

# Chapter 1

## Environment, Safety, and Health Considerations for the Neutrino Source

### 1.1 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 accelerator facilities at BNL and elsewhere while others are novel in magnitude. 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 Laboratory, 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 their support.

### 1.2 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. Design, analytical and operational requirements are currently provided in the BNL Standards Based Management System (SBMS) Accelerator Safety and Hazard Analysis Subject Areas as well as the applicable SBMS Subject Areas on environmental protection [1].

#### 1.2.1 Environmental Protection Procedural/Regulatory Matters

All new DOE projects are subject to the National Environmental Policy Act (NEPA). In accordance with the National Environmental Policy Act (NEPA) and Cultural Resources Evaluations Subject Area [1], the project will generate an Environmental Evaluation Notification Form and request DOE, to make a determination on the level of documentation to comply with NEPA. Based on the proposed design

and past determinations on other accelerator projects, an Environmental Assessment (EA) should be sufficient and would be the expectation of the determination that DOE will make. The decision making process and content of the EA is prescribed in NEPA along with the requirement to seek public comment. The conclusion of the EA process is either a Finding of No Significant Impact (FONSI) or a determination of need to prepare an Environmental Impact Statement (EIS). The NEPA process is rigorous, but one that BNL has the expertise to conduct and complete. 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 for construction. This was the case for the previous RHIC Project. Any permits that apply to operations will be identified when if and when the EA identifies regulated effluents. 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 permits. Historical sites have previously been identified on the BNL site that will be reviewed in the NEPA process.

### **1.2.2 Environment, Safety and Health Procedural and Regulatory Compliance**

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). Since the project will be a Major System Acquisition the preparation of a Preliminary Safety Assessment Document (PSAD) is required as a scoping document for the hazards involved in construction and operation. The PSAR will also be the basis for the EA and must be complete and reviewed by DOE before funding is approved to start construction. The main 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, will later document the resolution of them in the final detailed design of the architecture and components of the machine. It is customary for DOE to review these safety documents by utilizing an external independent review teams throughout the preliminary and final design stages. DOE is presently “self-regulating” in the areas of industrial safety and occupational radiation protection. This situation could change at some future time if external regulation is applied to DOE facilities. Related developments are being monitored closely to identify new requirements or procedures that might apply to new projects such as the Neutrino Source.

## **1.3 Occupational Safety During Construction of the Facility**

The beamlines all would be located at or just below grade, but above the water table. At this level, construction is likely to proceed by the standard “cut and fill” method. The Occupational Safety and Health Administration regulations (OSHA) in 29 CFR 1926 apply to the construction activities. These rules are flowed down to BNL staff and contractors through SBMS and general conditions specified in contracts, as appropriate. There are no unconventional occupational safety issues expected to be associated with the construction work. The beamlines and target station will be heavily shielded to reduce onsite and offsite exposure from prompt radiation. The shielding will typically be constructed with a sand berm as has been employed by other accelerators at BNL. The production target will require a more dense and complex shield matrix to reduce prompt radiation and protect the groundwater in the vicinity, but the design will not present any special problems with respect to conventional construction .

## 1.4 Environmental Protection During the Construction of the Facility

The Laboratory as an institution is registered to the ISO 14001 Environmental Management System (EMS) [1], which will be used as the platform to identify Environmental Aspects and Impacts during construction. The EMS process will identify Operational Controls to ensure the legal and other requirements are maintained to protect the environment and provide the framework to manage the Environmental Aspects.

Based on the past experience with the conventional construction at RHIC, environmental protection must be addressed during the conceptual design phase. With respect to the restoration of the forested area that will be disturbed to build the beamlines, only the area of the beam enclosure will be cleared to minimize this impact. If additional fill material is needed to construct sand berms for shielding, clean fill will be brought in from off-site without disturbing any existing vegetated land. A plan to restore the environment will be required to facilitate regrowth of the vegetation on the disturbed land and over the newly constructed beamlines.

### 1.4.1 “Ordinary” Operational Occupational Safety Hazards

The operational occupational safety hazards typically encountered at BNL and 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.
- 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.

## 1.5 Novel Occupational Safety Hazards

### 1.5.1 Use of Nonflammable Cryogenics

The extensive use of large amounts of nonflammable cryogenics in both magnets and RF structures presents special problems, but similar to those solved at RHIC and other accelerators facilities. Portions of these cryogenic systems will reside in machine enclosures and present oxygen deficiency hazards (ODH). As was done for the cryogenic components in RHIC, the ASME Boiler Code will be used in design as previously described in the RHIC SAD. The Oxygen Deficiency Hazards Subject Area [1] will be followed to implement worker controls in operations.

