14. **Environment, Safety, and Health Considerations for the Neutrino Source**

14.1 Introduction

The Neutrino Source presents a number of challenges in the general area of environment, safety, and health. It is the intent of this chapter to identify these challenges and make a preliminary assessment of how they might be addressed and of their potential impact on the project. Many of these issues are very similar to those that have been encountered and solved during the construction and operation of other facilities at Fermilab and elsewhere while others are quite novel. The novel ones will require particular attention as the project proceeds to assure their timely resolution in a cost-effective manner that meets the approval of the Department of Energy and the public. It is concluded here that with adequate planning in the design stages, these problems can be adequately addressed in a manner that merits the support of the Laboratory, the Department of Energy, and the public.

14.2 Procedural/Regulatory Matters

The actual design, construction, and operation of the Neutrino Source will have to meet a number of procedural/regulatory milestones in the area of environment, safety, and health to assure its success. The devotion of early attention to these issues is likely the best way to enhance public support of the project. These requirements are currently provided in Fermilab's Work Smart Standards in Environment, Safety, and Health which is reviewed annually [1]**.**

14.2.1 Environmental Protection Procedural/Regulatory Matters

All new DOE projects are subject to the National Environmental Policy Act (NEPA). Initially, the project will be the subject of an Environmental Assessment (EA). The required analysis is broad in scope and includes societal impacts along with the standard environmental protection topics. DOE will choose the methods used to involve the public. The conclusion of the environmental assessment process is either a Finding of No Significant Impact (FONSI) or the need to prepare an Environmental Impact Statement (EIS), a likely result for this project due to its scope and cost. The completion of the EIS results in the issue of a formal notice called a Record of Decision (ROD). The NEPA process is generally considered to be arduous, but one that can be followed to a successful conclusion. This task must be completed, customarily by using external resources, prior to expenditure of project funds. Other procedural requirements apply in the arena of environmental protection in the form of environmental permits that will be needed. Some of these apply during the construction stages, others apply to operations, and some apply during to both stages. Topics covered by such permits include storm water discharges, discharges of cooling water, wetlands mitigation, releases of air pollutants for both non-radioactive pollutants and for radionuclides, and construction in any floodplains. The lead-time required for submittal of these permits is typically 180 days. Archaeological sites are also located on the Fermilab site which might need further investigation and study prior to the commencement of construction.

14.2.2 Safety and Health Procedural/Regulatory Matters

The Laboratory will be required to prepare an assessment of the environment, safety, and health issues associated with this project in the form of a Safety Assessment Document (SAD). Given the size, and scope of this project, the preparation of a Preliminary Safety Assessment Document (PSAD) will likely occur first. The purpose of the PSAD is to identify the relevant ES&H issues at an early stage and propose how they might be mitigated. The SAD, then, documents the resolution of them. It is nearly certain that DOE will review these safety documents by utilizing an external review team. Just prior to facility operation, a readiness review will be conducted in similar fashion. PSAD/SAD activities generally begin after funds are issued. Here, too, early planning will help this task. DOE is presently "self-regulating" in the areas of industrial safety and occupational radiation protection. This situation could change at some future time. Related developments are being monitored closely to identify new requirements or procedures that might apply to new projects such as the Neutrino Source.

14.3 Occupational Safety During Construction of the Facility

14.3.1 Proton Driver, Target Station, Cooling Region, and Muon Acceleration Linacs

These facilities all would be located within the glacial till strata at a distance below the surface of less than 30 ft (10 meters). At this level, the construction is likely to proceed by the standard "cut and fill" method. The Occupational Safety and Health Administration's (OSHA's) regulations on the construction activities will be followed. Industrial radiography operations and any other work conducted using radioactive sources must be performed in compliance with State of Illinois requirements. There are no new occupational safety issues identified with this work.

14.3.2 Muon Storage Ring (MuSR)

The MuSR will be excavated through several geologic units that are shown in Figure 1. The glacial till does not contain an aquifer. All of the bedrock units contain aquifers except for the Galena/Platteville, which is largely an aquatard. The 13.16-degree downhill slope poses some unique issues. While the eastern (uphill) end would be accessible by conventional means of egress, the western (downhill) end, would be located approximately 630 feet (192 meters) below the surface. Regulations pertaining to underground operations (i.e. "mining" activities) come into play. Concerns about tunneling safety, material movement, and provisions for emergency response including underground rescue must be addressed. The NuMI project should provide valuable experience in these matters.

