend for about 40 meters (130 feet) and travel underneath the MI-10 Service Building. The pipe would be installed by using directional drilling techniques under the MI-10 Service Building.

Beyond the buried pipe there would be a Beamline Enclosure, having an arc about 200 meters (660 feet) long. It would cross under the Main Injector Road and under the East Branch of Indian Creek. The Beamline Enclosure would contain a series of magnets to bend the beam away from the Main Injector Tunnel by approximately 95 degrees. A straight section would be included in the arc to allow for future switching of adjacent primary beams on either side of the central beamline that could be used for BooNE. Low conductivity water (LCW) would be used as the primary cooling medium for the magnets in the Beamline Enclosure, by the Target in the Target Hall, and by the beam absorber in the Decay Pipe. LCW would be made available via existing equipment at MI-10. The cooling system for the magnets in this enclosure would contain about 3000 liters (780 gallons) of LCW. Power supplies for the magnets would be housed at MI-10 and powered by a new 750 KVA transformer that would replace an existing 500 KVA transformer. Permanently disturbed land would amount to approximately one hectare (2.5 acres), including roads, hardstands, and parking lots. The power required by the 8 GeV Fixed Target Facility, needed mainly to power the magnets in the Beamline Enclosure, would be 1.5 Mw.

In Fig. 4 are shown also the two branches of Indian Creek affected by the construction area. The West Branch would be permanently diverted to the west by as many as 18 meters (60 feet) at the northern most point of construction. The East Branch would be temporarily diverted approximately 6 meters (20 feet) to the north at the point where the creek crosses over the Beamline Enclosure, and would be allowed to flow at about 90° into the West Branch. The construction of the Beamline Enclosure would take place in two phases: The part of the tunnel that lies south of the East Branch of Indian Creek would be completed first, including the installation of a culvert. The creek would then be diverted back through the culvert, and the remaining portion of construction completed.

The northern most end of the Beamline Enclosure would be connected to the Target Hall. (See Fig. 5.) The Target Hall houses a target and the interaction of the proton beam with the target would produce secondary particles, which would be focused by a series of magnetic devices into the Decay Pipe. Some of the particles would decay into neutrinos over the length

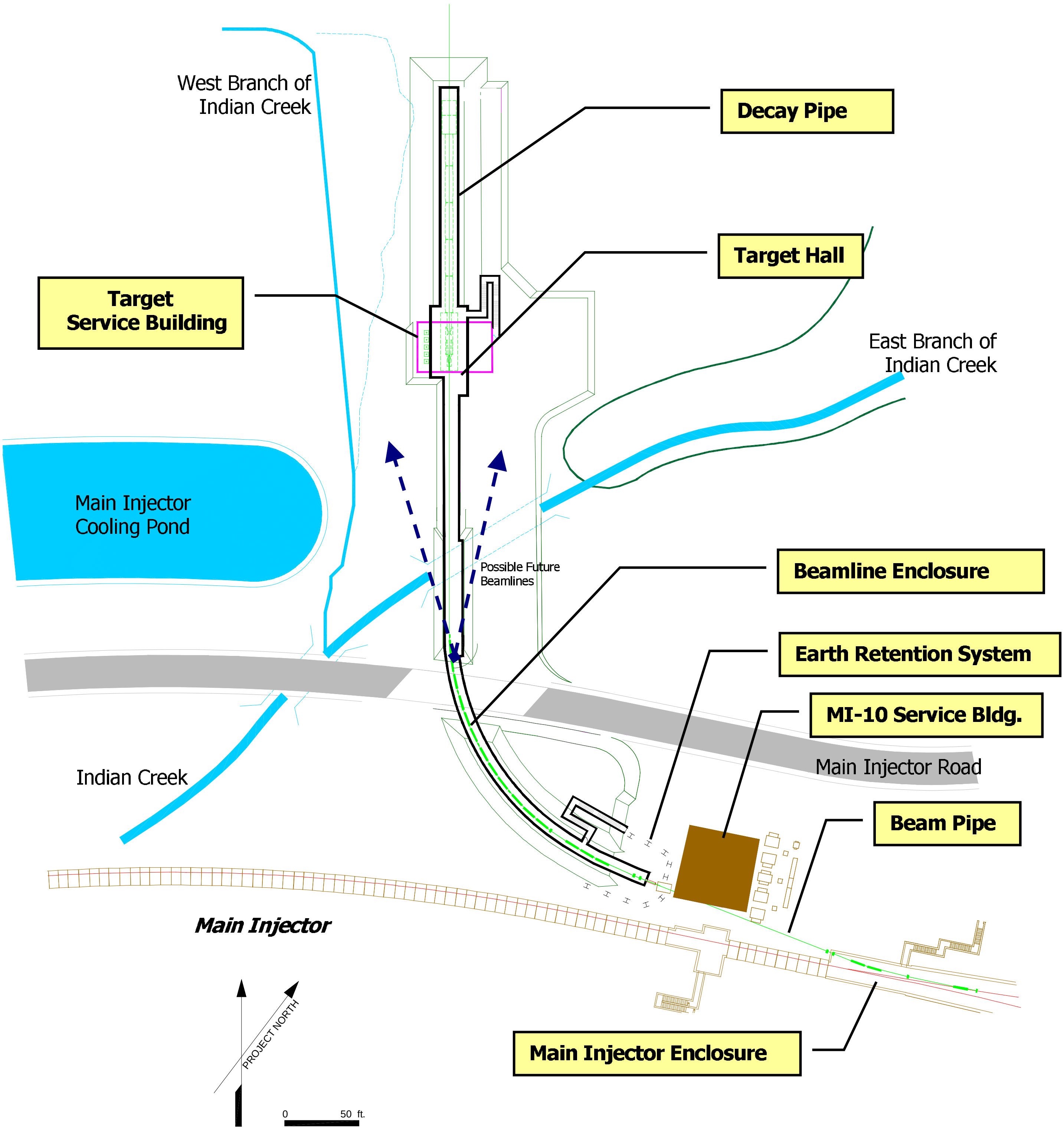

Figure 4: Schematic layout of the proposed 8 GeV Fixed Target Facility, including Beamline Enclosure, Target Hall, Target Service Building and decay pipe showing a plan view of the structures. A cross-section of the Target Hall and Target Service Building is shown in Fig. 5.

of the Decay Pipe, of about 50 meters (165 feet). The neutrinos travel to Detector 1, which would be located 500 meters (1640 feet) downstream from the target. The Target Hall would also contain a "hot storage" area for highly radioactive elements that might be produced by interaction with the beam in the Target Hall.

A steel sided metal frame service building would be located on the surface, and would be heated and ventilated. It would provide services, such as power supplies, energy storage (capacitors), computer control and monitoring, and limited crane coverage for the Target Hall. A 20 ton bridge crane would be positioned over a shield hatch and would be used for equipment handling and servicing of the components in the Target Hall.

Further north of the Target Hall would be a Decay Pipe, where the particles would travel through a set of plastic containers or pipes, about 2.0 meters (6.5 feet) in diameter. At the end of the pipe 50 meters (164 feet) north of the target, and at a point 25 meters (82 feet) north of the target, provision will be made to place a steel absorber to stop all the protons and secondary particles. The neutrinos created between the target and the absorber would continue to travel through the earth to Detector 1.

Also included is the construction of a gravel road from Main Injector Road to the Target Hall, a hardstand at the Target Hall, and a culvert for Indian Creek. Personnel exits would be located within 15 meters (50 feet) of the south end of the Beamline Enclosure, a second near the end of the Target Hall. Communication lines would be installed between MI-10, the Beamline Enclosure, and the Target Hall, extending through a 2.5 cm (one inch) PVC pipe to the detectors.