### 1.5.2 Use of Flammable Cryogenics

The use of ionization cooling in a liquid hydrogen (LH2) medium presents significant fire and explosion hazards. Also, the LH2 cells will be interleaved with RF structures and magnets that handle a great deal of electrical energy. In the past, BNL has successfully used stringent review procedures involving

internal Cryogenic Safety Committee as well as external review committees of experienced individuals to provide advice on the design basis and management of cryogenic systems. Because of the high level of hazard nature and expected large volume of LH2 an intensive process of safety review will begin at the earliest reasonable stage in the design process.

### 1.5.3 Muon Storage Ring Life Safety (Egress) Considerations

The MuSR, as aligned for this study, constitutes a long above grade tunnel sloped at a the ring is tilted 13.1 degrees with respect to the horizontal. The fire protection/egress considerations of this configuration will need to be evaluated for life safety by a 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.

### 1.5.4 Muon Storage Ring Slope Hazards

The steep slope of the MuSR presents unique hazards during operation as well as during construction. There will be safety engineering consideration to move heavy machine components and equipment to support installation and maintenance. 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.

## 1.6 Prompt and Residual Radiation Safety During Operation of the Facility

### 1.6.1 Proton Driver

#### Production Target and Prompt Radiation Shielding

The conceptual target design is a 5 mm radius liquid mercury jet with a velocity of 30 m/s. The jet is tilted vertically downward at an angle of 100 mrad with respect to a 20 T solenoidal field. A 24 GeV proton beam with an RMS radius of 1.5 mm tilted vertically downward at an angle of 67 mrad with respect to that same solenoidal field collides with the mercury jet 45 cm from the jet nozzle. That 45 cm distance is to the intersection of the jet and beam centers; due to the finite diameter of the jet and the beam, they interact over a range of 15 cm to 75 cm from the nozzle. The nozzle is embedded in an iron pole face which helps control the uniformity of the solenoidal field, and the proton beam will be coming through that same pole face. Every 400 ms, 6 bunches of  $1.7 \times 10^{13}$  protons each, separated by 20 ms, will hit the mercury jet target.

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 and intensity regime. Detailed calculations made using MARS have already been performed to assess the prompt radiation inside the target hall a carbon based determine the amount of shielding required for a similar proposal made by Fermilab [2]. The transport of beam from the synchrotron to the Target Station poses no peculiar problems with respect to prompt radiation shielding although a deployment of a Design Basis Accident (DBA) and Beam Loss Scenario as was done for the RHIC Project is needed to complete the

detailed design of shielding for the various regions of the beamline [3], as well as for analysis of the existing AGS ring to model the current infrastructure for addition upgrades shielding and penetrations

The Proton Driver, under maximal operation, will handle an expected 7-14 times the beam power of the present AGS complex. Since the impacts to the AGS ring would scale roughly with the beam power, modifications to handle such a large upgrade are planned. Direct injection to AGS from a new 600 MeV Linac instead of existing Booster, coupled with the improved transition crossing with gamma T jump, should lead to lesser beam losses during the acceleration and ejection of beams. Therefore, it is assumed that the normal beam loss per second in the AGS will remain at or less than the current level. The handling of this large beam power has already received, and merits, careful attention. 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 impacts.

Because BNL resides on a Sole Source Aquifer, activation of soil and contamination of groundwater are both considerations near the target station. The amount of high density shielding, i.e. steel, tungsten, must be optimized to mitigate production of H-3 and Na-22 along with moisture barriers to prevent migration of the isotopes to the water table.

A study to assess shielding of prompt radiation from the storage ring was performed using MARS. [15] For a muon beam momentum of 20 GeV/c,  $2 \times 10^{20}$  muons per year decay in the straight section of the storage ring. The straight section is 126 m long, and the arcs are 53 meters for 180 degrees of rotation, (16.87 m radius). The BNL administrative design criteria for control of off-site radiation dose equivalent is 5 mrem/yr, and the drinking water standard in DOE Order 5400.5 requires less than 1 pCi/mL tritium and 0.2 pCi/mL Na-22. For shielding calculations, the Fermilab wet soil properties were used with the density of 2.24 g/cm<sup>3</sup> and scaled to the BNL value of 1.9 g/cm<sup>3</sup>. For neutrino-induced radiation, the soil density is negligible; therefore the results are transferable to BNL soil. Using the above assumptions the required soil thicknesses scaled to the BNL soil density of g/cm<sup>3</sup> are listed below [15]:

- During normal operation and a design criterion of 0.25 mrem/hr, occupancy in the underground facilities (electrons rooms, etc.), there must be at least 7-8.3 m of shielding outward from the arc tunnel enclosure, and 2.4-3 m of shielding on all other sides of the tunnel. The radiation that is being shielded from here is due to electron showers.
- For groundwater protection from radiation due to electron showers, a geomembrane is required to prevent water flow within 1.8 m of the tunnel in all directions. In addition, there must be a geomembrane preventing water flow through a region extending 3.5 m from the end of each straight section in the direction of those straight sections. As for neutrino-induced activation, it results in radionuclide concentrations a factor of 800 below BNL-imposed limits for tritium, and even lower for Na-22.
- To meet the off-site radiation requirement of 5 mrem/yr due to neutrino-induced radiation, a plane extending 30 m from the outside of the arc tunnel enclosure, within a band +/- 10cm from the orbit plane, must be kept on-site (see Fig. 1.1). In addition, an ellipsoid of 2 m half-width, 1300 m long, the long axis extending in the direction of the production straight, must be kept within the site (see Fig. 1.2 and discussion in Section 1.6.3).

### Residual 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<sup>-1</sup> (tens of Sv h<sup>-1</sup>). There will also be significant activation of

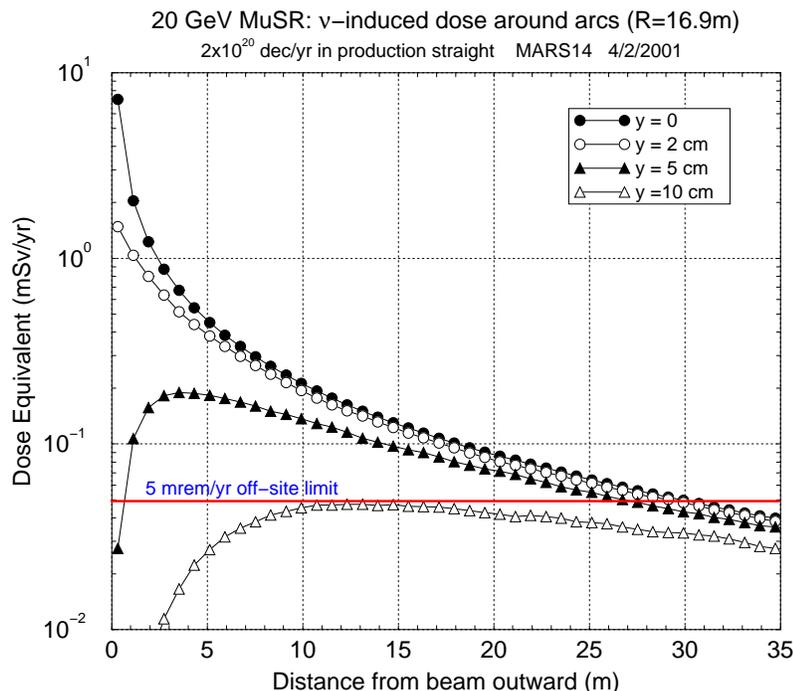


Figure 1.1: Neutrino-induced dose around the arcs as a function of the distance from the arc.

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 Neutron Science Center (LANSCE) and those planned for the Spallation Neutron Source (SNS) at the Oak Ridge National Laboratory will be needed.

Fission products will be produced from the primary interactions of protons on elemental mercury resulting in a source term of volatile and non-volatile radionuclides. Air activation will be enhanced by the neutrons that will be produced from (p, Hg) interactions. Some of the isotopes produced in the target will exceed the thresholds for a Non-reactor Nuclear Facility. Therefore the target will require compliance with 10 CFR 830 Nuclear Safety Management and a DOE approved Safety Analysis Report. Nuclear 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 a Nonreactor Nuclear Facility excludes accelerators such that the balance of the complex will remain regulated under the Accelerator Safety Order, DOE 420.2. Definition of the facility as a nuclear facility needs to be resolved. The target station from a regulatory standpoint, should be segregated from the rest of the facility to the extent possible. The Laboratory continues to monitor the ongoing development of DOE requirements on this topic.