Given the location within several major aquifers, and the downward slope, it is clear that stringent measures must be taken to prevent flooding both during the construction period and thereafter. Likewise, the downward slope, about four times that of the NuMI tunnel, requires careful planning to include provisions for adequate protection against uncontrolled, hazardous downward movements of equipment and materials. These protective measures need to be consistent with mitigation of environmental protection concerns (see below).

14.4 Environmental Protection During the Construction of the Facility

14.4.1 Proton Driver, Target Station, Cooling Region, and Muon Acceleration Linacs

Erosion control measures similar to those employed elsewhere will be employed in accordance with good engineering practice and Federal and State regulations. Dust from any spoil piles must be kept under control. Likewise, a stormwater management plan will need to be developed. Since more than 5 acres (2.0 hectares) of land surface are impacted by the construction, a National Pollutant Discharge Elimination System (NPDES) Stormwater Permit for construction will be needed which will include specific actions which must be followed during the construction period. The usual precautions to prevent pollution from spills of regulated chemicals from the construction equipment will need to be taken. Noise from construction activities is not expected to be significantly more intense than that associated with normal civil construction activities in the vicinity of Fermilab. If more than 3 acres (1.2 hectares) of wetlands are impacted, compensatory man-made wetlands will need to be created. It is important to demonstrate adequate care for floodplains due to significant local public concerns about flood prevention.

14.4.2 Muon Storage Ring (MuSR)

The tunneling in the bedrock units will result in the removal of a considerable volume of rock. The NuMI experience will be most useful in learning how to manage the rock spoil, dust, noise, vibration, and "aesthetic" issues. The storm water management plan will need to take into account any releases of groundwater generated in the course of "dewatering" the tunnel. Careful hydrogeologic studies need to be performed to understand the interplay of the construction of the project with the various aquifers. This must be done to establish with certainty that the construction activities will not cause significant perturbations of the local individual and municipal water supplies, either in quality or in quantity. The exact depth of the top of the aquatard of the Galena/Platteville unit is known to be non-uniform across the Fermilab site. Accurate measurements of it are needed to plan a strategy for preventing the tunnel from serving as a possible path of contamination from the upper aquifers, commonly used by individual wells and municipalities, to those below the aquatard, commonly used by the local municipalities. During construction, precautions are needed to guarantee that spills of chemicals, including lubricants and fuels from the construction equipment, are captured before they enter the groundwater. The downward slope presents special considerations in this regard.

14.5 Occupational Safety During the Operation of the Facility

14.5.1 "Ordinary" Occupational Safety Hazards

The occupational safety hazards encountered at all other large particle accelerator facilities will be found in this facility. These have been successfully addressed by well-known techniques and are simply listed below:

- The project will use high current electrical circuits in the magnets on a large scale.
- Radiofrequency (RF) generation and distribution equipment will be used extensively.
- Large amounts of cables in cable trays, with associated fire protection implications, will be installed.
- Long tunnels will be present with corresponding egress and fire protection issues that need to be addressed.
- There will be movements and alignment of large, heavy components.

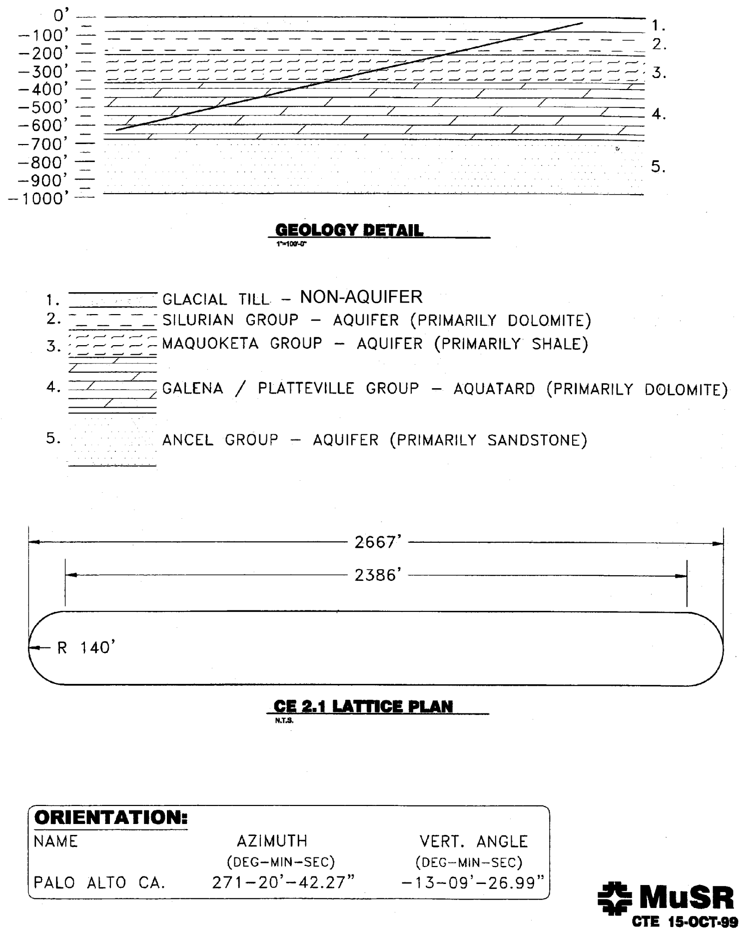


Figure 1: Conceptual layout of the Muon Storage Ring (MuSR) in the various geological units**.**