The relative overall size of the structures and the Detectors is given in Table 1.

The volume of excavation involved would be about 23,000 m^3 (30,000 yd^3). The areas are entirely within the Fermilab site. Soils excavated in preparation for construction would be used as fill, or overburden for the completed construction. Excess soil from excavation is expected to be small, and would be moved by truck to an existing Fermilab stockpile.

Monitoring sumps would be installed in the vicinity of the Target Hall and decay pipe to monitor the concentrations of radionuclides in the groundwater. (See 4.2.3.)

The target and beam absorber for the 8 GeV Fixed Target Area would be cooled by a circulating closed-loop water system similar to existing Fermilab target stations. The cooling system volumes are approximately 200 liters (50 gallons). The closed-loop cooling system for the 8 GeV Fixed Target Area

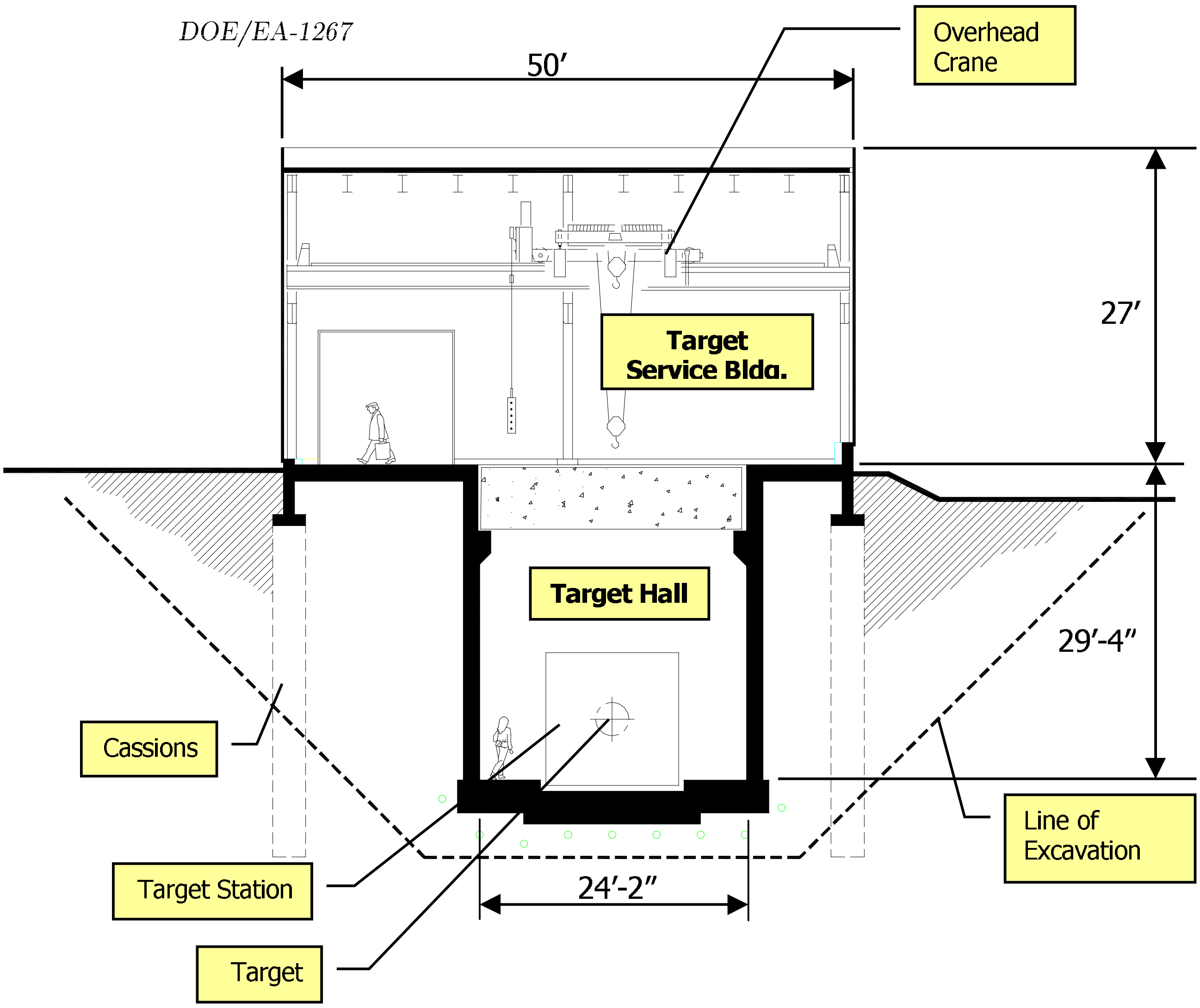

Figure 5: A cross-sectional view of the Target Hall and above ground Service Building.

Table 1: Listing of Structures that would be Constructed as Part of the Proposed Action on the Fermilab Site (along with their Approximate Volumes and Dimensions)

Structure	Approximate Dimensions (meters)	Approximate Volume (cubic meters)
Beam Pipe from MI Enclosure to start of Beamline Enclosure.	0.5 diameter X 40	10
Beamline Enclosure to Target Hall	2 X 2.75 X 130	700
Target Service Building	15 X 10 X 8	1200
Target Hall	12 X 9 X 7	760
Decay Pipe	2.0 diameter X 47	300
BooNE Detector 1 or Detector 2	12 diameter	900

would be similar. A steel shield (Target Station), having a cross section about 4 meters (12 feet) by 4 meters (12 feet) would surround the target and collecting elements. The shield would protect the groundwater from radiation when the beam is operating, and would protect personnel from residual radiation after the beam was turned off. The elements within the steel shield would have a separate closed loop cooling system, commonly referred to as a RAW (radioactive water) system. It would contain approximately 200 liters (50 gallons) of water. The steel absorber would have its own water cooling system.

2.1.2 The BooNE Detectors

In order to maximize the event rate [3], the detector must be massive because neutrinos interact very weakly with matter. The associated detector for BooNE, shown schematically in Fig. 6, would include civil engineering design and construction of a 12 meters (40 foot) diameter tank, filled with mineral oil, and housed in a cylindrical underground enclosure. The enclosure is covered with an earth berm for shielding from cosmic rays. The tank would be located at approximately 450 meters North of the 8 GeV Fixed Target

[3] The event rate is the number of neutrino interactions observed in the detector per minute. For BooNE, an event or interaction is observed approximately every 10 seconds of operating time. The experiment would operate for about 2×10^7 seconds per year yielding about two million events.

Facility. Permanently disturbed land would amount to approximately 0.2 hectares (0.5 acres), including roads, hardstands, and parking lots.

The top of the detector sphere would be near grade level. It would be lined with an array of about 1500 phototubes whose signal cables exit at the top of the sphere. An access tunnel would connect the top of the vessel to an enclosure within the berm that covers the detector. (See Fig. 7.) The electronics would be housed in this enclosure. After assembly, the vessel would be filled with about 775 tons (238,000 gallons) of mineral oil which may remain stored there for an extended period of five to ten years. Mineral oil is a petroleum product of slight flammability and low health hazard. A small amount of Butyl PBD may be added to the oil. (See Appendix A.)

