Fermi National Accelerator Laboratory

Safety Assessment Document

Revision 5

April 30, 2013

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SAFETY ASSESSMENT DOCUMENT ACCELERATOR READINESS REVIEW DOCUMENTATION FORM

This form records the PSAD/SAD/ARR review process required for operations at Fermi National Accelerator Laboratory.

PSAD/SAD/ARR TITLE AND DATE: Fermi National Accelerator Laboratory
Safety Assessment Document
April 30, 2013

THIS DOCUMENT DESCRIBES:

New Facility		New Experiment	
Existing Facility	X	Major Modification	
Entire Program		Decommissioning	
Readiness Review			

FERMI NATIONAL ACCELERATOR LABORATORY

Safety Assessment Document Approval	X	Completion of Readiness Review	
Authorization to Operate Facility	X	Program/Facility Requires PSAD	

Project Leader/Date: [signature] 2 MAY 13
LINAC CHAPTER

Project Leader/Date: [signature] 05/02/13
Main Injector / Recycler Chapter

Fermilab Division/Section/Center Head(s)/Date: [signature]

Fermilab ESH Director/Date: [signature] 5-7-13

Fermilab Director/Date: [signature] 5/13/1
(if appropriate)

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Revision History

Author	Description of Change	Revision No. & Date
John E. Anderson Jr.	Appendix A - Accelerator Safety Envelope, Revision 4, April 25, 2013. Updated DOE O 420.2B to DOE O 420.2C. Updated ASE text to reflect credible accident scenarios. Modified Operating and Safety Envelope beam parameters for the Main Injector, Recycler, and NuMI. Updated shielding assessment references for the revised Main Injector, Recycler, and NuMI shielding assessments. Updated Linac groundwater limit reference to new MARS calculations. Removed Operating and Safety Envelope beam parameters for Tevatron Circulating Beam, A0 and C0 Abort Absorbers, and the Pelletron; placing the areas in standby. Removed the Booster Radiation Damage Facility Operating and Safety Envelope beam parameters.	
John E. Anderson Jr. David Capista	Initial release of the Main Injector/Recycler Chapter for the Fermi National Accelerator Safety Assessment Document (SAD). Revision 0 April 23, 2013.	
William Pellico, Fernanda G. Garcia	Initial release of the Linac Accelerator Chapter of the Fermi National Accelerator Safety Assessment Document (SAD). Revision 0, March 18, 2013.	Revision 5 April 30, 2013
John E. Anderson Jr.	Appendix A - Accelerator Safety Envelope, Revision 3, February 15, 2012. Added beam limits for the Neutrino Area.	
Thomas R. Kobilarcik	Initial release of the Neutrino Area Chapter for the Fermi National Accelerator Safety Assessment Document (SAD). Revision 0 February 14, 2012	
John E. Anderson Jr.	Initial release of the 8 GeV Line Chapter for the Fermi National Accelerator Safety Assessment Document (SAD). Revision 0 January 20, 2012	
Eric McHugh	Initial release of the MiniBooNE Detector chapter of the Fermilab Safety Assessment Document (SAD). Revision 0 January 9, 2012	Revision 4 February 16, 2012

Peter Kasper Elmie Peoples-Evans Robert C. Webber	Initial release of the High Intensity Neutrino Source (HINS) Linac at Meson Detector Building (MDB) Chapter for the Fermi National Accelerator Safety Assessment Document (SAD) Revision 0 March 21, 2011	
John E. Anderson Jr.	Revision 2, Appendix A - Accelerator Safety Envelope. Added beam limits for HINS Linac.	Revision 3 March 21, 2011
Herman B. White	Initial release of the MuCool Test Area (MTA) Chapter for the Fermi National Accelerator Safety Assessment Document (SAD) Revision 0 January 20, 2011	
John E. Anderson Jr.	Revision 1, Appendix A - Accelerator Safety Envelope. Added beam limits for MTA.	Revision 2 January 20, 2011
	Revision 0, initial release of the Fermilab SAD Section ,I Chapters 1 – 10, Overview of Fermilab Facilities.	
John E. Anderson Jr.	Revision 0, initial release of Appendix B - Fermi National Accelerator Laboratory Shielding Policy.	Revision 1 October 26, 2010
John E. Anderson Jr.	Revision 0, initial release of Appendix A - Accelerator Safety Envelope.	Revision 0 December 10, 2009

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Fermi National Accelerator Laboratory Safety Assessment Document

Section 1 Overview of Fermilab Facilities

Revision 0
October 26, 2010
Author(s)
John E. Anderson Jr.

Revision History

Author	Description of Change	Revision No. & Date
John E. Anderson Jr.	Initial release of the Fermilab SAD Section I, Chapters 1 – 10, Overview of Fermilab Facilities.	Revision 0 October 26, 2010

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Section I Table of Contents

I - 1 Executive Summary

The Fermi National Accelerator Laboratory (Fermilab) facilities are subject to the requirements of the Department of Energy (DOE) Accelerator Safety Order (ASO), DOE O 420.2B[1]. These requirements are promulgated through the Fermilab Directors Policy Manual[2], the Fermilab Environment, Safety, and Health Manual[3] (FESHM) and the laboratory's Radiological Control Manual[4] (FRCM). Fermilab is classified and designed as a low hazard facility. Low-hazard facilities are defined in DOE O 420.2B to be facilities with no more than minor on-site and negligible off-site impacts to people or the environment.

A detailed analysis of the hazards found at Fermilab has been conducted and documented in this Safety Assessment Document (SAD). The results presented in this SAD, along with the supporting documentation, describe the measures used in the Fermilab Accelerator Facility to conform to the standards presented in the FESHM and FRCM such that the potential for hazards are reasonably minimized. From these analyses, the Accelerator Safety Envelope (ASE), Appendix A, has been developed to define the physical and administrative controls that define the bounding conditions for safe operation of the facility. Operations within the ASE provide adequate assurance that the hazards to employees, the public, and the environment from facility operations are negligible both onsite and offsite.

I - 2 Introduction

Fermilab is operated by the Fermi Research Alliance (FRA), LLC for the U.S. Department of Energy. This SAD has been prepared to meet the requirements and definitions of the DOE Accelerator Safety Order, DOE O 420.2B consistent with best practice outlined in DOE G 420.2-1[5].

I - 2.1 Scope, Objective, and SAD Document Layout

The scope of this document covers the Fermilab facilities, experimental areas and experimental detectors, accelerator research and development areas, and radiological facilities serving accelerator operations.

The objective of this assessment is to document both the typical industrial and uniquely accelerator-specific hazards presented by the operation of the Fermilab facilities. It conforms to the standards presented by the Fermilab Director's Policies, Fermilab Environment Safety and Health (ES&H) Manual, and the Fermilab Radiological Control Manual. These documents contain Fermilab's implementation of all applicable ES&H laws, regulations, and contractual Work Smart Standards Set[6], and provide the framework for Fermilab's ES&H training program. This SAD provides the necessary information to demonstrate that operation of Fermilab's accelerators, associated experimental areas, and accelerator research and development areas can be conducted in a manner that will produce minimal risks to the health and safety of Fermilab personnel, visiting scientists, the public, and the environment.

The SAD is divided into five major sections and two appendices. Section I contains an overview of the Fermilab facilities. Section II contains a description of each accelerator module. An accelerator module is a distinct, stand-alone section of the Fermilab facilities. Section III describes the experimental areas and experimental detectors used at Fermilab. Section IV covers the advanced accelerator research and development areas and Section V covers the radiological support facilities that serve accelerator operations. Appendix A contains the ASE and Appendix B is the Fermilab Shielding Policy. The document layout was chosen to create the framework necessary to develop a SAD that is coherent, readily adaptable to the ever-changing program of accelerators, experiments, and their operations, internally consistent in both content and nomenclature, and non-redundant in content.

I - 2.2 Assessment Methodology

Section I Chapter 4 takes a systematic approach to identifying the conventional industrial and uniquely accelerator-specific hazards presented by accelerator operations at Fermilab. The conventional industrial hazards are discussed along with the Fermilab policies that are in place to mitigate those hazards. The measures used to control and mitigate conventional hazards conform to generally accepted national codes and/or standards.

The uniquely accelerator-specific hazards warrant further analysis. Section I, Chapter 4 provides an overview discussion of hazards in this category along with the mitigation measures used to reduce the risk to acceptably low levels. The hazards in this category form the basis for the credited controls that are necessary for safe accelerator operations and the set of all credited controls form the ASE detailed in Appendix A. Additional details and analysis of these uniquely accelerator-specific hazards for a specific area are contained in the individual chapters of Sections II through V.