14.6 Novel Occupational Safety Hazards

14.6.1 Large Scale Use of Cryogens

The extensive use of cryogenics in both magnets and RF structures presents special problems, but similar in kind to those solved at present accelerators. Portions of these cryogenic systems will be deep underground, at the lower end of the Muon Storage Ring and on large slopes. Provisions will need to be made for the safe release of cryogens to the surface both during normal operations and in the event of quenches. Standard engineering practices developed to mitigate both direct cryogenic hazards and the accompanying oxygen deficiency hazards (ODH) should be used.

14.6.2 Utilization of Liquid Hydrogen (LH_2)

The use of ionization cooling in a LH_2 medium presents significant fire/explosion hazards. Also, the LH_2 cells will be interleaved with RF structures and magnets that handle a great deal of electrical energy. In the past, Fermilab has successfully used stringent review procedures involving internal and external review committees of experienced individuals to provide advice on the management of large scale usage of LH_2 in bubble chambers and targets. A recommended approach to address concerns related to this system is to convene a review committee of qualified individuals at the earliest reasonable state in the design.

14.6.3 Muon Storage Ring Life Safety (Egress) Considerations

The MuSR, as aligned for this study, constitutes a long tunnel with the western end rather deep in the ground. The fire protection/egress considerations of this configuration, including the adequacy of the access shaft and "safe room", will need to be reviewed by a qualified fire protection professional, and others, for adequacy. Plans will need to be made for the evacuation of any injured or ill personnel through the sloped arcs. Again, the NuMI experience should be helpful.

14.6.4 Muon Storage Ring Slope Hazards

The steep slope of the MuSR presents unique hazards during operation as well as during construction. The surface of the finished floor should be made sufficiently rough to provide good traction to individuals wearing ordinary shoes. Gutters should be provided to direct water flowing into the tunnel toward the large sump pits at the lower end. They might also be designed to retard the unwanted downhill movement of large items, particular that of any portable pieces of equipment on wheels. An idea that might address this, and other considerations, is to arrange the gutters in a spiral fashion, regularly crossing the tunnel to direct such items toward one of the walls. Regular tie-down points for heavy items of equipment could be provided. These problems can be solved if they are addressed early in the design process.

14.7 Ionizing Radiation Safety During Operation of the Facility

14.7.1 Proton Driver

14.7.1.1Prompt Radiation Shielding

The Proton Driver and the Neutrino Source Target Station will require massive amounts of hadron shielding similar in scale and type to that of other proton accelerators in this energy regime. Detailed calculations made using MARS have already been performed to determine the amount of shielding required [2]. It is clear that suitable combinations of steel, concrete, and earth shielding can meet the standard criteria for above ground shielding at Fermilab. At 16 GeV, the range of the muons of maximum energy is less than 30 meters of earth. Due the their forward-peaking, any muons produced by stray beam loss should be ranged-out and hence are of no consequence. Thus, the shielding against the prompt radiation hazards is well understood and can be addressed by conventional means. The transport of beam from the synchrotron to the Target Station poses no peculiar problems with respect to prompt radiation shielding. Provision for the shielding of "stray", large-angle muons, not captured into the muon beam, should be provided downstream of the target.

14.7.1.2Residual Radioactivity of Components

The Proton Driver, under maximal operation, will handle up to 40 times the beam power of the present Fermilab Booster. Many important radiation effects scale roughly with the beam power. The handling of this large beam power has already received, and merits, careful attention [3]. Efforts should continue to better control such losses of beam both from the standpoint of component activation and also with respect to soil and groundwater activation.