### 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 muon facility. At this early stage, a comparison with the work already done by Fermilab on the NuMI Target Station [6] may be useful since the beam powers

## 1.6. PROMPT AND RESIDUAL RADIATION SAFETY DURING OPERATION OF THE FACILITY 7

of the two facilities are comparable, although the source term for the Hg target is likely to exceed that Fermilab analysis of a carbon target and the site boundary distance may be different. The NuMI Target Station in the Fermilab proposal 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  $^{11}\text{C}$  (half-life = 20.3 min.) and 9.8 Ci (363 GBq) of  $^{41}\text{Ar}$  (half-life = 1.83 hours). Such releases will result in an annual dose equivalent of about 0.009 mrem (0.09 microSv) at the Fermilab site boundary. An evaluation of the offsite dose equivalent from airborne releases from the BNL design is required to assess whether 0.1 mrem (1 microSv) in one year may occur. If that threshold is possible at the site boundary from the new beamlines at BNL, then a NESHPS Permit must be submitted. A continuous monitoring program and other requirements are specified by U. S. Environmental Protection Agency Regulations. [7] The monitoring program will have to be designed to demonstrate that the regulatory limit of 10 mrem (100 microSv) in one year is not exceeded. The design of the beam enclosure ventilation system will have to maximize the decay in transit and/or filtration from the point of production to the point(s) of release.

### Radioactivity in Soil and Groundwater

The calculation of the radioactivity produced in the soil for entire facility can be accomplished using current versions of Monte-Carlo shielding codes. As stated above the Target Station is the most significant source. The impact of the beam loss on soil and ground water will be reassessed for new beamlines as well as the AGS Complex as part of the design process.

### 1.6.2 Cooling Stages and Muon Acceleration Stages

In the Cooling Stages, the collected muons from pion decays will deposit considerable energy in the LH2 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.

### 1.6.3 Muon Storage Ring

#### 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[9],[10]. 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 [11]. These limits rather clearly refer

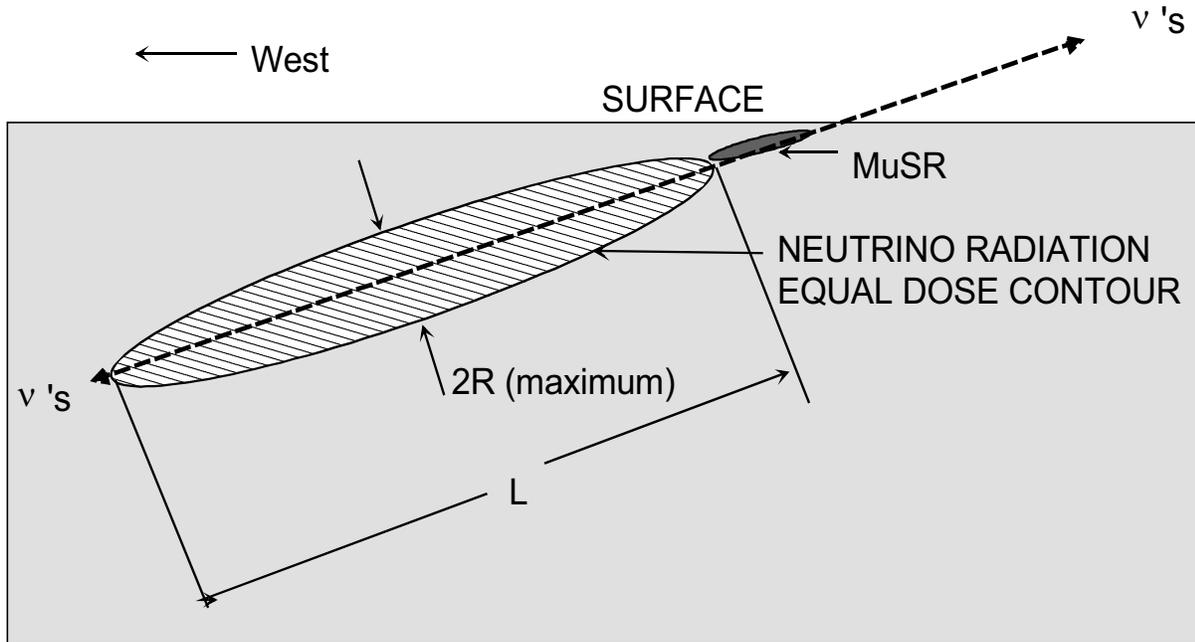


Figure 1.2: Schematic representation of the neutrino radiation fields due to muon decays in the MuSR. The gray region is the earth while the cross-hatched region is a schematic representation of the region inside of a selected contour of equal dose equivalent due to the neutrinos resulting from downward 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.

to the dose equivalent that could plausibly be delivered to actual people. For individual members of the public, the limit in DOE Order 5400.5 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) [12]. Figure 1.2 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 to 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) [13]. As stated in Section 1.6.1 and

as applied to BNL, to meet the off-site radiation requirement of 5 mrem/yr due to neutrino-induced radiation, a plane extending 30 m from the outside of the arc tunnel enclosure, within a band +/- 10cm from the orbit plane, must be kept on-site (see Fig. 1.1). In addition, an ellipsoid of 2 m half-width, 1300 m long, the long axis extending in the direction of the production straight, must be kept within the site. In that regard, because the eastern site boundary is 2200 m away, 1300 m to the east of the proposed location for the storage ring is well within the BNL site boundary. At the BNL site boundary the trajectory of beam put it at an elevation of 335 m. Therefore it can reasonably assumed that a high-rise building that large will not be built, and no occupancy will occur in that aperture.