I - 3 Site, Facility Design Criteria, and Operations

I - 3.1 Fermilab Purpose

The primary purpose of Fermilab is to make the particle beams provided by the accelerators available to qualified experimenters conducting high energy physics and particle beam physics research. Fermilab is uniquely positioned at the energy and intensity frontiers providing proton and electron beams for this kind of basic research.

The mission of Fermilab is to advance the understanding of the fundamental nature of matter and energy by providing leadership and resources for qualified researchers conducting basic research at the frontiers of high energy physics and related disciplines. This mission is accomplished by Integrated Safety Management of operational and safety concerns at all levels of the laboratory organization. The laboratory is committed to excellence based on its use of best business management practices and continuous improvement in all aspects of its work. This includes ensuring the safety and health of staff and visitors, a safe work environment, and minimal impact to the environment.

I - 3.2 Site Overview

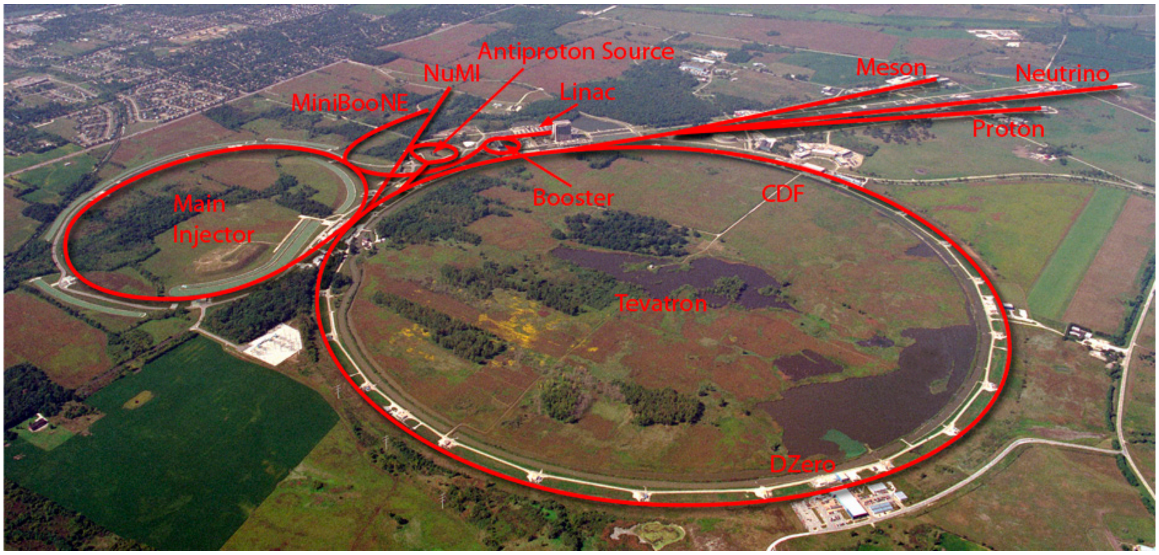
I - 3.2.1 Site Location

The 6,800 acre Fermilab site was acquired in the late 1960s by the Atomic Energy Commission from the State of Illinois; see section I-3.2.2 below for an aerial site map. The dividing line between Kane County and DuPage County passes through the site from north to south, with the majority of the site located in DuPage County.

The development of permanent facilities has generally followed the initial site planning which was accomplished in the late 1960s and early 1970s, modified from time-to-time by programmatic needs to the current date. The Tevatron is located in the south central portion of the site with the adjacent Linac, Booster, and Main Injector including the Recycler, located to the west along with the Antiproton Source. Three major fixed-target beam line areas, Meson, Neutrino, and Proton extend from the Switchyard area which in turn extends from the northwest side of the Tevatron enclosure and points in a northeasterly direction. The two neutrino beamlines, MiniBooNE and NuMI extend from the northeast side of the Main Injector in a northwesterly direction. New facilities, as they are developed, continue to be assessed for environment, safety, and health considerations early in the design process, according to the requirements of the FESHM.

I - 3.2.2 Site Map

Aerial view of Fermilab site with major accelerator sections overlaid.



I - 3.2.3 Site Design Criteria

The Fermilab facilities are required to conform fully to the requirements imposed by all applicable Federal, State and local laws, orders, and regulations concerning Environment, Safety and Health as expressed in the Fermilab Work Smart Standards. The operations shall also conform fully to the requirements imposed by the FESHM, the FRCM, and the Fermilab Emergency Response Plan[7]. The civil construction phases followed all applicable building codes and standards at the time of construction.

In all instances, where any applicable ES&H requirements are in conflict, the requirements leading to the higher level of safety apply. Where no specific codes or Fermilab standards existed, the designers used best engineering practices, peer review, and/or outside consultants during the design stage.

I - 3.2.3.1 Worker Safety Program

Fermilab policy states that employees, subcontractors and users will only perform work in a safe and environmentally sound manner. To that end, Fermilab has integrated environment, safety and health protection into all aspects of work via its Integrated Environment, Safety and Health Management (IES&HM) program. The Worker Safety and Health Program[8] (WSHP) is one aspect of the overarching IES&HM program, and implements DOE regulations found at 10 CFR 851[9]. The WSHP also integrates the IES&HM program and the Work Smart Set of

Standards (WSS) that have been incorporated into the Management and Operating contract between DOE and FRA.

Fermilab management and staff are committed to safe operations. The laboratory has established the following safety priorities: 1) the ES&H Director is a member of the laboratory Directorate, or "key personnel" within FRA; 2) weekly senior staff meetings include safety discussions; 3) cutting edge communications and data management tools advance safety performance; 4) program documentation such as the Director's Policy Manual, the FESHM, the ES&H training program, and relevant databases and guidance are readily available on the ES&H website; and 5) employee input assures a more complete program tailored to the hazards and the work to be performed. Employee involvement also promotes employee acceptance of requirements and commitment to comply.

I - 3.2.3.2 Radiation Safety Program

The operation of the Fermilab facilities conforms to the FRCM, and thus achieves conformance with applicable requirements of Title 10, Code of Federal Regulations, Part 835; keeping radiation exposures of operating personnel As Low As Reasonably Achievable (ALARA); maintaining control of radioactive contamination and radioactive materials; complying with environmental radiation limits; and satisfies environmental monitoring requirements. Design, installation, use and maintenance of the following are also in conformance with the FRCM and consistent with the Fermilab SAD: signs and posting of areas in which radiation may be present, radiation safety interlock systems, interlocked radiation detectors, search and secure procedures, controlled access procedures, personnel training, procedures for maintenance and testing of radiation safety interlock systems, and documentation of radiation safety interlock systems.

I - 3.2.3.3 Environmental Protection Program

All operations and maintenance activities shall conform to environmental protection requirements stated in the 8000 series chapters of the FESHM as well as applicable state and federal regulations (e.g., Title 40 of the Code of Federal Regulations and Title 35 of the Illinois Administrative Code). Chapter 8010 describes Fermilab's overall Environmental Management System that was developed to conform to ISO standard 14001. Fermilab is registered to that standard. Specific environmental topics covered in the 8000 series include, but are not limited to, erosion control, chemical and radioactive waste management, wastewater discharges to sanitary sewers, oil pollution prevention, air emissions control, and National Environmental Policy Act (NEPA) review.

I - 3.2.3.4 Fire Protection Program

The operation and maintenance of the Fermilab facilities follows the fire safety requirements found in the FESHM. A computerized Fermilab Incident Reporting and Utility System (FIRUS) monitors the accelerator facility fire alarm systems. Fire protection-related equipment or status that FIRUS monitors includes: smoke and heat detectors, sprinkler flows, pull stations, very early smoke detection alarm (VESDA) systems, emergency power back-up generators, and redundant sump pumps. FIRUS also monitors other equipment not related to fire protection (e.g., site utility and security systems). The Communications Center continually monitors the FIRUS system and dispatches the on-site Fermilab Fire Department and other emergency services in response to an alarm.

The Fermilab Fire Department provides site fire suppression and emergency medical services (EMS). The Fire Department is Certified by the State of Illinois and follows the National Fire Protection Association (NFPA) 1500 Standard on Fire Department Occupational Safety and Health Program and 1710 Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments requirements for Fire Departments.