14.7.1.3Residual Radioactivity at the Target Station

Given the high beam power, the residual activation of the Target Station merits special attention. The residual absorbed dose rates to be found in the Target Station are not presently known in detail, but will be large, of the order of krads hr^{-1} (tens of Sv h^{-1}). There will also be significant activation of water used to cool the non-cryogenic components as well. Remote handling capabilities of the style used by other facilities such as the Los Alamos Meson Physics Facility (LAMPF) and being planned for the Spallation Neutron Source (SNS) at the Oak Ridge National Laboratory will be needed. The activation of the carbon target itself will be quite significant. ^{3}H (12.3 year half-life), ^{7}Be (53.6 day half-life) and ^{11}C (20.3 minute half-life), will be the dominant, long-lived radionuclides produced. Each 16 GeV proton produces about 1.5 nuclear interactions (i.e., "stars") in a carbon target. Using the standard values of the total inelastic cross section for high-energy interactions along with the production cross sections for the nuclides ^{3}H [4], ^{7}Be and ^{11}C [5], one can estimate the total activities in the target. The calculation has been done for 1.5 MW beam power, at saturation (i.e., after a run that is long in duration compared with any of the half-lives). The result is about 1540 Ci (57 TBq) of ^{3}H, 1020 Ci (3.8 TBq) of ^{7}Be, and 2055 Ci (76 TBq) of ^{11}C. The gamma-emitting ^{7}Be will be the major contributor to residual exposure rates. Taking its branching ratio of 10.4 % into account, and crudely assuming the target to be a "point" source, the absorbed dose rate at 1 meter would be about 21 rad hr^{-1} (0.21 Gy h^{-1}).

DOE has developed special requirements for nuclear facilities [6]. Such facilities are subject to levels of safety analysis, quality assurance, and training requirements that are significantly more stringent than those normally applied to accelerator facilities. The present DOE definition of nonreactor nuclear facility excludes accelerators. However, it is not clear that it excludes radioactive materials in excess of certain levels of activity as specified in the requirements [7]. While the values calculated above for the target itself do not exceed these thresholds, the total activity for the target station might. Questions about the status of the facility as a nuclear facility need to be resolved. If the target or target station ends up being classified as a nuclear facility, it would be advisable to segregate the operation of the target from that of the rest of the facility to the extent possible. The Laboratory continues to monitor the ongoing development of DOE requirements on this topic.

14.7.1.4 Airborne Radioactivity

The production of airborne radioactivity in the vicinity of the Target Station will constitute the dominant source of airborne radioactivity emissions for the facility. At this early stage, a comparison with the work already done on the NuMI Target Station [7] may be useful since the beam powers of the two facilities are comparable. The NuMI Target Station will operate at a beam power of 0.404 MW. It will release a total of about 15 Ci (555 GBq) annually. This is dominated by 5 Ci (185 GBq) of ^{11}C (half-life = 20.3 min.) and 9.8 Ci (363 GBq) of ^{41}Ar (half-life = 1.83 hours). Such releases will result in an annual dose equivalent of about 0.009 mrem (0.09 microSv) at the site boundary. The NuMI Target Station was designed to assure that this level is well below a value of 0.1 mrem (1 microSv) in one year, which is a threshold for the sum of the emissions from all sources at Fermilab. Above 0.1 mrem in one year, a stringent continuous monitoring program and other requirements specified by U. S. Environmental Protection Agency Regulations [8] must be met to demonstrate that the regulatory limit of 10 mrem (100 microSv) in one year is not exceeded. The NuMI results were achieved by carefully designing the ventilation system to maximize the decay in transit from the point of production to the release stack. The helium volume immediately surrounding the target that is proposed elsewhere in this report should help to mitigate this problem. The Laboratory must also decide which other facilities might operate concurrently with the Neutrino Source since these emissions, effectively, represent a "zero sum game" for all of Fermilab.

14.7.1.5 Radioactivity in Soil and Groundwater

The calculation of the radioactivity produced in the soil around the Proton Driver and Target Station can be accomplished in a straightforward manner using current versions of Monte-Carlo shielding codes. Recent studies have found that the glacial till generally provides for very small hydraulic conductivities. When the gradients are included, a very slow migration downward of radionuclides produced in the soil results, affording considerable time for decay in transit. However, before the exact location of the facility is irrevocably determined, detailed hydrogeologic studies should be conducted to determine the relevant parameters precisely, as they are known to vary over the Fermilab site. Documented methods for calculating groundwater concentrations of radionuclides exist [9].