This amount of mineral oil represents about 15 rail tanker cars. If the mineral oil is shipped from the refinery by rail to the Fermilab railhead via tanker cars the oil would be transferred from the tanker cars to semi-trailer trucks. It would take about four truckloads to empty one rail car, making a total number of truck trips about 60. The process of filling the detector with mineral oil would be dominated by the time it takes to pump from the rail car to the truck, and then from the truck to the detector. It is expected that there would be about two truck trips per day. Transport would be done in compliance with the Fermilab Environmental Health and Safety Manual [18]. The road leading to the detector would be constructed to carry heavy loads to accommodate trucks as well as those transporting gravel, concrete, steel, semi-tankers of mineral oil, mobile cranes, etc. However, the oil may be shipped directly to the BooNE site by truck. This would require about the same number of truckloads, but would avoid the need to handle the oil at the railhead.

The Detector tank would be subject to control measures to assure that the environment would be protected. The enclosure in which the detector would reside would be constructed to provide secondary containment in the event of a spill or a leak. The following precautions would be met.

1. The tank would be made of steel using new materials that are in accordance with the requirements of API (American Petroleum Institute) 620. The design of the tank and ports shall be based on the applicable rules contained in API 620 and NFPA (National Fire Protection Association) 30.

2. There would be a leak-test of the tank before filling with oil. This would consist of either a water-fill or gas-overpressure test.

3. The tank walls will be of substantial thickness for structural rigidity and will not be in contact with groundwater. There is no chance of corrosion causing a leak in the tank.

4. The level of the oil inside the tank would be monitored constantly to within a few millimeters allowing quick leak detection.

5. If the oil is shipped by tanker cars, a detailed spill plan would be drawn up and approved by the necessary authorities. This would include spills that might occur in the transport of oil from the railhead to the tank, and spills associated with filling and removing oil from tanker cars or the tank. In general, spills would be avoided, and if they occur, would be remedied immediately.

A second nearly identical detector might be built, if results of measurements in the first tank are positive. Based upon best current estimates, the second detector, Detector 2, would be placed at a distance of 1,000 meters (3,300 feet) from the target. However, other locations at 250 meters (820 feet) and 2,000 meters (6,600 feet) are also possible.

2.1.3 Construction Schedule: 8 GeV Fixed Target Facility

The construction site for the 8 GeV Fixed Target Facility would be approximately 300 meters (985 feet) long, 20 meters (66 feet) wide at the surface, and 7 meters (23 feet) deep. The schedule would have a preparation and mobilization phase which would last approximately two months. During this time, survey monuments would be established, stockpile areas would be marked and erosion control would be put in place. None of these activities would have any effect on the normal operation of the Laboratory.

Clearing the surface area of brush, relocating the creek crossing, and the underground construction near the accelerator complex would be done in the next phase with the FMI not operating. This is the only portion of the proposed action that would affect normal Laboratory operation. This would last approximately three months. Open cut construction would be used throughout, except near MI-10 where an earth retention system would be installed to protect the building and adjacent Main Injector Enclosure. The earth retention system would use steel H beams to form vertical walls just north and west of the MI-10 service building. (See Fig. 4.) From within the area formed by the earth retention system, "directional drilling" equipment would be set up to bore a hole 0.67 meters (24 inches) in diameter by 40 meters (125 feet) long, under the MI-10 service building into the Main Injector Tunnel.

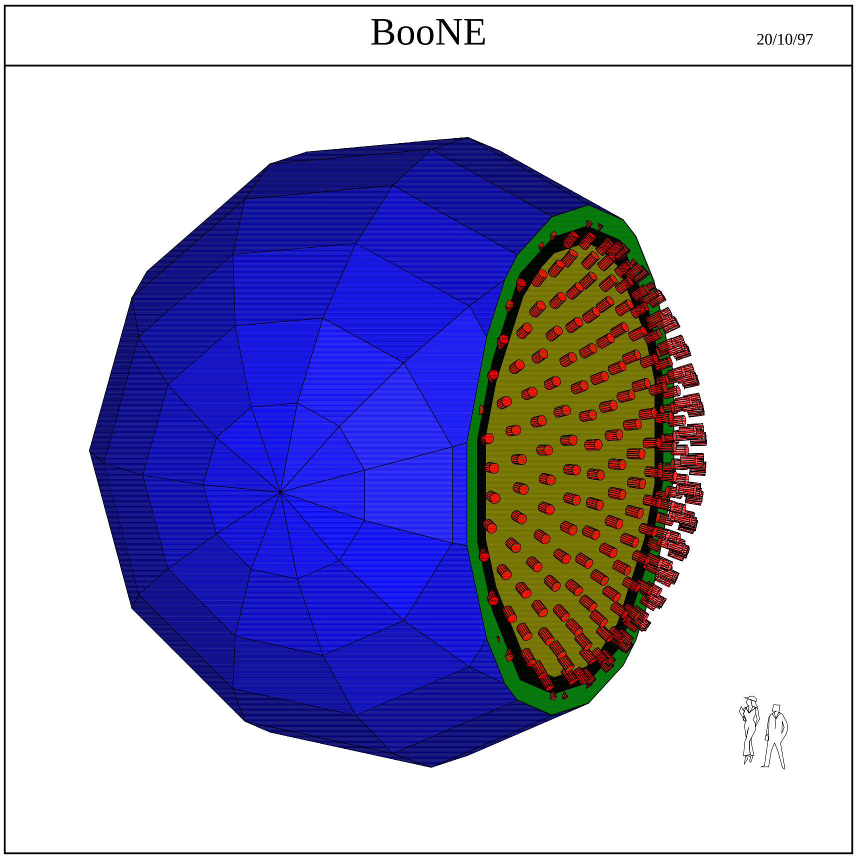

Figure 6: A computer generated schematic of the proposed detector.

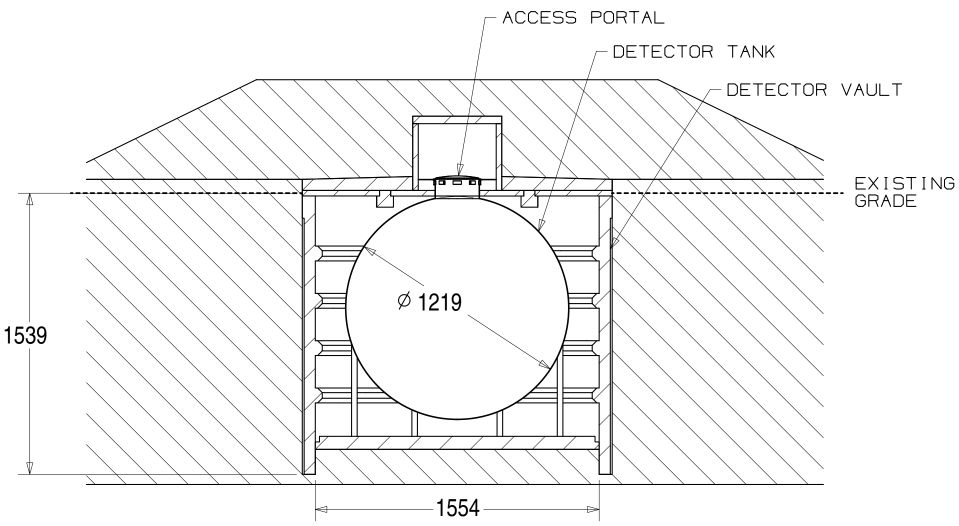

Figure 7: Cross-sectional view of the BooNE detector. Dimensions are in centimeters.