Buildings are designed to the International Building Code and applicable NFPA Codes and Standards and maintained under the code of record. Underground facilities are designed using NFPA 520: Standard on Subterranean Spaces. The Site-Wide Emergency Warning System (SEWS) provides mass emergency notification to all occupied buildings and remote personnel through integration with life safety voice systems and pagers.

I - 3.2.3.5 Other Design Criteria

The operation of the Fermilab facilities conforms to the Occupational Safety and Health requirements stated in the 5000 series chapters of the FESHM. Topic areas addressed include: powered lifting equipment, pressurized gas safety, including pressure vessels, general electrical safety, chemical safety, industrial hygiene requirements, biological hazards, engineering controls, protective clothing and equipment, warning signs and devices, and lock out and tag out procedures. Construction modifications or additions involving subcontracted labor to the Fermilab facilities also conform to the requirements stated in the 7000 series chapters of the FESHM.

I - 3.2.4 Organization

The Fermilab organization is based on a line management structure. The head of the Laboratory organization is the Director. The laboratory is further divided into Divisions, Sections, and Centers (D/S/C) based on organizational and project need.

The laboratory ES&H Section primarily advises the Directorate and the other D/S/Cs on all ES&H matters, whereas the Director and heads of the Divisions, Sections, and Centers implement ES&H policy through the line management organization.

The Director has established the Fermilab Environment, Safety, and Health Committee (FESHCom). It is chaired by the Chief Operating Officer and consists of a representative from each Division and Section. The FESHCom has established several standing subcommittees. These subcommittees are primarily composed of technical and ES&H professionals; the chairs of these subcommittees are also members of the FESHCom. The subcommittees provide a means for independent safety reviews of designs by people who are both technically knowledgeable and also independent of the line managers who have direct line responsibility for the work that is under review.

The Chair of FESHCom has established two review subcommittees, the Safety Assessment Document and Shielding Assessment Document review subcommittees. These two subcommittees have the responsibility to review the results of each safety assessment document chapter and shielding assessment for methodology, completeness, and compliance with the FESHM and FRCM.

In accordance with the FESHM Chapter 2010, each D/S/C Head establishes a policy which covers the safety review of projects that are not automatically subject to review by the Fermilab ES&H Section.

The Fermilab Integrated Safety Management Plan[10] (ISMP) documents define the functional relationships among the Fermilab D/S/Cs, ES&H Section, FESHCom, and other Laboratory organizations. The ES&H responsibilities of the ES&H Section and the other D/S/Cs are provided in detail in the FESHM.

I - 3.2.5 Experimental Programs

Scientists have identified three frontiers of scientific opportunity for the field of particle physics: the Energy Frontier, the Intensity Frontier and the Cosmic Frontier. Answers to the most challenging questions about the fundamental physics of the universe will come from combining the most powerful insights and discoveries at each of the three frontiers. Fermilab's scientific program pushes forward with world-leading research at all three interrelated frontiers.

I - 3.2.5.1 Energy Frontier Physics

Particle accelerators at the Energy Frontier produce high-energy collisions that signal new phenomena, from the origin of mass to the nature of dark matter and extra dimensions of space. Fermilab's Tevatron experiments, CDF and DZero, continue to set new records in a physics program of exciting discoveries and ultra precise measurements, involving over 1,000 scientists from 150 institutions in some 30 states and 30 countries. Fermilab is the U.S. host laboratory for the CMS experiment at the Large Hadron Collider at CERN, in Geneva, Switzerland. Some 1,700 U.S. scientists from 87 universities and seven national laboratories carry out research at the LHC, the world's new energy-frontier accelerator.

I - 3.2.5.2 Intensity Frontier Physics

Scientists use intense beams from particle accelerators for intensity-frontier experiments that explore neutrino interactions and ultra-rare processes in nature. Neutrino discoveries are central to understanding key questions of 21st century physics: How did the universe come to be? What happened to the anti-matter? Do all the forces unify? Precise observations of nature's rarest processes open a doorway to realms of ultra-high energies beyond those that any particle accelerator could ever directly achieve, to the region where physicists believe all of nature's forces become one.

I - 3.2.5.3 Cosmic Frontier Physics

At the Cosmic Frontier, astrophysicists use the cosmos as a laboratory to investigate the fundamental laws of physics from a perspective that complements experiments at particle accelerators. Thus far, astrophysical observations, including the bending of light known as gravitational lensing and the properties of super-novae, reveal a universe consisting mostly of dark matter and dark energy. A combination of underground experiments and telescopes, both ground-and space-based, will explore these mysterious dark phenomena that constitute 95 percent of the universe.

I - 3.2.5.4 Accelerator Physics and Engineering

From the construction of the first particle accelerators in the 1930s to the latest 21st-century innovations, the revolutionary ideas and technologies of particle physics have entered the mainstream of society and transformed the way we live. Today, more than 17,000 accelerators are in operation around the world in industry, in hospitals and at research institutions. PET scans, superconducting wire, synchrotron light sources, cancer treatment, grid computing and the development of the World Wide Web are just some of the applications that have come from particle physics laboratories. Fermilab continues to explore new accelerator physics and engineering technologies to advance accelerator research and further transform the way we live.

I - 3.2.6 Operations

The Fermilab facilities are a complex of particle accelerators and beam transport enclosures used to provide the proton and antiproton beams used in the Laboratory's experimental research program. The main accelerator facilities can operate in either or both of two modes: fixed-target, in which beams of accelerated particles are directed upon a number of stationary targets in various locations, or colliding beam, where beams of protons and antiprotons traveling in opposite directions are brought into collision. In the fixed-target mode, the primary proton beam is distributed among some number of fixed-target beam lines. Each of the fixed-target beam lines can also operate in a variety of different modes depending on the needs of the experimenters using them.

There are a number of experimental research facilities that accelerate electron beams that are directed upon stationary fixed targets. Like the proton accelerator, these research facilities can operate in a variety of operating modes.

The Accelerator Division's Operations Department is responsible for the operation of the majority the accelerator and fixed target transport enclosures, as well as the associated power supplies, electronics, utilities, and control systems. The smaller experimental research facilities are operated by approved members of the experimental collaboration.

I - 3.2.6.1 Commissioning Activities

Initial commissioning of new accelerator modules or experiments is conducted in phases. For accelerator modules, the beamline components are divided into three separate commissioning phases: a) system checkout, b) commissioning with primary beam to satisfy DOE CD-4 requirements, and c) commissioning with primary beam to satisfy physics requirements. The commissioning phases are described in detail in the accelerator module commissioning plans that are part of the Accelerator Readiness Review (ARR).

System checkout is performed after all necessary safety approvals are granted. An ES&H/QA review committee is assigned to oversee the review process for each project. When the project reviews are complete for systems that pose unique hazards, prior to the checkout phase, the review committee requests approval for initial system operation from the relevant D/S/C Head.

After all system checkouts are complete, the accelerator module is physically ready for beam. In accordance with AD Policy ADAP-11-0001[11], the AD Head grants approval for start of commissioning when all necessary safety reviews have been completed, the Accelerator Safety Envelope approved, and the Run Condition approved. The beamline Run Condition documents the radiation safety interlock status and any administrative controls that are required to be in place before the Operations Department is authorized to transport beam within that section of the facility. The Run Condition states the maximum beam intensity that is authorized for the area.

Experiments approved for operation provide a Preliminary Hazard Assessment as part of their MOU with the Laboratory. Generally the Particle Physics Division (PPD) is responsible for conducting ES&H reviews of the systems identified in the Preliminary Hazard Assessment. Documentation of these reviews is the first part of the Operational Readiness Clearance (ORC). The ORC is a permit approved by the PPD head for the commissioning and unattended operation of an experiment system or detector. The ORC process requires documentation of potential hazards and their mitigation, a review of the documentation, and a walk-through inspection of the experiment installation. Sub-systems within a detector can be reviewed individually and granted a partial ORC; as detector installation progresses, partial ORCs are accumulated for all sub-systems. PPD ES&H assigns a review committee to conduct the sub-system reviews and inspections of installations in the experimental areas.

The PPD head grants a final ORC to the experiment, which has the following components:

- Copies of sign-offs from the ES&H review committee(s). This is a collection of partial ORCs.
- PPD determination that the experiment is covered by this SAD. This statement specifies that the experiment complies with the requirements of a specific version of the Safety Assessment Document.
- PPD determination of the need for an experiment Conduct of Operations document. This statement documents the determination that sufficient engineered controls are in place to obviate the need for formal Conduct of Operations.
- Copy of an experiment hazard communications document.