14.7.2 Cooling Stages and Muon Acceleration Stages

In the Cooling Stages, the collected muons from pion decays will deposit considerable energy in the LH_2 cells in the course of being "cooled". This energy will end up largely in the form of heat transferred to the hydrogen and dispersed by the refrigeration equipment. Given the low energy of the muons at this stage only energy loss by ionization is important. It is straightforward to design shielding appropriate to ranging out "stray" muons that might miss the cooling apparatus as well as the electromagnetic cascades induced by the decay electrons. Present Monte-Carlo codes are adequate to provide accurate calculations of this effect. The forward-peaked nature of the muon field should minimize the lateral extent of the shielding necessary. The production of induced radioactivity in these stages is also severely limited by the energy, and the fact that leptons are the only particles present. At the higher energy stages, the scale of the muon shielding required will increase, but even the final muon energy is still relatively small since the mean range of a 50 GeV muon in soil is only about 109 meters. Likewise the size and importance of the electromagnetic cascades produced by the decay electrons will grow as the energy increases. Radioactivation could be expected, but at levels much smaller than those to be experienced in the Proton Driver and Target Station.

14.7.3 Muon Storage Ring

14.7.3.1 Control of Radiation Dose Due to Neutrinos

The most unusual radiation consideration pertaining to the Muon Storage Ring is that due to the neutrinos produced by the decaying muons. Obviously, the design of the entire facility is optimized toward the production of a high fluence of neutrinos in the intended direction downward (westward). This also results, unavoidably, in a similar stream of neutrinos in the upward direction. The methods for calculating radiation dose equivalent from the neutrino fluence have been described elsewhere[10],[11]. The Department of Energy has specified the annual limits on the radiation dose equivalent that can be received by occupational workers and members of the public [1][12]. These limits rather clearly refer to the dose equivalent that could plausibly be delivered to actual people. For individual members of the public, the primary limit is 100 mrem (1mSv) in a year, not including man-made, medical, or enhanced natural radioactivity. Special reporting requirements apply when the annual dose equivalent received by an individual exceeds 10 mrem (0.1 mSv) in a year. For comparison, the average annual radiation dose equivalent received by individuals living in the United States from natural sources of radiation, including exposure to radon indoors, is about 300 mrem (3000 microSv) [13].

Figure 2 schematically shows the "lobe" of neutrino radiation due to neutrinos produced by muon decays in the downward (westward) production straight section of the MuSR. The parameters *L* and *R* describe the length and maximum radius of a chosen contour of equal annual dose equivalent. *L* is measured from the end of the MuSR straight section along the centerline of the neutrino trajectory, while *R* is measured perpendicular to the neutrino trajectory. Cylindrical symmetry should hold about this axis for this radiation field. Due the extreme forward peaking, the dose equivalent at the surface due to these neutrinos is zero. A similar radiation field will penetrate the surface due to muon decays in the upward (eastward) return straight section of the MuSR centered about the axis of the return straight section. Mokhov has calculated these radiation fields and has plotted the results for two different contours of annual dose equivalent, 1 mSv (100 mrem) and 0.1 mSv (10 mrem) [14]. These values are given in Figure 3. One might decide to place the MuSR so that a selected annual isodose contour, say either 10 or 100 mrem, lies entirely underneath the present Fermilab property. Also, performing a simple inverse-square scaling, a dose equivalent rate of about 4.8×10^{-5} mrem (0.48 nSv) per year is found at SLAC/LBNL, 2700 km downstream on the centerline axis, a value completely insignificant compared with local variations in natural background.

It is also desirable to also locate the MuSR so that there is no exposure to offsite areas near the surface of the ground from the upward lobe of neutrinos. Somewhat arbitrarily, one postulates that it is extremely unlikely that a tall building, say 600 ft (183 meters), will be built just outside of the eastern boundary of the Fermilab site during the projected lifetime of the Neutrino Source. If such a building were to be constructed, one would desire the annual dose equivalent due to the neutrinos at any level of the building to be less than 10 mrem (100 microSv). To do this, simple trigonometry requires that the center of upward lobe to emerge from the ground at least 2600 feet (792 meters) west of the eastern site boundary. The operational year of the Neutrino Source specified in this study of 2×10^{7} sec amounts to 5555 hours. Thus, following present practice of limiting prompt radiation levels in fenced outdoor levels to 100 mrem h^{-1}, the annual dose equivalent that could be delivered in such an outdoor, fenced area could be as high as 5.7×10^{5} mrem. Performing a simple scaling calculation, one finds that the annual dose equivalent due to the neutrinos is reduced to 5.7×10^{5} mrem at a distance of 24.2 meters (79.4 feet) from the end of the MuSR enclosure on the axis of the neutrino beam. If this end of the enclosure is located a distance of 5.5 meters (18 feet) below the surface, the highest annual dose equivalent accessible above the surface will not exceed this level, and thus the above-ground area could simply be fenced off. At these levels of neutrino fluence, given the small interaction cross sections involved, the radioactivation of soil and ground water is insignificant.

Figure 4 and Figure 5 show how the Neutrino Source could be placed on the Fermilab site and meet these criteria.