The construction of the remainder of the Beamline Enclosure, and the Target Hall, decay pipe, and Service Building would be the next phase and could be accomplished after the FMI resumes operation. The approximate time for this phase would be eleven months. The Beamline Enclosure would be constructed with inverted "U" shaped precast concrete sections placed on a cast-in-place concrete base slab. Steel shielding might be required over the top of the enclosure at the MI-10 hardstand and where it would cross under the Main Injector Road. (Steel is more effective shielding, because it has higher density than earth or concrete.) In addition, construction at the road must accommodate existing power and communication duct banks, industrial cold water (ICW) piping and pond water piping.

The 8 GeV Fixed target area could be available for operation early in FY01.

2.1.4 Construction Schedule: The BooNE Detector 1

The construction of the BooNE detector would require a depth of approximately 18 meters (60 feet) and an area of 30 meters (100 feet) by 60 meters (200 feet). The schedule would also have a preparation and mobilization phase to prepare survey monuments, stockpile areas, and establish erosion control procedures. The detector construction can be done at any time, since it would not affect normal laboratory operations.

Because the BooNE detector would be located 450 meters (1475 feet) beyond the end of the decay pipe, the construction of the spherical containment vessel would be a separate project, completely independent of construction of the 8 GeV Fixed Target Facility. Excavation to a depth of about 18 meters (60 feet), construction of the detector enclosure, the installation of the containment vessel, and backfilling to grade level would take about four months. During the next three months the surface structures would be completed. The 1200 phototubes and their cables would be installed over the next three months, to be followed by testing and commissioning for the next three months. Filling the vessel with oil would take about one month.

If funding permits and the EA and FONSI are approved, the Detector would be ready for operation in FY01.

2.1.5 Operation

Operation of the 8 GeV Fixed Target Facility and Detector 1 at Fermilab would comply with standard Fermilab safety and beam operations procedures and guidelines [21]. These procedures are based on the principles of ALARA – achieving conditions that correspond to radiation levels and exposures as low as reasonably achievable in the implementation of radiation protection. A Safety Assessment Document including a hazards analysis would be written and approved before commencement of operations of the beamline.

The beam intensity would be maintained within normal operating levels approved by the Laboratory Director in accordance with the Fermilab Radiological Control Manual. Normal operation of the primary proton beam would be approximately 5 trillion (5×10^{12}) protons per pulse, and as many as 10 pulses per second.[4] The Beamline Enclosure, Target Hall and beam absorber would all be adequately shielded to accept off-normal beam conditions in which the entire Booster beam is delivered to the 8 GeV Fixed Target Facility. Under these conditions, the Booster delivers all of the 15 Hz beam at (5×10^{12}) protons per pulse or 7.5×10^{13} protons per second to the 8 GeV Fixed Target Facility. The target and beam absorber would be designed to be able to operate under these conditions for extended periods of time with no adverse effect.

[4] The 8 GeV Fixed Target Facility would not use all of the 15 pulses per second available from the Booster Accelerator. The remaining Booster beam is used to support other parts of the Fermilab physics program.

Water in the zone immediately outside the Target Hall would be collected through a system of underdrains and piped to sump pits within the enclosure. Water in the sump pits would be analyzed periodically to determine the concentration of tritium (H^3) and radioactive sodium (Na^{22}). Based on other Fermilab tunnels of similar size, location, and depth, the tunnel inflow of water would be approximately 40 liters (10 gallons) per minute.

2.1.6 Decommissioning

The Fermilab Environment, Safety, and Health Manual [18], contains written policies and procedures for creating and maintaining proper documentation for all facilities to transfer them to other future uses. Information necessary for the future decommissioning of the 8 GeV Fixed Target Facility and the associated detectors would be maintained using these policies. At the present, specific decommissioning activities are difficult to define in detail. They would depend on the future use of the 8 GeV Fixed Target Facility, which would depend on the future goals of the physics research program as established by the Department of Energy. The apparatus and beamline could be reused for future experiments at their present location. It is presently anticipated the experimental apparatus would be used well into the 21st Century. New projects would require appropriate review under the National Environmental Policy Act.

2.2 Alternatives and their Impacts

2.2.1 Location at an Alternate Site within the U.S.

No proton accelerator exists currently that meets the requirement for a high intensity, low energy (8 GeV) beam. Location at a DOE Laboratory other than Fermilab would therefore require the construction or modification of a high-intensity, low-energy accelerator complex. Duplication of such an accelerator at another location would be expensive, much more so than the cost of a Fermilab Booster upgrade, and involve potentially greater negative environmental impact than the proposed action. The opportunity to utilize the Fermilab Booster for a neutrino oscillation experiment, while having no impact on the other participants in the Fermilab Physics program, is unique to Fermilab.

2.2.2 Location of an 8 GeV Fixed Target Facility in the Existing Fixed Target Area at Fermilab

The existing Fixed Target Experiments Area at Fermilab is shown in Fig. 2. With considerable modification and construction, the 8 GeV beam from the Booster could be transported into this area to carry out neutrino oscillation experiments. Current plans call for the installation of two beamlines for transport to this area for other experiments – an 800 GeV proton beam, and a 120 GeV beam. This alternative would require the installation of a third dedicated beamline, for running 8 GeV protons, greatly adding to the congestion within the beam enclosures. In addition, the length of this beamline would be much greater than the preferred choice near MI-10. Operational and construction impacts are greater for this alternative than for the preferred alternative.

2.2.3 Alternative Locations at Fermilab.

The proposed location of the 8 GeV Target Hall was chosen to minimize construction impact on the surrounding environment. Construction further to the West would involve greater impact on known wetland, and archeological sites. Construction further to the East would involve more disturbance of existing infrastructure, and would thereby more severely affect the existing wetland in that area.

The proposed location of the BooNE Detector provides for no off-site impact in the event that a second detector is constructed. The preferred alternative provides substantial space for extending the distance of the detector from the source to 2,000 meters (6,600 feet) without impacting the surrounding communities.

2.2.4 No Action Alternative

The no action alternative would mean that the achievement of the scientific goal of confirmation of the LSND effect would not be possible in the U.S. in the near future.

There would be no environmental impacts from implementing the no action alternative. The present research program being conducted on the Fermilab site would continue, as modified by the ever-changing needs and scientific goals of the particle physics research community.

3 THE AFFECTED ENVIRONMENT

3.1 Site Description and Land Use

The preferred site of the proposed action, as shown in Fig. 3, is near developed areas that include the 4 mile circumference underground accelerator ring (Tevatron), the Anti-Proton Area, the Lederman Education Center, the Prairie Interpretive Trail and the Central Laboratory Area. To the southwest lies the newly constructed Main Injector Ring. In the near future, the NuMI project is expected to add two new surface buildings shown in Fig. 3 as the proposed NuMI U.S. and the proposed NuMI D.S. Service Buildings. The NuMI beamline will be about 60 meters (200 feet) below grade at the point where it crosses under the BooNE beamline. None of these areas would be impacted by the proposed activities.

The structures for the proposed action would be constructed in areas disturbed by farm activities and currently consisting of undeveloped remnant woodlands and old fields of non-native grasslands and scrub plant communities. Surveys of the proposed site have identified no threatened or endangered species in the area [35]. Fermilab has also conducted comprehensive surveys for prehistoric and historic sites within its boundaries [4, 32, 41]. No archaeological or historical resources are present at the proposed site. No areas having federal or state special designation (e.g., parks, wilderness areas, etc.) or prime agricultural lands are located in the project area. For a complete overview of the existing conditions at the Laboratory, including the area of the proposed construction, see information on the WWW [16]. The construction will disturb surface soils by an amount equal to approximately: 30 meters (100 feet) by 55 meters (175 feet) south of Geise Road, 55 meters (175 feet) by 135 meters (450 feet) north of Geise Road, and 3 meters (10 feet) by 455 meters (1500 feet) between the Target hall and the Detector 1. The Detector 1 construction will disturb approximately 30 meters (100 feet) by 60 meters (200 feet) of surface area. This amounts to a total of about 1.2 hectares (3 acres) of surface land that would be affected. About one third of this area would be permanently changed.