### **Other 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 [14]. Residual dose equivalent rates due to these cascades will be small, less than about 1 mrem h<sup>-1</sup> (10 microSv h<sup>-1</sup>) 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.

## **1.7 Non Radiological Environmental Protection Issues During Operation**

### **1.7.1 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 regulated mixed or hazardous wastes and to control environmental spills. Surface water discharges should be managed in accordance with the current Laboratory policies and any New York State SPDES permits already in place. In general management of regulated materials will be via the ISO 14001 EMS.

### **1.7.2 Muon Storage Ring**

The location of the MuSR over a sole Source Aquifer especially stringent protection against spills. Careful attention to these problems and employment of EMS elements during the design and construction phases should lead to their successful solution.

## **1.8 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 BNL and other accelerator laboratories. 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.

# Bibliography

- [1] Brookhaven National Laboratory Standards Based Management System (SBMS), [www.sbms.bnl.gov](http://www.sbms.bnl.gov).
- [2] N. V. Mokhov, Particle Production and Radiation Fields at a Neutrino Factory Target Station, presentation at BNL, January 29-31, 2001.
- [3] Stevens, A., Musolino, S., and Harrision, Design Criteria For Prompt Radiation Limits on the Relativistic Heavy Ion Collider Site, *Health Physics*, 66, (1994), 300-304.
- [4] M. Barbier, *Induced Radioactivity*, (North-Holland Publishing Company, Amsterdam and London, Wiley Interscience Division, John Wiley and Sons, Inc, New York, 1969).
- [5] U. S. Department of Energy, "Nuclear Safety Analysis Reports," DOE Order 5480.23, April 30, 1992. The classification criteria specified in this Order are provided in a DOE Standard, "Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports," DOE-STD-1027-92 Change Notice No. 1, September 1997. The criteria are augmented by additional radionuclides in LA-12981-MS, UC-940, "Table of DOE-STD-1027-92, Hazard 3 Threshold Quantities for the ICRP-30 List of 757 Radionuclides," Los Alamos National Laboratory Report, August 1995.
- [6] N. L. Grossman, D. J. Boehnlein, and J. D. Cossairt, "Production and Release of Airborne Radionuclides Due to the Operation of NuMI," Fermilab Report TM-2089, August 1999.
- [7] United States Code of Federal Regulations, Title 40, Part 61, Subpart H, "National Emissions Standard for Hazardous Air Pollutants (NESHAP) for the Emission of Radionuclides other than Radon from Department of Energy Facilities," 1989.
- [8] J. D. Cossairt, "Use of a Concentration-Based Model for Calculating the Radioactivation of Soil and Groundwater at Fermilab," Fermilab Environmental Protection Note 8, December 1994 and J. D. Cossairt, A. J. Elwyn, P. Kesich, A. Malensek, N. Mokhov, and A. Wehmann, "The Concentration Model Revisited," Fermilab Environmental Protection Note 17, June 1999.
- [9] J. D. Cossairt, N. L. Grossman, and E. T. Marshall, "Assessment of Dose Equivalent Due to Neutrinos," *Health Physics* 73 (1997) 894-898.
- [10] N. V. Mokhov and A. Van Ginneken, "Neutrino Induced Radiation at Muon Colliders," presented at the 1999 Particle Accelerator Conference, New York, New York, March 19-April 2, 1999, FERMILAB-Conf-99/067.
- [11] U. S. Department of Energy, "Radiation Protection of the Public and the Environment," DOE Order 5400.5, January 7, 1993.

- [12] National Council on Radiation Protection and Measurements, Ionizing Radiation Exposure of the Population of the United State and Canada from Natural Background Radiation, NCRP Report No. 94, December 1987.
- [13] N. Mokhov, private communication, January 2000.
- [14] N. Mokhov, "Radiation Load on Muon Storage Ring Magnets," Presentation given at Fermilab, January 25, 2000.
- [15] N. Mokov, Fermilab email communication to J..S. Berg, Radiation around storage Ring, April 2, 2001.