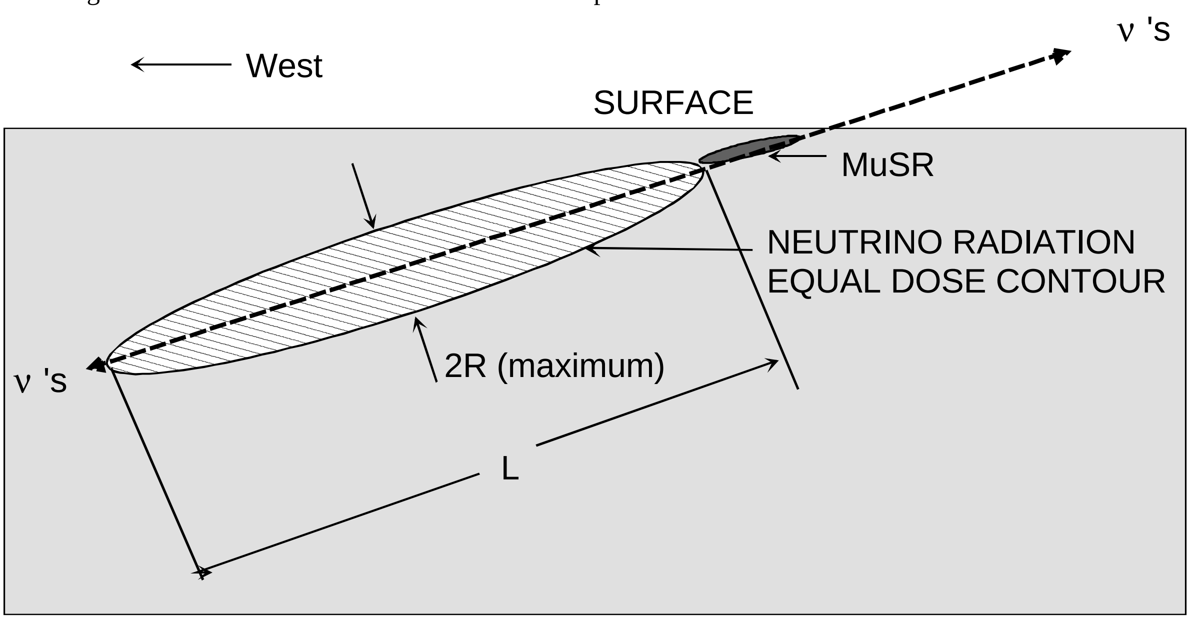


Figure 2: Schematic representation of the neutrino radiation fields due to muon decays in the MuSR. The gray region is the earth while the cross-hatched region is a schematic representation of the region inside of a selected contour of equal dose equivalent due to the neutrinos resulting from downward muon decays. A similar neutrino radiation lobe is to be found in the upward direction due to upward muon decays in the other straight section of the ring. The parameter L describes the intersection of this isodose contour with the centerline of the neutrino beam trajectory while R is its maximum radial extent. The actual contours are more forward-peaked, and narrower than this symbolic ellipse. Symmetry about the center line of the neutrino trajectories is expected.

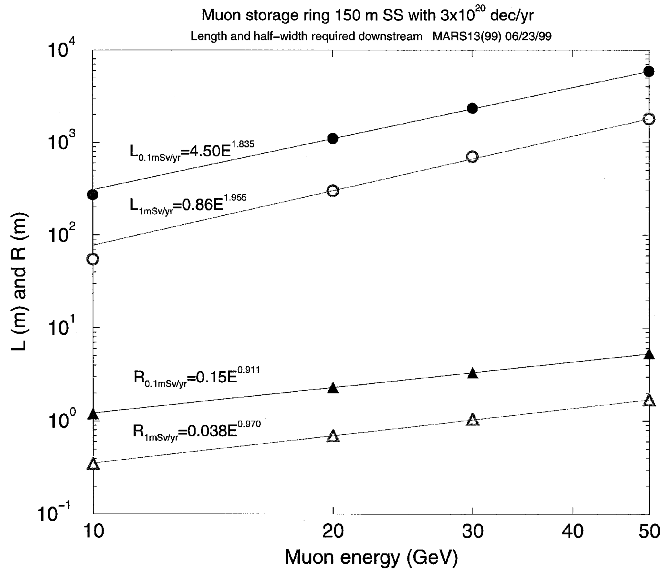


Figure 3: Results of calculations of the values of L and R (see Figure ESH.2) which describe the neutrino radiation field resulting from muon decays from one Muon Storage Ring straight section ("SS") as a function of muon energy[14]. Results are given for two different annual dose equivalents, 1 mSv y^{-1} and 0.1 mSv y^{-1}.