- Verification from spokesperson that any required procedures are approved and in effect. Where safety procedures are required, as determined by the partial ORC reviews, the experiment must demonstrate to the PPD head that these procedures are in place and that appropriate training has been given.

I - 3.2.6.2 Normal Operations

The operational safety of accelerator and experimental areas is maintained through both administrative and hardware mechanisms. The hardware serves as a primary protection and normally the administrative procedures serve as a backup and support or reinforce the limits set through hardware. The exceptions are those administrative mechanisms through which the safety envelope is determined and enforced.

Governing accesses into enclosures is an important part of the responsibilities of the AD Operations Department. There are two basic types of access to these enclosures, supervised and controlled. A supervised access is used when there is a need for extensive work inside an enclosure. In this case, a full radiological survey is performed to document the hazards, and the hardware safety system is used to disable beam so that a Search and Secure of the enclosure needs to be performed before beam can be re-enabled. The AD Operations Department with the ES&H Department is responsible for maintaining a current written Search and Secure procedure, designed to ensure that all personnel have been cleared from an enclosure before a beam permit can be issued by the safety system.

A controlled access is used whenever limited work is being performed and it is desirable to maintain the security of the enclosure. This method of access limits the extent of the access and removes the need for a subsequent Search and Secure. All personnel entering a beam enclosure under Controlled Access conditions are required by the FRCM to complete Fermilab Controlled Access Training, or to be escorted by trained personnel. During a controlled access, each person entering the enclosure must have an enclosure access key in their possession at all times. The enclosure access key is interlocked to the radiation safety interlock system thereby disabling beam until the access is complete and the key is returned. Current written procedures for “Controlled Access” are maintained by the AD.

Before maintenance is performed on devices connected to hazardous energy sources, Lockout/Tagout is performed in compliance with OSHA 29 CFR 1910.147, "The Control of Hazardous Energy", and Chapter 5120 of the FESHM. The operators verify that the people who make accesses meet the training requirements for access, which may include such courses as

Radiation Worker, Controlled Access, Oxygen Deficiency Hazard (ODH), Confined Spaces, and Lockout/Tagout (LOTO) Level 2. In addition to LOTO, as a supplemental safety feature, power supplies with exposed connections and potentially hazardous devices are interlocked off via the safety system.

Administrative procedures and documents, such as Beam Permits and Running Conditions, are used to define safe operational parameters, such as intensity limits, energy limits, and repetition rates. An analysis of the level of protection afforded by the shielding over and around the enclosures is used to determine beam limitations which ensure conformance with the FRCM. These limits are enforced by means of hardware settings that are controlled by the Operations Crew Chief.

The AD ES&H Department keeps a log of the total beam intensities accelerated, transported, and/or delivered to targets, beam absorbers, and experiments. Summaries of these logs are given to the ES&H Section and are included as part of the Environmental Monitoring Program described in Section I Chapter 6. This program defines administrative limits on the total amount of beam that can be delivered to these areas annually.

I - 3.2.6.3 Emergency Management

Emergencies affect normal operations. For on-site emergencies, the laboratory has an emergency management structure in place which is lead by the Emergency Director (Chief Operating Officer) and members of the Emergency Operations Center staff in conjunction with the Incident Commander in the field. This organization is responsible for interfacing with outside agencies, DOE Headquarters, the media, and coordination of emergency response assets and resources. Emergency response procedures are found in the Fermilab Emergency Response Plan. The Hazard Assessment Document[12], updated triennially, contains details of the types of emergencies Fermilab can experience.

Emergencies requiring AD Operations Department response include such things as fire alarms, ODH alarms, radiation alarms, spills and leaks, flammable gas alarms, and other potentially dangerous situations affecting the facility. The AD Operations Department has emergency response procedures that are kept up to date and are consistent with the Fermilab Emergency Response Plan. These procedures consist of specific instructions and/or flowcharts to be used by both the control room and the operators responding to the emergency in support of the emergency response organization of the Laboratory.

Other events which are beyond the scope and control of the emergency management system include severe weather and offsite events having the potential to impact laboratory operations. The laboratory utilizes the SEWS to pass on information to personnel.

I - 3.2.6.4 Decommissioning Activities

Decommissioning is a general term for a formal process to remove an activity, operation, or facility from active status. As the Fermilab accelerator is developed over time, support facilities, accelerator and beamline equipment, and experiments (all “modules” of the Fermilab accelerator) will proceed through a life cycle. At the completion of the operational stage of the life cycle of a given module, decommissioning will be conducted. ES&H Manual Chapter 8070 is the relevant statement of Fermilab’s policies on decontamination and decommissioning activities.

I - 3.2.6.4.1 The forms of Decommissioning

Decommissioning activities can take several forms:

1. Placement of a given module in a state of preservation awaiting possible resumption of use in a configuration similar in kind to that previously operational state (so-called “mothballing”)
2. Continued maintenance of the civil structure with removal of the equipment utilized during the operational state
3. Removal of the previously operational equipment with the civil structure reconfigured to await some future purpose, defined or undefined at the time of decommissioning
4. Removal of the equipment and civil structure and replacement with a new module
5. Removal of the equipment and civil structure with restoration of the site to a condition similar to the pre-operational state
6. Removal of the equipment and civil structure with restoration of the site to a condition similar to that found before the creation of Fermilab

I - 3.2.6.4.2 Data Collection in Support of Decommissioning

The implementation of FESHM Chapter 8070 throughout the life cycle of a given module of the Fermilab accelerator, inclusive of all Fermilab support facilities, will ensure the collection of the information needed to effectively implement decommissioning, once that time in the life cycle is reached. In particular this information should include the collection of the following for the module to be decommissioned:

1. Volumes, locations, and levels of radioactivity in radioactivated items of equipment, parts of the civil structure, and adjacent shielding components such as soil, concrete, and earth as well as levels of removable radioactivity from components
2. Locations and quantities of hazardous and regulated chemicals
3. Identification of possible areas of potential interference with utilities (electrical, domestic water lines, industrial cooling water systems, low conductivity water systems, cryogenic transfer lines, radiofrequency systems, fire protection systems, controls and communications systems, HVAC systems)
4. Identification of any environmental monitoring points or locations crucial to environmental permit compliance

I - 3.2.6.4.3 The Process of Decommissioning

Decommissioning will proceed through a sequence of stages tailored to the particular end objective of the process as defined by overall Fermilab plans. These stages are anticipated to meet the needs of a particular defined future use for a given module being decommissioned but, in alignment with any relevant DOE-specified project planning activities, would be expected to follows a process such as:

1. Identification of need and scope of decommissioning
2. Compliance with NEPA requirements (see FESHM Chapter 8060) as needed during the planning process
3. Detailed planning including preparation for removal of regulated and hazardous materials, removable radioactivity, activated components and structures, and activated shielding materials as defined within the scope of decommissioning
4. Planning for appropriate disposal of materials and components removed from the module
5. Supervision of subcontractor services used to perform the decommissioning including documentation of all stages of the process, with special attention given to any structures and components that remain in place
6. Documentation of the final state subsequent to completion of decommissioning
7. Certification of completion of decommissioning by Laboratory management including the ES&H Director

I - 4 Safety Assessment

This safety assessment is intended to document the conventional, accelerator-specific, and experimental detector hazards found at the Fermilab facilities. The conventional hazards section contains hazards that are generally found in most industrial environments. As such they do not warrant a specific safety analysis since the measures used to control them conform to generally accepted national codes and/or standards. The accelerator-specific hazards section outlines the hazards and typical mitigation employed to control these hazards. This section forms the basis for the ASE and outlines the typical credited controls instituted to mitigate these hazards to acceptable levels.

I - 4.1 Conventional and Environmental Hazards

These sections describe various conventional and environmental hazards which, apart from exposed electrical bus, have been judged as not warranting specific individual safety analysis since the measures used to control and mitigate these hazards conform to generally accepted national codes and/or standards.

I - 4.1.1 Electrical Hazards

Construction or modification of electrical equipment at Fermilab is done in conformance with the safety and design standards of the FESHM, the Fermilab Engineering Standards Manual[13], the National Electrical Code (NEC NFPA 70), the National Electrical Safety Code (ANSI C2-1984) and OSHA 29 CFR 1910.331-335 "Safety Related Work Practices" where applicable.