3.2 Surface Water

The Fermilab site is relatively flat as a result of past glacial action. The highest area, with an elevation of 244 m (800 ft) above mean sea level, is near the northwestern corner. The lowest point, 218 m (715 ft) above mean sea level, is toward the southeast. There are three watersheds that collect water on site. Most of the Fermilab surface water runoff is to the southeast into Ferry Creek. The northern part of the site drains to Kress Creek. These two creeks drain to the West Branch of the DuPage River. Surface drainage in the west and southwest is to Indian Creek which flows off-site into the Fox River.

There is a small wetland in the vicinity of the Beamline Enclosure, at the point at which it crosses under Indian Creek [14, 36]. A small, man-made tributary to Indian Creek flows adjacent to the the Main Injector Road in the area of the proposed 8 GeV Fixed target Area. Although man-made, this stream has been identified as jurisdictional wetland due to the dominance of wetland vegetation (primarily Typha spp., Carex spp., and Scirpus spp.), and historically hydric soils. The hydrologic indicator for this wetland is inundation.

3.3 Groundwater

The uppermost aquifer beneath Fermilab property is located within the dolomite bedrock, at a depth of 18 to 30 meters (60 to 100 feet) below ground surface. The direction of groundwater flow in the dolomite aquifer is generally toward the south/southeast, however this flow is locally affected by gradients induced by on-site wells used to supply drinking water to the majority of the site. Water within the dolomite aquifer is generally available for use, and historically, many farm wells utilized water drawn from this geologic stratum. The characteristics of this aquifer qualify it to be designated by the Illinois EPA as a resource (or Class I) groundwater. There is no special source of water located in the project area.

The dolomite layer is overlain by glacial deposits and windblown river, lake and pond sediments. The glacial deposits are primarily very low permeability clays which do not support groundwater production. Water in this layer is designated as Class II water by the state. IEPA has much more stringent numerical limits on contamination for Class I waters. Beneath the dolomite is the Maquoketa shale, which acts as a hydraulic barrier isolating the upper aquifer from lower water-bearing units. The hydraulic permeability in the glacial till is low, generally from 10^{-6} to 10^{-8} cm/sec [20], implying that groundwater movement is very slow.

Additional geological information is maintained by Fermilab and is accessible through its web site [38]. Specific studies would be performed to further characterize the subsurface conditions in the impacted areas prior to the commencement of construction [43].

4 ENVIRONMENTAL CONSEQUENCES OF THE PROPOSED ACTION

4.1 Construction Impacts

4.1.1 Occupational Safety and Health

The Fermilab Integrated Safety Management Plan [26] establishes policy for construction safety. The Plan includes ES&H requirements for activities involving contractors, participating guests and visitors. It specifies that contractors will have integrated safety into their business activities and follow all applicable ES&H requirements. It has provisions in all subcontracts for stopping work and terminating contracts for lack of ES&H performance. It also provides for refusing to allow certain subcontractor individuals on site for failure to follow ES&H requirements. Fermilab has a practice of excluding subcontractors from bidding if they have a record of poor ES&H performance at Fermilab. Fermilab also prequalifies its subcontractors on the basis of demonstrated technical expertise and successful ES&H programs. Fermilab's comprehensive construction safety program is documented in Chapter 7010 of FESHM [18].

Fermilab employees, visitors and experimenters, and members of the public would not be involved in the construction activities as access to these areas would be restricted to construction workers and those Fermilab and U. S. Department of Energy employees who would be engaged in the administration and monitoring of construction activities.

Personnel working within the detector vessel may be exposed to a potential oxygen deficiency risk. Although risk cannot be completely eliminated, quantitative risk analysis is used to prescribe precautions to protect against worker injury. These precautions include posting of warning signs, training, medical surveillance, and oxygen monitoring. Personnel working inside the vessel would be required to follow Fermilab's confined space program as prescribed in the Environmental, Safety, and Health Manual [18].

4.1.2 Surface Water Quality and Wetland Assessment

Erosion and sediment controls would be instituted as part of a Stormwater Pollution Prevention Plan according to guidance from the Illinois Environmental Protection Agency [28]. These would minimize the potential for increased pollutant loading to Indian Creek during construction activities. Surface water discharges associated with the construction (erosion, etc.)

would be evaluated in accordance with State and Federal Regulations concerned with the discharges of surfaces waters [22]. Some permit modifications may be indicated. (See Sec. 4.2.4.)

The proposed action would be outside of the 100 year floodplain as determined by reference to information provided by the Federal Emergency Management Agency [17, 8]. The point at which Indian Creek would cross over the Beamline Enclosure is at the edge of a known floodplain. Care would be taken in the design of the creek diversion to keep the floodplain area well removed from the 8 GeV Fixed Target Facility.

It was determined that a wetland assessment is appropriate and required per 10 CFR 1022 [8] for the activities proposed in this document. An assessment must include information on project description, wetland effects, and alternatives. These are individually addressed below.

<u>Project Description:</u> The nature and purpose of the proposed action has been described above (see Section 1.1). Figures 3 and 4 indicate the location of the impacted wetland. Beamline construction would require a temporary diversion of a section of the east branch of Indian Creek. (See Section 2.1 for construction details.) After completion of the construction phase, the creek would be returned to its original course.

<u>Wetland Effects:</u> The impacted wetland consists of a small man-made ditch and associated embankments. A wetland delineation [14] identified this portion of Indian Creek as jurisdictional wetland due to the fact that the soils within this location are historically hydric soils. The wetland is characterized by a dominance of common wetland vegetation (e.g., Typha latifolia, Carex aquatilis, Scirpus fluviatilis, and Leersia oryzoides). The hydrologic indicator is inundation. The wetland could be classified as "palustrine, emergent, semi-permanently flooded, excavated."

Impacts on the wetland along the east branch of Indian Creek would be minor (i.e., temporarily impact less than 0.3 of an acre). The impact would be temporary because during construction the creek would be diverted and the soil containing the wetland seed bank would be stockpiled. After the construction phase, the creek would be restored to its original course and the wetland re- vegetated by redistribution of the stock-piled soil. The temporary disturbance during the construction phase would have no long-term impact on the wetland's survival, qualities, or values. Upon return of the creek to its original course, the re-vegetated wetland recovery would be well underway after one growing season.

<u>Alternatives:</u> Alternative locations for constructing the proposed project have been addressed in Section 2.2 along with potential impacts. All alterna-

tives (with the exception of the "no action" one) identified potentially greater negative construction, operational, and/or environmental impacts (including wetlands).

4.1.3 Air Quality

The impact of this proposed action would be much less than the normal fluctuations in air quality in this area. During construction there would be minor, short-term, localized impacts on air quality from vehicular traffic and earth-moving operations. Dust would be controlled by established engineering practices, chiefly by water sprinkling of all disturbed earth surfaces and earth stockpiles. Exhaust fumes from construction traffic and internal combustion equipment used at the construction site, should rapidly disperse.

4.1.4 Waste Generation and Disposal

Excavated soil would be re-used for the backfill over the target and pretarget area, and as part of the earth shielding. Clearing and grubbing debris, demolished building material, vegetative matter, trash, rubbish and all other non-hazardous waste material would be disposed of in accordance with the requirements set forth by state and federal regulations [39] [13] [24]. All materials would be surveyed for possible contaminants before being removed from the Fermilab site.