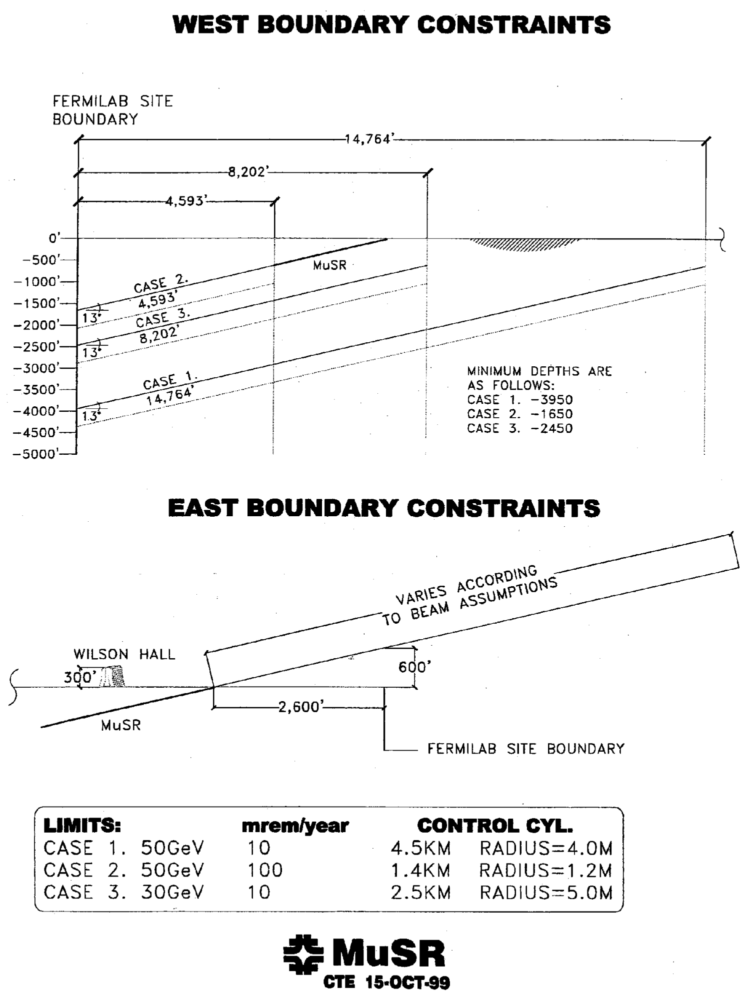
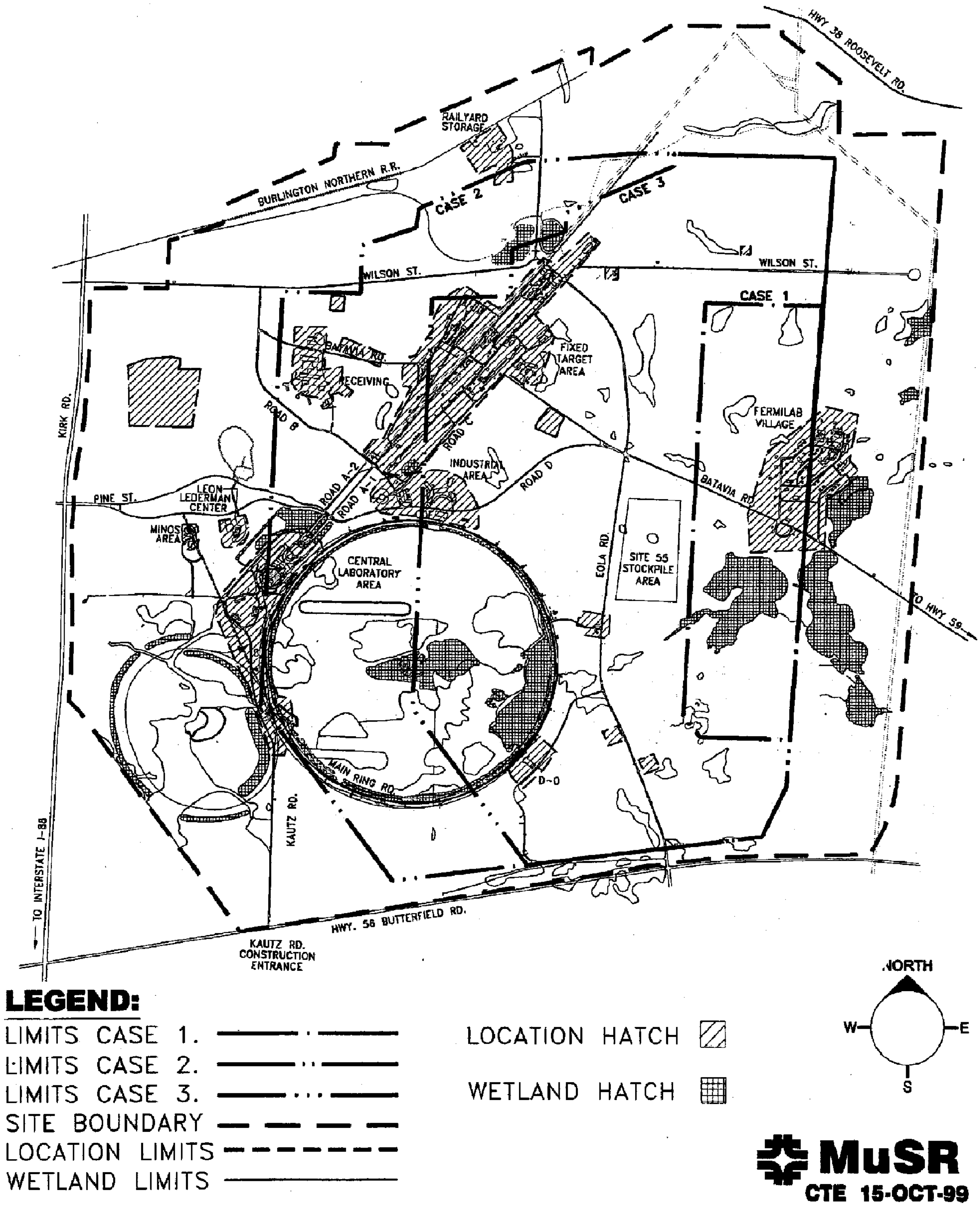