Electrical bus work is either protected by physical barriers or is de-energized by the electrical interlock system prior to personnel access to the area. Power supplies that feed power to exposed conductors are required by FESHM and AD ES&H procedures to be connected into the electrical interlock systems. The electrical interlock system provides an additional level of safety but does not replace the need for LOTO when working on hazardous energy sources.

I - 4.1.2 Mechanical Hazards

The small service buildings that house the satellite refrigerators for the Tevatron contain rotating machinery (expansion engines) in a relatively small room. Mechanical guards and emergency stop switches are provided for personnel protection in each of these buildings. A "two-person rule" is enforced in the buildings when the machinery is operating, and the buildings are locked when unoccupied.

Two kinds of transport vehicles used in the Tevatron could cause damage to the superconducting magnet system and thereby generating a possible cryogenic hazard. These are the motorized battery-powered carts used to transport employees working the tunnel and the battery-powered magnet mover used in the tunnel. Fixed barriers have been installed to prevent the battery-powered carts from colliding with valves, gauges, and exposed beam tubes. Administrative procedures require that the magnet mover may not service a component above a Tevatron magnet in the tunnel if there is liquid helium at that location.

Many service buildings and enclosures utilize overhead bridge cranes, hoists, fork trucks, and aerial lifts. All cranes, hoists, and fork trucks are maintained and inspected by FESS-OPS. All crane and fork truck operators complete the appropriate training requirements as identified in their Individual Training Needs Assessments (ITNAs). Aerial lifts are maintained by the lift owner and lift operators are trained by the lift owner.

I - 4.1.3 High Pressure Hazards

High pressure gas systems and pressure vessels are potential mechanical hazards. There are many such systems throughout the complex. A policy for safety reviews for all such vessels has been established at the Laboratory and is outlined in the FESHM. The Laboratory's policy requires that pressure vessels purchased by or built at Fermilab be fabricated in accordance with the American Society for Mechanical Engineers (ASME) code, Section VIII. Pressure vessels built at Fermilab are required to be designed to the requirements of the ASME code and reviewed by an independent, qualified reviewer other than the designer and preferably from another group not reporting to the designer or his supervisor.

Engineering Notes required of all pressure vessels in use at Fermilab include details of design calculations, materials specifications, test data, operating procedures and welding information. Engineering Notes are retained by the Fermilab ES&H Section. The Laboratory Director is authorized to grant an exception from the Laboratory policy as stated in the FESHM if that exception is explained and analyzed in the Engineering Notes. The documentation of these exceptions is on file in the ES&H Section.

I - 4.1.4 Fire Prevention

The accelerator areas are classified as a conventional hazard in terms of fire prevention. Fire prevention and protection is enhanced by independent fire department inspections, Highly Protected Risk Assessments, and prompt on-site fire department response. Continuous monitoring of systems by the AD Operations Department also contributes to quick detection of problems. Equipment is designed with the application of the criterion that minimizes or eliminates combustible material.

Service buildings and beamline enclosures are constructed primarily of non-combustible material. The primary fire hazard is from the numerous power and signal cables that are distributed throughout the buildings and tunnels. Extensive tests of fire propagation in horizontal cable trays were conducted and the results indicate that sprinklers would be ineffective in mitigating the damage associated with a cable tray fire because these fires propagate extremely slowly, generate only low temperatures, and self extinguish. Where possible, penetrations between services buildings or equipment galleries and enclosures are sealed.

To mitigate the hazards associated with fires in the service buildings and beamline enclosures, fire detection and suppression systems were installed based on the fire loading, codes, and/or design criteria in place at the time of initial construction. In conjunction with facility modifications and the application of more stringent criteria, additional systems have been installed and upgrades to pre-existing systems have been made. Alarm systems consisting of manual pull stations are located in all service buildings and enclosures with a few minor exceptions. Ionization smoke detection systems are preset in most service buildings. Other service buildings and some beamline enclosures are provided with High Sensitivity Air Sampling Detection (HSSD) systems. Linear heat detector (Protectawire) systems are used in some beamline enclosures. Wet-pipe sprinkler systems are provided in several service buildings and in alcove areas of the Main Injector beamline enclosure. Selected helium compressor buildings are provided with special total-flooding type suppression systems which utilize water mist or a dry chemical extinguishing agent. Halon protection has been maintained in the Main Control Room and two central computer rooms. Activation of the detection or suppression systems initiates local alarms and a central alarm is also transmitted via the FIRUS system to the Lab Emergency Dispatcher

General housekeeping is the responsibility of line management. The Building/Area Manager Program and scheduled walk-through inspections of all areas contributes to the monitoring and minimization of excessive accumulations of flammable and combustible materials. Minimization of excess material and proper housekeeping for the enclosures is specifically addressed by radiation worker training and waste minimization practices. Flammable materials are stored in approved flammable storage cabinets. Hazardous operations, such as welding, cutting, and brazing, are regulated by appropriate permits issued by the Fermilab Fire Department.

I - 4.1.5 Flooding Protection

The enclosures have sump water-level alarms with remote readout in the Main Control Room. Flooding in these enclosures does not pose a threat to personnel safety but does represent a minor threat to equipment. Capability exists for remote operation of these sumps with a mobile generator in the event of an extended power outage.

I - 4.1.6 Industrial Hygiene

The control of hazards in this category is addressed through the application of the relevant OSHA standards and other applicable standards (such as ANSI and ACGIH). The Fermilab facilities areas have numerous industrial hygiene issues including lasers, hazardous atmospheres, confined spaces, and hazardous material control.

The Laboratory employs a professional ES&H staff that monitors industrial hygiene hazards for compliance with the standards and the FESHM. When necessary, procedures are developed by the ES&H staff to further mitigate the hazards.

I - 4.1.7 Personnel Exposure to Magnetic Fields

Generally, administrative rules, enforced by use of the electrical interlock system, prohibit personnel from being in enclosures when electromagnets, other than small powered correction elements, are energized. The fields associated with permanent magnets used in certain accelerator and beamline applications and the small powered correction elements that might be energized during normal access are generally constrained to the interior of the magnets. Leakage fields from such magnets do not present a significant exposure hazard. Thus, under most circumstances there can be no possibility of personnel exposure to high strength magnetic fields.

In some cases however, specialty magnets in the enclosures need to remain on. In those cases, access to the magnetic fields is restricted and areas above the action levels specified in the FESHM are posted.

I - 4.1.8 Environmental Hazards

Environmental hazards are addressed through compliance with legal and regulatory requirements imposed by DOE Orders, Federal, State, and local regulations, and FESHM. Numerous activities at Fermilab have the potential to produce environmental impacts. These include air emission sources such as fuel combustion, component cleaning, and paint spray booths, soil erosion from construction activities, and oil spill sources from transformers and generators utilized within the electrical distribution system, and glycol spill sources from various cooling systems. The laboratory has an IEPA-approved air emissions permit and a PE-certified Spill Prevention, Control and Countermeasures Plan (SPCC). New activities are reviewed for potential environmental/regulatory issues as part of the NEPA process.

I - 4.2 Accelerator-Specific Hazards

This section describes the accelerator-specific hazards and outlines the mitigation employed to control these hazards. This section forms the basis for the ASE and outlines the typical credited controls instituted to mitigate these hazards to acceptable levels.

Each chapter in Sections II – V has a hazard table at the beginning of the chapter outlining the hazards found within that section of the facility. The hazard table outlines both the conventional and accelerator-specific hazards found within a specific portion of the facility. Not all areas will contain all of the accelerator-specific hazards outlined below. In the case where an accelerator-specific hazard exists within an area, additional safety analysis is warranted and will be described further in the relevant section of the chapter.

I - 4.2.1 Radiological Hazards

The predominant radiation hazard in the Fermilab accelerator areas is caused by the interaction of beam particles in the materials surrounding the beam pipes and beam line elements. Additional radiation hazards involve the handling and use of radioactive sources and X-ray producing devices. The FRCM describes the policies and procedures that must be followed in order to provide appropriate protection of personnel against radiation hazards.

The AD ES&H Department administers and monitors access control procedures, radiation interlocks, and personnel training that have been developed to protect personnel from possible exposure to radiation inside the beam enclosures. This program follows the prescribed Work Smart Standards Set and ALARA principles specified in the FRCM.

There are three categories of beam-induced radiation hazards:

1. Prompt radiation levels inside and surrounding the enclosures which are present during beam transport and may propagate offsite;
2. Residual radiation due to activation of beamline components which can give rise to radiation exposures to personnel during accesses to the beam enclosures for repair, maintenance and inspection activities; and

3. Environmental radioactivity due to the operation of the accelerators and beam transport systems particularly at the beam absorbers and targets such as the activation of air, soil, and groundwater.