4.2 Operational Impacts

4.2.1 Occupational Safety and Health

Protection of workers against exposures to common industrial hazards would be controlled in accordance with regulations established by the Occupational Safety and Health Administration [9], which are prescribed and enforced by DOE. Specific review procedures would be implemented to assure proper control of all materials used in the experiments in order to maintain a safe working environment. Provisions for egress would be made and maintained in accordance with the standards of the National Fire Protection Association standards [34]. The control of ionizing radiation hazards is discussed in Sec. 4.2.2. Hazards associated with confined spaces and areas that possess a potential for oxygen deficiency are subject to policies and practices given in the FESHM [18].

4.2.2 Prompt Radiation

There would be some generation of prompt radiation and radioactive wastes in the course of operation of the 8 GeV Fixed Target Area. Radioactive wastes are covered in section 4.2.8. Radiation issues due to off-normal operations are discussed in section 4.2.10.

Prompt radiation is produced by the interaction of the beam with materials such as a target, collimators, absorbers, beamline focusing elements, wall of the beam pipes, and consists primarily of neutrons and muons. It is present only when the beam is on, and would be generated during the operation of the proposed 8 GeV Fixed Target Area. The neutrons would be produced in all directions relative to the beam direction, while the muons would be produced in the direction of the beam (forward). Exposure to neutrons would be minimized by shielding combinations of soil, concrete or steel surrounding the beamline. The muon contribution to prompt radiation would be unimportant because muons would decay in the soil below ground level. Only low energy muons would be generated at the 8 GeV Fixed Target Facility, typically about 3 GeV. Three GeV muons produced at the target in the 8 GeV Fixed Target Facility would stop in approximately 9 meters (30 feet) of earth, and do not appear at the surface. Neutrinos will penetrate all materials, but they interact very weakly, contributing nothing to radiatiation exposure. There would be a minor contribution to dose to workers from the use of radiation sources as well. Table 2 summarizes the estimated annual doses that may be received from various sources of radiation due to the proposed action, which are well below the annual limits set by Federal Regulations [6] of 50,000 μSv. For comparison, the average annual dose a person receives from natural sources [33] is approximately 3600μSv (360 mrem).

Exposure to workers would be minimized by the observance of Fermilab's existing administrative limits for allowable dose to radiation workers. Typical radiation workers at Fermilab receive no more than 1000 μSv (100 mrem) in a year while the highest levels received are typically less than 10,000 μSv (1000 mrem) in a year. Workers at the proposed target station would be subject to the same levels.

The beam intensity would be comparable to that encountered during current normal operations at Fermilab. Shielding in the region north of MI Road up to the Target Enclosure would be fenced to restrict worker and public access. Maximum dose rates at the fence lines would be 1,000μSv/hr (100 mrem/hr). Dose rates south of MI Road would be limited to less than 10μSv/hr (1 mrem/hr) by steel shielding of the Beam Transport Enclosure and would require no fencing.

Table 2: Summary of Estimated Maximum Annual Doses Due to Ionizing Radiation Associated with the Construction and Operation of the 8 GeV Fixed Target Area.

Source	Who is receiving the dose.	Maximum Annual Dose	
		(μSv)	(mrem)
Neutrons produced during operation	members of the public or occupational workers	0	0
Muons produced during operation	members of the public or occupational workers	0	0
Use of radioactive sources	radiation workers	100	10
Radionuclides produced in groundwater	members of the public	0	0
Air activation	members of the public at the Fermilab site boundary	0.07	0.007
Work on radioactive target station components	maximally exposed worker	10,000	1000
Natural background radiation	everyone	3600	360

The International Commission on Radiation Protection has calculated the risk of latent cancer fatalities to be 0.4 latent cancer fatalities (LTF)per people-μSv [27]. Thus, the health effect attributable to the dose ($10,000\mu$Sv or 1,000 mrem, see Table 2.) to maximally exposed workers from operations of the 8 GeV Fixed Target Facility is 4000 per 10 million people. The LTF for the public , which is due to neutrons, muons, groundwater and air activation (see Table 2) is much less than one per 10 million people – so small that it cannot be reliably calculated.

4.2.3 Residual Radiation

High energy beams striking beamline components produce residual radiation of those beamline components. This residual radiation remains after the beam is turned off. Residual radioactivity in beamline components and shielding within the proposed beamline enclosures would not produce detectable dose rates above ground because the amount of shielding required for prompt radiation is more than sufficient to shield the residual radiation to undetectable levels.

The target station and associated equipment would become radioactive due to the operation of the 8 GeV Fixed Target Area. This equipment is inaccessible during beam operations and must be serviced and maintained with the beam turned off. The radiation dose rates due to both long and short-term operation of the target station have been calculated. The target station would be designed so that the dose rates would be less than 100 μSv per hour (10 mrem per hour) for large portions of the target station area. There would be a few accessible locations near the target itself that would have levels ranging from 1000 to 15,000 μSv per hour. These higher dose rates would be encountered only for short periods of time during maintenance. Such exposures would be minimized in part by carefully designing the equipment to be as reliable as possible to minimize maintenance time. The 8 GeV Fixed Target Area also includes a "hot storage" area on one side of the Target Hall. Highly radioactive elements would be held in that space for cool-off prior to working on them or before transporting them to off-site radiation handling facilities for disposal. The radiation exposures to these workers would be routinely monitored. It is estimated that radiation exposures in the range of 10,000 μSv (1000 mrem) per year would be received by only a small number of radiation workers. (Typically less than ten, see Table 2.) These exposures remain below the regulatory limit [6] of 50,000 μSv (5000 mrem) per year.

Excavation activities at the proposed site, except for the connection through the tunnel wall of the FMI Transfer Line, would be done in areas where radiation levels are not above natural background. The choice of such a site would assure that construction workers would not receive any exposure to radiation while working in that area. The only construction that would take place near activated areas would be at the Main Injector Tunnel. Because beam losses in the FMI Transfer Line would be kept small, activation of the tunnel concrete would be minimal. Based on relevant experience with other construction at Fermilab [31] workers exposed to a low level of activated soil, concrete, and other material in proximity with the Main Injector Tunnel would be expected to receive less than 10 mrem during the time that construction would take place in this area. Those construction activities associated with the connection with the Fermilab Main Injector would be conducted in accordance with the applicable Federal Regulations and U.S. Department of Energy Orders concerning radiological protection [6, 15].

4.2.4 Surface Water Quality

Discharges to surface water from sump pits would be less than 10 gpm. This water would be analyzed periodically to determine H^3 and Na^{22} levels. Unintentional discharges to surface water of radioactive water from RAW system leads would be minimized by the construction of suitable secondary containment around the cooling systems. This water would ultimately be disposed of as low-level radioactive waste if it exceeded the DCG in DOE Order 5400.5. If the DCG is not exceeded, the water would be released to surface water.

The need to modify Fermilab's present National Pollutant Discharge Elimination System (NPDES) permit for discharges of commingled non-process, non-contact cooling water [30] would be evaluated as the detailed design proceeds to assure compliance with IEPA requirements [22]. Fermilab also would apply for coverage under the Illinois general permit for stormwater runoff from construction sites.

Diversion of Indian Creek would require Corps of Engineers' and Illinois Office of Water Resources (OWR) permits.