Figure 4: East-west vertical cross section through the Fermilab site showing the radiological constraints on siting the MuSR explained in the text for two different choices of annual dose equivalent and two different choices of muon energy.



LIMITS:		**mrem/year**	**CONTROL CYL.**	
CASE 1.	50GeV	10	4.5KM	RADIUS=4.0M
CASE 2.	50GeV	100	1.4KM	RADIUS=1.2M
CASE 3.	30GeV	10	2.5KM	RADIUS=5.0M

Figure 5: Map of the Fermilab site that displays the siting constraints for locating the MuSR explained in the text for two different choices of annual dose equivalent and two different choices of muon energy.

14.7.3.2Other Radiation Sources

The bombardment of the walls of the MuSR components will involve a nearly uniform irradiation by electrons. Calculations of both the energy deposition in the superconducting magnets and the induced radioactivity due to these electromagnetic cascades were performed by Mokhov [15]. Residual dose equivalent rates due to these cascades will be small, less than about 1 mrem h^{-1} (10 microSv h^{-1}) after a 30 day irradiation and a 1 day cooldown. It is feasible for the muons stored in the MuSR to be catastrophically lost in the event of a sudden power outage or some other failure of the magnets. However, given the orbit time of 6 microseconds and the likely inductive time constants of the magnets, the loss of the muons during such an event would be distributed over many turns and large portions of the ring. Only a tiny fraction of them would be directed in a manner in which they penetrate the surface. Further calculations should be made to demonstrate this. It is certain that the near detector halls will be exclusion areas during operations due to neutrinos as well as the other background sources that are unavoidably present.

14.8 Non Radiological Environmental Protection Issues During Operation

14.8.1 Proton Driver, Target Station, Cooling Region, and Muon Acceleration Linacs

The issues are straightforward ones related to the control of non-radioactive wastes. Efforts should be made to prevent the creation of regulatory mixed wastes and to control spills. Surface water discharges should be managed in accordance with the current Laboratory policies and any State and Federal environmental permits that may be in place. These considerations are quite similar to those encountered at other Fermilab facilities located in the glacial till.

14.8.2 Muon Storage Ring

The location of the MuSR in aquifer units requires especially stringent protection against spills. It is also very important to continue to avoid the cross-connection of surface waters with the various aquifer layers and cross-connections between different aquifer layers. Efforts must be made to assure that any pumping necessary to keep the enclosure dry does not create perturbations of local community or individual drinking water supplies. Careful attention to these problems during the design and construction phases should lead to their successful solution.

14.9 Summary

The Neutrino Source provides a number of challenges in the area of environment, safety, and health. Many of these have been encountered, and effectively addressed, at Fermilab and other accelerators. Some of the problems are common to technological advancements in other accelerators worldwide. For these, collaborative efforts should continue to develop and improve the solutions that are needed. This project raises a few new issues that must be addressed. Continued attention to these issues is anticipated as the project proceeds.

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