I - 4.2.1.1 Ionizing Radiation

In order to protect workers and the general public, the enclosures and beam pipes are generally surrounded by sufficient amounts of shielding (earth, concrete or iron). The shielding creates exclusion areas that are interlocked by the Radiation Safety Interlock System. In areas where there is insufficient shielding, networks of interlocked detectors keep any prompt radiation within acceptable levels. Detailed shielding analyses have been performed and are updated as necessary to determine that the shielding is adequate during beam operations. Guidelines for performing these analyses are given in the FRCM. This particular type of analysis is referred to as a shielding assessment. The Fermilab ES&H Section maintains the complete documentation of the shielding assessments and their review.

Accident conditions occur when the beam is lost in an area which is not intended for use as a beam absorber or when the operational beam limitations are exceeded. In many cases, the increased levels of radiation produced by an accident condition will be detected by an appropriately positioned and interlocked radiation detector that will automatically disable the beam. The detectors are subject to administrative procedures defining beam restart to ensure that the maximum possible hourly dose rates do not exceed acceptable limits. The shielding around the enclosures and the number, position, and trip settings of the interlocked radiation detectors are chosen so that no radiation protection guidelines can be exceeded under accident conditions.

Losing beam for an extended period of time on devices not designated as beam absorbers is not an immediate safety concern if the shielding over and around the enclosures is adequate. However, it can cause excessive activation within the enclosure. Enclosures in which such an accident could conceivably occur are surveyed for excessive radiation levels. If excessive radiation levels are found, they are noted and posted accordingly. Additional restrictions are imposed if work needs to be done in these areas.

The shielding assessment is intended to assure the effectiveness of the ASE for containing a beam-on radiation hazard. The general methodology used follows the approach described below.

1. A maximum limiting beam condition in terms of beam power is chosen and a general and conservative guideline for the amount of shielding required is

calculated and applied to an entire area. For those locations satisfying the general guideline, the radiation shielding is adequate for the chosen beam condition, and no further analysis is needed.

2. For those locations that are found to have insufficient shielding, calculations specific to the location are performed. If the shielding is then found to be adequate, no further analysis is needed for that location.

3. For locations where specific calculations indicate the shielding to be insufficient, either radiation measurements are performed to verify the adequacy of the shielding or, corrective actions must be taken. Possible corrective actions include adding additional shielding around the location, adding radiation detectors to the Radiation Safety Interlock System, or increasing the level of access control to the areas outside the shielding as described in the FRCM.

Radiation exposure to personnel is possible for those in enclosures during beam operation. This hazard is averted by excluding access to the enclosures when beam is potentially present. In addition to the training of all personnel, the principal means of protection of personnel against this hazard is a fail-safe, redundant system of interlocked access gates, doors, and critical devices. Critical devices, which are interfaced to this system, are driven to such a state so as to prohibit beam from entering an enclosure for which the Radiation Safety Interlock has been broken. Critical devices include such equipment as bending magnet power supplies, beam stops, and collimators. The design, review, approval, and operating criteria for the Radiation Safety Interlock System are described in the FRCM. The Radiation Safety Interlock System test procedures and results are kept as part of Fermilab's permanent records.

I - 4.2.1.2 Residual Activation

Even when the accelerators and beam transport systems are not in operation, many enclosures remain radiological areas because of residual activation, and therefore access is tightly controlled. These controls include verification of training, centralized authorization, and key entry. The level of control depends on the level of residual radiation. The controls required for different radiation levels are detailed in the FRCM.

A feature of the access control procedures for these areas is that the access keys are issued only to personnel from approved lists of personnel who have received the required radiation safety training.

Work in high radiation areas (>100 mrem/hr) is further restricted through Radiation Work Permits (RWPs) and specific Radiation Safety Officer approval.

The bulk of radioactivity produced is at locations selected by beamline design that include beam collimators, primary target stations, and beam absorbers. Other locations that routinely exhibit high levels of radioactivity are those areas where the particle beam is altered from its normal circulating, accelerating or transport path.

Large radiation doses to personnel are usually avoided by simply delaying any required work in these areas and allowing for a period of time for radiation levels to decay for the typical accelerator-produced radioisotopes.

In order to locate areas that contain residual radioactivity, radiation rates are measured during controlled accesses, and radiation surveys are performed and documented prior to allowing supervised accesses. The procedures for performing, documenting, and filing the surveys are approved by the Radiation Safety Group of the AD ES&H Department. During the survey, all areas with dose rates at or exceeding limits specified in the procedures are posted with dose rate information. Pre-printed survey maps are used to log this information in the respective beam enclosures. In addition to checking for dose rates, the survey crew or local ES&H Group also checks for loose surface radioactive contamination and, where appropriate, decontamination procedures are subsequently employed.

After the survey is complete and acceptable radiological conditions are verified, qualified personnel may enter the enclosures on supervised access. The two primary means of understanding the hazards present in the enclosures are by referring to the survey maps and by taking note of the local postings where work is to be performed. Survey maps and Radiation Work Permits, when necessary, are made available to personnel in the Main Control Room or at the point of entry for review prior to entering the enclosures.

I - 4.2.1.3 Non-Ionizing Radiation

The two common types of non-ionizing radiation hazards found in use at the laboratory are radiofrequency (RF) radiation and coherent light sources e.g., lasers. RF systems are utilized throughout the accelerator complex to accelerate particle beams. The primary mechanism to protect personnel from exposure is to contain the RF waves inside of coax cabling or waveguide. Periodic surveys are performed by the D/S/C ESH Departments for stray RF fields.

Lasers are used in some experiments to provide light sources for detector calibration or provide photo-cathode light excitation to an electron gun. The use of lasers is governed by the requirements found in the FESHM. Most lasers are Class I, Class II, or IIIa where it is unlikely that the laser would cause an inadvertent injury. In the locations where Class IIIb or IV lasers are used, additional measures, including approval by the laboratory Laser Safety Officer prior to operation, are in place to control this hazard. In summary, non-ionizing radiation has the potential for no more than minor impact on-site and no impact off-site.

I - 4.2.1.4 Environmental Radiation Hazards

The environmental radiation hazards considered include off-site radiation doses from muons produced by proton interactions with targets, activation of the air in enclosures which is subsequently released to the environment, and irradiation of unprotected soil surrounding the enclosures leading to radioactivity in the groundwater or surface water.

These hazards are concentrated at the target stations and beam absorbers. By limiting the total amount of beam that may be sent to these areas, the amount of radiation that is released into the environment is kept within the limits specified in the FRCM. The total beam limitations due to activation of air, groundwater, surface water, soil, and external exposure have been determined for each of the accelerator enclosures, target stations, and beam absorbers. The most limiting is included in determining the ASE. Target and absorber locations routinely incorporate “Closed Loop” water systems to contain the activated water for proper disposal in accordance with the FRCM.

Locations where there is a potential for the release of airborne radionuclides in measurable concentrations are identified and appropriately monitored to insure compliance with applicable standards. Groundwater and surface water are monitored on an as needed basis by the applicable RSO or the ESH Section to insure compliance with the FRCM and applicable standards.

I - 4.2.2 Cryogenics

Superconducting magnets and other cryogenically-cooled components are used in the Fermilab facilities. They are cooled by liquid helium and liquid nitrogen distribution systems. The design and operation of the components, their power supplies, and the associated low-temperature cryogen distribution systems considers the following potential hazards arising from the use of the cold, pressurized, liquid helium and nitrogen:

1. High speed gas flow from venting;
2. Freezing from contact with the extremely cold fluids and gases or material in contact with them; and
3. Suffocation from the displacement of oxygen by these inert gases.

The high speed gas flow from venting hazard exists at the roof of satellite refrigerators and compressor buildings situated near Tevatron enclosures. Sudden venting activity has the potential of significantly startling personnel who might be present on the roof to the extent that they might fall off the roof. This hazard is mitigated by procedurally restricting access to the roofs of satellite refrigerator and compressor buildings.

The freezing hazard posed by extremely cold fluids and gases is addressed in training for affected personnel and by requirements for wearing of personal protective equipment (PPE) in performing work with, or in the vicinity of, cryogens. PPE requirements are addressed in cryogenic operating and maintenance procedures. The hazard of suffocation is addressed below in the Oxygen Deficiency Hazards section.

The safety analysis and review program for cryogenic systems has been developed at Fermilab with the help of ad hoc External Cryogenic Review. Details of this program are described in the FESHM.