4.2.5 Soil and Ground Water Impacts

The soil surrounding the Target Station can become activated due to the neutron component of the prompt radiation. The two isotopes of potential concern are H^3 and Na^{22}. It is known that these two elements are the only isotopes produced at accelerators that contribute to the groundwater because of their long lifetimes and high leachability in soil. The subsequent leaching of this radioactivity would migrate toward the underlying aquifer located in the dolomite. (See section 3.3, entitled The Affected Environment, Groundwater.)

Standard computer modeling techniques have been used to calculate the potential radionuclide concentrations in the groundwater resources adjacent to the Target Hall and decay pipe, where the largest deposition of prompt radiation might be expected to occur. The calculation supports a shielding design that protects the Class I groundwater resources so that radionuclide concentrations would be below regulatory limits specified in State Regulations for water quality in groundwater resources [23]. (See Table 2.)

4.2.6 Air Quality

Radionuclide emissions to the atmosphere due to beam operation consist of short-lived (half-lives from 2 minutes to 1.8 hours) radionuclides (typically C^{11}, O^{15}, N^{13}, and Ar^{41}) produced as an unavoidable result of proton interactions with targets and absorbers. Because it is produced in greatest abundance, and because it has a relatively long half life of 20.5 minutes, C^{11} is the most important of the radionuclides produced.

Environmental emissions would be limited by minimizing the ventilation of the tunnels during operations and by allowing sufficient time for decay of the airborne radioactivity after beam shutdown and prior to any personnel access. (See Table 2.) For example, a one hour decay period followed by rapid ventilation of the Target Hall would result in the release of no more than 1 (one) Ci of C^{11} to the environment. The activities of the other radionuclides would be less than the release of the C^{11}. It is estimated that this target station would be open to access in a manner that would allow release of these radionuclides a maximum of twice per month. Thus, a maximum of approximately 25 Ci per year would be released to the environment. This would be within the limits of the present Fermilab NESHAP permit, which limits releases to less than 100 Ci/year on average and a maximum of 900 Ci for any specific year. Typical releases from Fermilab in recent history are around 30 Ci per year. Thus the operation and transport of the beam to the Target Hall would not cause Fermilab to approach air permit limits. All releases would be reported annually to the Illinois Environmental Protection Agency (IEPA) and the U. S. Environmental Protection Agency (EPA) in accordance with conditions of the relevant environmental permit [29].

Compliance with 40 CFR 61 requirements, limiting dose to any member of the public to 100 μSv (10 mrem[5]) in any given year, (assuming that that person is present at the Fermilab site boundary on a full time basis) would be assured. In a typical recent year of operation, Fermilab accelerators release 34 Ci of such radioactivity, resulting in an estimated maximum dose to a member of the public of approximately 0.1 μSv (0.01 mrem). The maximum release of 25 Ci estimated above for operation of the beam should result in a maximum dose to a member of the public of 0.07 μSv (0.007 mrem). At 0.4 latent cancer fatalities (LTF) per 10 million people-μSv [27], the health effect attributable to the off-site dose from proposed action is far too small to be meaningful.

[5] The regulation actually establishes limits that are 10$\times$ higher. At Fermilab we choose to be more conservative.

Dose to workers from activated air would be minimized by excluding personnel from the enclosure in the region of the target station when the beam is operating and for two hours following cessation of operations, after which time the concentration limits for occupational workers specified in [6] would be readily met due to rapid decay of the radionuclides. Along with other sources of radiation exposure to workers, these exposures would be properly monitored in accordance with federal regulations applicable to occupational radiation exposures.

Ventilation systems for the service building would be completely separate from that used for the target station and adequate to preclude exposure of individuals to radioactive air.

4.2.7 Utilities

The increase in Fermilab utility requirements as a result of the operation of the 8 GeV Fixed Target Facility would be very small, and would not impair the ability of public utilities to supply their other customers.

4.2.8 Waste Generation and Disposal

Although the 8 GeV Fixed Target Facility represents additional activity at Fermilab, the level of new waste generation would be small compared to other levels at Fermilab, and would not be distinguishable from normal, routine fluctuations in waste volumes. There would be no TRU or high level radioactive wastes generated by the proposed action.

4.2.9 Socioeconomic Impacts

The number of personnel engaged in BooNE would not alter the Laboratory's staffing level beyond the numbers of normal routine fluctuations.

4.2.10 Off-Normal Events

The most significant potential off-normal events for the 8 GeV Fixed Target Facility would be a beam "loss" whereby the proton beam is absorbed by the beamline components in some unplanned location in part of the beam line upstream of the target. Extensive instrumentation would be employed to quickly detect and correct the undesired off-normal operational conditions. As stated in Sec. 4.2.2, the prompt radiation shielding for the 8 GeV Fixed Target Area would be designed to meet levels established in Fermilab policies, written in accordance with federal regulations [21]. These policies impose stringent requirements on the design of shielding in order to control such unplanned interactions of the proton beam. Off-normal residual radiation dose delivered to the air, and groundwater are estimated to be less than 0.001 of normal dose. The health effect attributable to this dose from the proposed action is far too small to reliably calculate.

Since the 8 GeV Fixed Target Area would receive beam at a 10 Hertz rate from the accelerator, and the maximum delivery rate is 15 Hertz, the difference between off-normal and normal operation would only be 50% greater. The inadvertent transport of the full intensity of the accelerator would have a negligible effect on the overall airborne emissions or the irradiation of the soil.

4.2.11 Environmental Justice

Executive Order 12898, Federal Actions to Address Environmental Justice in Minority and Low-income Populations, requires federal agencies to analyze disproportionately high and adverse environmental effects of proposed actions on minority and low-income populations. Off-property impacts of the proposed action would be minimal and limited to the area immediately surrounding the Fermilab property where there is no significant population of minority or low-income residents.

4.3 Decommissioning of the 8 GeV Fixed Target Facility and Associated Detectors

If the 8 GeV Fixed Target Facility or the associated detectors were to be decommissioned, the experimental apparatus and beamline would be disassembled. The components would be reused elsewhere at Fermilab, shipped to other laboratories for use, or made available as surplus equipment according to standard procedures for disposition of United States Government property [18]. For the duration of the proposed action, information necessary for eventual decommissioning of the BooNE experiment would be collected, documented, and retained for future reference in accordance with existing Fermilab policies. This information would include the details of the design, the history of operation, and records of environmental monitoring.

Each component of the experimental apparatus and beamline would be surveyed by health physics personnel in order to identify, label and isolate all components made radioactive by beam operations. It is anticipated that many components, excluding some of the beam line and target station items, the decay channel, and beam absorber material would be free of radioactivity. Radioactive components for which there is no longer a use would be packaged for shipment and disposed of as radioactive waste according to DOE specifications and federal, state, and local regulations in effect at the time of disposal. Non-radioactive wastes would be properly disposed, in accordance with applicable regulatory requirements. There are no disposal sites for any waste materials on the Fermilab site and none would be planned for the future.