Cryogenic systems may only be operated after review by the designated Cryogenics Safety Subcommittee Review Panel followed by operational authorization from the D/S/C Head responsible for the area. The cryogenic system operational authorization documentation is maintained by the respective division, section, or center.

I - 4.2.3 Oxygen Deficiency Hazards

A comprehensive study has been made of all conceivable types of incidents involving cryogens for all of the Fermilab Facility areas. A safety analysis for each cryogenic subsystem is reviewed by the Cryogenic Safety Subcommittee Review Panel. The D/S/C Head approves operations based on the recommendations of the Panel. The following items of documentation are provided by the system designers for review by the subcommittee: a system description including engineering design criteria, system schematics, preliminary operating procedures, results of system operating tests, and hazards analyses such as "failure mode and effects" analyses and "what-if" analyses.

The Laboratory has developed a policy and procedures for addressing potential oxygen deficiency hazards. The objective of the policy is to require that, in potential ODH areas, the probability of a fatality shall be clearly below the value for workers in U.S. industry as a whole. This policy is detailed in FESHM.

The ODH policy requires a calculation for each such work area and specifies the appropriate administrative controls and protective measures to be followed.

As discussed in Section I - 4.2.2, the potential exists under certain failure conditions in the cryogenic systems for an oxygen deficiency in the atmosphere in the surrounding workspaces. Each operation or event with the potential for causing oxygen deficiency in a given enclosure or service building is evaluated for its probability of occurrence and the associated ODH consequences. In addition, enclosures or service buildings adjacent to potential event areas, which have a leakage path, are also evaluated. The appropriate ODH Class is then assigned. The procedures used to determine the ODH Class are described in detail in the FESHM. The analysis documenting the ODH classifications within the Fermilab facilities is contained in the Accelerator Division ODH Assessment[14].

The documented analyses for determining the ODH classifications along with pertinent review panel correspondence are maintained by the respective D/S/C Cryogenics Department or Group. In summary, the oxygen deficiency hazards posed by operation of the cryogenic system are mitigated by engineered controls, safety analyses and reviews, resulting determination of ODH Classification, and adherence to established policies and procedures related to ODH area entry. This, in conjunction with review and necessary authorization by the Division Head to operate cryogenic systems, effectively mitigates oxygen deficiency hazards so that potential impacts to personnel are minor on site and no impact off site.

Oxygen deficiency hazards from the use of Sulfur Hexafluoride (SF6) as a dielectric insulating gas is also assessed in accordance with FESHM. The resultant risk assessment is reviewed by an independent engineer and approved by the D/S/C Head. The oxygen deficiency hazards posed by the use of SF6 are mitigated by engineered controls, risk assessment and reviews, resulting determination of ODH Classification, and adherence to established policies and procedures related to ODH area entry. This, in conjunction with review and necessary authorization by the D/S/C Head to transfer SF6 gas, effectively mitigates oxygen deficiency hazards so that potential impacts to personnel are minor on site and no impact off site.

I - 4.2.4 Flammable Gases

The use of flammable gases in physics experiments presents a unique type of installation, requiring special considerations. In many cases, mixing of gases is involved. Large volumes of gases may be present; thus even small leaks or ruptures of thin windows may cause incursions into the flammable concentration region with a large inventory to support fire. Some flammable gases may be stored in the liquid state, increasing the inventory. Electrical equipment is an integral part of such installations and can thus provide an ignition source if such a system is improperly designed, fabricated, or operated.

The FESHM outlines the requirements for storage and use of flammable gases. The chapter requires that a risk analysis be developed and a review of the system be performed by the designated Fire Safety Subcommittee Review Panel, followed by operational authorization from the D/S/C Head responsible for the area. The operational authorization documentation is maintained by the respective D/S/C. The risk analysis, independent review, and operational authorization effectively mitigates the hazards from the use of flammable gasses so that potential impacts to personnel are minor on site and there is no potential impact off site.

I - 4.2.5 Unique High Pressure or Vacuum Hazards

For most accelerator beamlines and experiments, high pressure vessels or vacuum vessels are routine industrial hazards that are covered within the section I - 4.1.3 High Pressure Hazards above. Occasionally experiments or beamlines have unique requirements for large pressure or vacuum vessels that are not typically found in the industrial environment.

I - 4.2.6 Unique Electrical or Magnetic Field Hazards

For most accelerator beamlines and experiments, electrical and magnetic field hazards are routine industrial hazards that are covered within the section I - 4.1.1 Electrical Hazards or section I - 4.1.7 Personnel Exposure to Magnetic Fields above. Occasionally experiments or beamlines have very electrical requirements or significant magnetic field hazards that are not typically found in the industrial environment.

I - 4.3 Credited Controls

Credited controls are the primary controls that assure that the level of risk to all workers, the public, and the environment is maintained at an acceptable level. The credited controls listed in the ASE must be in place and functional for all operational areas.

The credited controls are divided up into three main categories: passive controls, active engineered controls, and administrative controls. Passive controls are elements that are part of the physical design of the facility that require no action to function properly. These are fixed elements of the accelerator that take human intervention to remove. Active engineered controls are systems designed to reduce the risks from accelerator operations to an acceptable level. These are automatic systems that limit operations, shutdown operations, or provide warning alarms when operating parameters are exceeded. Administrative controls encompass the human interactions that define safe operations. These are the accelerator operating policies, procedures, beam energy, and intensity limitations that are followed to ensure safe accelerator operations.

I - 4.3.1 Passive Controls

Passive engineered controls reflect features that are part of the physical design of the accelerator facilities or other features that are incorporated into the fundamental design of the accelerators that require no action to function properly. These are the fixed elements of the accelerator. The passive controls considered necessary to ensure safe accelerator operations are discussed below.

I - 4.3.1.1 Passive Shielding

The passive shielding is the radiation shielding that is located between the exclusion areas and occupied areas to keep personal exposure to ionizing radiation within the limits specified in the FRCM. This shielding includes the concrete structure, e.g. walls, floors, and labyrinths, and the earth overburden surrounding the structure.

I - 4.3.1.2 Movable Shielding

The movable shielding is the radiation shielding that is placed between exclusion areas and occupied areas during accelerator operations to keep personnel exposure to ionizing radiation within the limits defined in the FRCM. This shielding is a credited control that may be moved during maintenance periods for equipment access.

I - 4.3.1.3 Penetration Shielding

The penetration shielding is the radiation shielding that is placed in penetrations, such as utility and RF waveguide routing between the exclusion areas and occupied areas during accelerator operations to keep personnel exposure to ionizing radiation within the limits defined in the FRCM. This shielding is a credited control that may be moved during maintenance periods for installation of additional utilities or equipment access.

I - 4.3.1.4 Radiation Fencing

Fences are used and posted to designate potential radiation areas during machine operations defining an exclusion area to keep personnel exposure to ionizing radiation within the limits defined in the FRCM.

I - 4.3.1.5 Guards, Postings, and Other Access Controls

From time-to-time, additional temporary or permanent controls are utilized to insure conformance with the FRCM. For example, guards and/or postings may be utilized to prevent access to a temporary radiological area in support of component radiography. Postings and locked barriers may be utilized to segregate contaminated accelerator items. The use of guards, postings, or other access controls are utilized within the limits defined in the FRCM.

I - 4.3.2 Active Controls

Active engineered controls are systems designed to reduce the risks from accelerator operations to an acceptable level. These are automatic systems that limit operations, shut down operations, or provide warning alarms when operating parameters are exceeded. The active engineered controls considered necessary to ensure safe accelerator operations are discussed below.

I - 4.3.2.1 Radiation Safety Interlock System

Radiation Safety Interlock Systems are used to prevent injury, death, or serious over-exposure from beam-on radiation, x-rays, and high voltage / high current power supplies and other hazards of this type. The principle method employed by the interlock systems is to establish and maintain exclusion areas surrounding accelerator operating areas. The interlock barriers are established such that sufficient distance is maintained between beamline operating components and the closest point of approach. If there is a potential for personnel to be within the defined exclusion area, the Radiation Safety Interlock System will not allow operations that create hazardous conditions.