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5 LIST of ABBREVIATIONS and ACRONYMS

Ar^{41}	A radionuclide of argon with mass number 41.
Bq	Becquerel
BooNE	Booster Neutrino Experiment
C^{11}	A radionuclide of carbon with mass number 11.
CY	Calendar Year
DOE	(U.S.) Department of Energy
EA	Environmental Assessment (U. S. Department of Energy)
EAW	Environmental Assessment Worksheet (State of Minnesota)
ES&H	Environment, Safety, and Health
EPA	(U. S.) Environmental Protection Agency
FNAL	Fermi National Accelerator Laboratory
FMI	Fermilab Main Injector
FY	Fiscal Year, Federal (October 1 through September 30)
H^3	A radionucllide of hydrogen, also known as tritium.
IEPA	Illinois Environmental Protection Agency
kW	Kilowatt, a unit of electrical power.
LSND	Liquid Scintillator Neutrino Detector
MINOS	Main Injector Neutrino Oscillation Search
mrem	millirem
μCi	microCurie, one millionth of a Curie
μSv	microSievert, or 0.1 mrem
N^{13}	A radionuclide of nitrogen with mass number 13.
Na^{22}	A radionuclide of sodium with mass number 22.
NFPA	National Fire Protection Association
NPDES	National Pollutant Discharge Elimination System
NSF	National Science Foundation
NEPA	National Environmental Policy Act
NESHAP	National Emission Standards for Hazardous Air Pollutants
NUMI	Neutrinos at the Main Injector
PAC	Physics Advisory Committee
O^{15}	A radionuclide of oxygen with mass number 15.
pCi	picoCurie or a micro-microCurie
SSC	Superconducting Super Collider
tritium	H^3 a radionuclide
TRU	Trans-uranic elements
USBM	U. S. Bureau of Mines

6 GLOSSARY

Accelerator.

A device for increasing the velocity and energy of charged particles, for example electrons or protons, through application of electrical and/or magnetic forces. Accelerators have made particles move at velocities approaching the speed of light. Types of accelerators include cyclotrons, synchrotrons, and linear accelerators.

Antiproton.

Matter in which the ordinary nuclear properties of the proton are replaced by correspondingly opposite properties of the antiproton. An anti-hydrogen atom, for example could be conceived as a negatively charged antiproton with a positively charged orbital positron.

Beam.

A stream of particles or electromagnetic radiation, going in a single direction.

Beamline.

A collective term referring to all the devices used to control, monitor, and produce a beam. The common elements of a beamline are magnets, intensity monitors, beam position monitors, and collimators.

Charge.

Electric charge carried by an elementary particle.

Closed-loop.

A system of circulating water in completely enclosed pipes where the water is isolated from any external surfaces.

Collimator.

An adjustable aperture, capable of absorbing the beam outside of the aperture opening, and permitting the transport of the beam within the aperture.

Commission.

The task of bringing into operation a designed system for the first time.

Curie or Ci.

The basic unit to describe the intensity of radioactivity in a sample of material. The Curie is equal to 37 billion disintegrations per second, which is approximately the rate of decay of 1 gram of radium. A Curie is also a quantity of any nuclide having 1 Curie of radioactivity. Named for Marie and Pierre Curie, who discovered radium in 1898.

Decay.

The spontaneous transformation of one nuclide into a different nuclide or into a different energy state of the same nuclide. The process results in a decrease, with time, of the number of the original radioactive atoms in a sample. It involves the changing of the nucleus by emission, absorption or fission.

Decommission.

The completion and disassembly of a system.

Diamacton.

A glacial sediment, generally unstratified, that is non-to poorly sorted and contains a wide range of particle sizes.

Dose.

As used in this assessment, the energy deposited in a unit of mass of tissue multiplied by a factor that takes into account the differences in biological effects due to different kinds of radiation. The unit of dose is the microSievert. One microSiever equals 10 mrem.

Electron.

The lowest mass lepton which is found bound in ordinary atoms and has negative electrical charge.

Fixed-target physics.

A method of study used in high energy physics in which a beam of high energy particles is collided with a material target that is stationary, or ''fixed'', in space.

GeV.

The unit of measure of the kinetic energy of particles accelerated by high energy accelerators. A proton accelerated through an electrical potential of 1 billion volts would have a GeV of kinetic energy.

Half-life.

The time in which half of the atoms of a particular radioactive substance disintegrates to another nuclear form. Measured half-lives vary from millionth of a second to billions of years.

Hertz or Hz.

A measure of frequency. One cycle per second.

Interlock.

A locked device engaged to beam components such that changes in the device will permit or not permit the components to operate.

Ionizing radiation.

Particles or rays that can cause electrons to be added to or removed from neutral atoms. Examples of ionizing radiation include alpha particles, beta particles, muons, gamma/X-rays and neutrons.

Isotope.

One of two or more atoms with the same atomic number (the same chemical element) but with different atomic weights. An equivalent statement is that the nuclei of isotopes have the same number of protons but different numbers of neutrons. Isotopes usually have very nearly the same chemical properties, but somewhat different physical properties.

Kaon.

An elementary particle having a mass about 970 times that of an electron.

Lepton.

A class of elementary particles that only interact by means of the electromagnetic and weak forces.

Main Injector.

A synchrotron at Fermilab that is designed to accelerate protons and antiprotons to an energy of 150 billion electron volts, (150 GeV).

Magnet.

The proton beam is transported from the accelerator to a target by magnets. A magnet consists of a steel core with copper windings or permanent magnet materials to produce a magnetic field. The magnetic field formed at the center of the magnet bends and focusses the beam as it passes through.

Mass Number.

An integer that expresses the mass of an isotope and designates the number of nucleons in the nucleus.

Mw.

Megawatt or one-million watts.

Millirem or mrem.

One one-thousandth of a rem (0.001). Rem is an acronym for roentgen equivalent in man. The unit of dose of any ionizing radiation that produces some biological effect, such as a unit of absorbed dose of ordinary X rays.

Muon.

An elementary particle, classed as a lepton with 207 times the mass of an electron. It may have a single positive or negative charge.

Neutrino.

Any one of several electrically neutral elementary particle with at most a very small mass. It interacts very weakly with matter and hence is difficult to detect. It is produced in many nuclear reactions, for example, in beta decay, and has high penetrating power; neutrinos from the sun usually pass right through the earth.

Neutron.

An uncharged elementary particle with a mass slightly greater than that of the proton, and found in the nucleus of every atom heavier than hydrogen. A free neutron is unstable and decays with a half-life of about 13 minutes into an electron, proton, and neutrino.

Oscillation.

The transition of a neutrino from one type to another.

Pico.

A prefix that divides a basic unit by one trillion. Same as micromicro.

Positron.

The antiparticle of the electron that has the same mass as the electron but has positive electrical charge.

Prompt radiation.

Radiation produced by the interaction of the beam with materials such as a target and consisting primarily of neutrons and muons, also considered as penetrating radiation.

Radioactivity.

The spontaneous decay or disintegration of an unstable atomic nucleus, usually accompanied by the emission of ionizing radiation. (Often shortened to ''activity''.)

Radionuclides.

A radioactive nuclide.

Sievert or Sv

A unit of measure of radiation exposure by human tissue, equal to 100 Rem. Also see millirem.

Spill

An event in which the beam is extracted from the accelerator.

Subatomic.

Any of the constituent particles of an atom: electron, neutron, proton, etc.

Target.

In a fixed target facility, protons from the accelerator are transported to, and focussed on a target, or a small solid object, typically made of metals such as aluminum, beryllium or copper. The protons interact with atomic nuclei in the target nuclei to create other particles, some of which decay into neutrinos, the particle that will be used in the first experiment at the 8 GeV Fixed Target Facility.

Tevatron.

A synchrotron at Fermilab that is designed to accelerate protons and antiprotons to an energy of one trillion electron volts, (1 TeV).

Tritium.

A radioactive isotope of hydrogen with two neutrons and one proton in the nucleus. It is man-made and is heavier than deuterium (heavy hydrogen). Tritium was used in industrial thickness gauges, and as a label in experiments in chemistry and biology.

7 APPENDIX A: MSDS for Mineral Oil, and Butyl PBD