The interlock systems utilize a modular redundant design where no single component failure will result in a loss of protection. To accomplish this two separate circuits are used to detect specific conditions. For example, each door that is monitored uses two separate switches to detect the status of the door. Each of these switches is connected to separate control circuits. If a failure occurred in one switch, the other would still operate providing the necessary protection. Another key characteristic used in designing the system is the concept of fail-safe circuits. All circuits are designed in such a way that if a circuit fails, the failure would most likely initiate a system shutdown, resulting in a safe condition. Since not all component failures can be detected by the interlock systems, functional testing in accordance with the FRCM needs to be performed at periodic intervals to ensure reliable operations.

I - 4.3.2.2 Oxygen Monitoring Systems

In-Place Oxygen Deficiency Monitors/Alarm Systems are employed to protect personnel from oxygen deficient atmospheres resulting from cryogenic fluid leaks. The oxygen monitoring system provides continuous monitoring of oxygen concentrations at entry locations to detect potential oxygen-deficient environments. The system utilizes redundant circuits for high reliability, separate upper and lower alarm limits to reduce undetected failures, and dual channels to allow for monitoring of two separate sensors. The unit provides both audible and visual alarms when the monitored oxygen concentration falls below pre-set levels. Auxiliary output relay contacts are provided for connection to external ventilation systems or equipment as necessary. To ensure reliable operations, functional testing and calibration of the systems need to be performed at periodic intervals.

I - 4.3.2.3 Flammable Gas Detections Systems

Flammable Gas Detection Systems are utilized to protect personnel and property from explosive atmospheres and are designed in accordance with FESHM. The systems continuously monitor the atmosphere for flammable gasses. The systems provide automatic shutoff of the gas supply when the monitored gas concentrations exceed pre-set levels. High level alarms no higher than 20% of the lower explosive limit automatically summon the Fire Department. Visual indicators at the storage location and experimental apparatus locations provide real time status of the “gas on” and “gas off” states. To ensure reliable operations, functional testing and calibration of the systems need to be performed at periodic intervals.

I - 4.3.2.4 Cryogenic Vessels Pressure Relief Valves

Pressure Relief Systems are utilized to protect personnel and property from over pressurization of cryogenic vessels due to vaporization of liquids. To ensure reliable operations, functional testing and calibration of the systems need to be performed at periodic intervals in accordance with FESHM.

I - 4.3.3 Administrative Controls

All accelerator operations at Fermilab with the potential to affect the safety of employees, researchers, or the public, or to adversely affect the environment, are performed using approved procedures. These procedures are the administrative controls that encompass the human interactions that define safe accelerator operations. The administrative procedures and programs considered necessary to ensure safe accelerator operations are discussed below.

I - 4.3.3.1 Accelerator Operational Approvals

AD Administrative Procedure ADAP-11-0001, Beam Permits, Run Conditions, and Startup, defines how each section of the accelerator complex is turned back on after extended down periods of generally 30 days or more, or turned on for new facilities. Prior to initiating beam in any section of the accelerator, a System Start-Up Sign-Off sheet is prepared for the area. This document is used to get formal approval from each support department head indicating that all work has been completed and the system is ready to accept beam. This document is also used to certify in writing, by the department head responsible for the accelerator area covered by the document, that all required radiation shielding is in place and configured as described in the current radiation shielding assessment before system startup.

The Beam Permit and Run Condition documents identify the beam power and operating parameters allowed for the accelerator area within the current ASE. The beam power limits are determined and approved by the AD Head in consultation with the ES&H Department Head, AD Radiation Safety Officer (RSO), and Operations Department Head on the Beam Permit. The Run Conditions for the area identifying the operating configuration are reviewed by the AD RSO, AD Operations Head and approved by the AD Division Head.

I - 4.3.3.2 Experiment Operational Approvals

The Operational Readiness Clearance (ORC), outlined in PPD ES&H procedure PPD-ESH-006, *ES&H Reviews for Experiments*, is a permit approved by the Particle Physics Division (PPD) Head for the commissioning and unattended operation of an experiment system or detector. The ORC process requires documentation of potential hazards and their mitigation, a review of the documentation, and a walk-through inspection of the experiment installation. Sub-systems within a detector can be reviewed individually and granted a partial ORC. As detector installation progresses, partial ORCs are accumulated for all sub-systems. PPD ES&H assigns a review committee to conduct the sub-system reviews and inspections of installations.

I - 4.3.3.3 Cryogenic System Approvals

Cryogenic systems are reviewed and approved in accordance with FESHM Cryogenic System Review. The safety analysis and review program for cryogenic systems utilizes the help of ad hoc External Cryogenic Review Committees and the on-going review of design and procedures by the Cryogenic Safety Subcommittee of the FESHCom. Cryogenic systems may only be operated after review by the designated Cryogenics Safety Subcommittee Review Panel followed by operational authorization from the appropriate D/S/C Head responsible for the area.

I - 4.3.3.4 Accelerator Staffing Levels

The AD Operations Department is responsible for the operation of the accelerator and fixed target beam transport enclosures, as well as the associated power supplies, electronics, utilities, and control systems. The Main Control Room is staffed with trained personnel from the Operations Department around the clock every day. The lead person on shift, the Crew Chief, has responsibility for machine operations and directs the activities of the other on-shift operators. The other shift operators can consist of accelerator or beamline physicists that are experts in the operating area, Operations Department Specialists that are experts in individual operating areas, and Operator Is and IIs that are working under the direct supervision of more experienced operations personnel. The department has a long-standing, well-documented training program for its personnel, consisting of reading materials, videotapes, lectures, walk-arounds, self-assessment quizzes, and on-the-job training (OJT).

I - 5 Accelerator Safety Envelope Basis

The ASE is a set of physical and administrative conditions based on ESH considerations as defined in the DOE Accelerator Safety Order, DOE O 420.2B, consistent with best management practices outlined in DOE G 420.2-1. The ASE establishes and defines the boundaries within which an accelerator and its experiments may be operated. Operations performed within the boundaries of the ASE provide for protection of the laboratory staff, scientific users, the general public, and the environment. The operating limits are designed to prevent the effects of unscheduled, but anticipated events from causing violations of the ASE. For example, an accelerator facility can experience an unplanned event, such as a power outage, that may interrupt operations but does not compromise the safety of the facility.

The ASE is composed of engineered and administrative controls applicable to the Fermilab accelerator facilities and provides for safe operation of the laboratory's accelerators and experimental areas. The credited controls are included in the ASE to mitigate the accelerator-specific hazards identified for the facility in Chapter 4. Some of the controls, such as shielding, apply to all of the accelerator facilities, whereas others are specific to each accelerator module. Significant changes to these controls, operating conditions, or the facility, that involve an unreviewed safety issue (USI) will require a revision or supplement to this SAD.

Because the facility operations necessarily take place with variability in the numerous operating modes, operating envelopes are used to provide assurance that the ASE is not exceeded as the operating conditions change. Fermilab has considerable experience operating the accelerator facilities. This operating experience shows that where operating envelopes are defined, each operating envelope limit affords time for corrective action response before the respective safety envelope is reached. By defining the limits beyond which the operating conditions would require corrective actions, operating envelopes serve as administrative controls to keep operations within the ASE. Variation of operating conditions parameters within the operating envelopes is normal. Variations beyond the boundaries of the ASE are treated as off-normal occurrences that must be reported to the DOE.

While credited controls provide a sufficient safety margin, as a conservative approach, some conditions are managed with additional controls to provide a defense-in-depth strategy that provides additional assurance of safe accelerator operations.

I - 6 Environmental Monitoring

The strategy for environmental monitoring and surveillance at Fermilab is established in the Fermilab Environmental Monitoring Program. This program ensures compliance with legal and regulatory requirements imposed by DOE Orders, Federal, State, and local agencies, confirms adherence to permit conditions, provides data for permit revision/renewal, detects unplanned releases to the environment, and provides data to support environmental management decisions. The comprehensive site-wide monitoring program assesses the effect of past, current, and future activities by measuring and monitoring effluents and emissions from Fermilab operations and by calculating the effects of those operations on the environment and public health. An important consideration in the development and implementation of the monitoring program has been to ensure that the monitoring activities at specific sites are appropriate for individual facility operations.

The scope of the environmental surveillance conducted on-site encompasses potential and identified effluents to air, surface waters, drinking water, storm and sanitary sewers, soil, and groundwater and includes analyses for both chemicals and beam-produced radionuclides. Penetrating radiation outside of the shielded areas is also monitored. Samples are collected and analyzed according to a predefined schedule. Measured concentrations of radioactive materials and chemicals are compared to applicable standards, concentration guides, natural levels, and previous results. A detailed description of the environmental monitoring and surveillance program can be found in "The Report to the Director on the Fermilab Environment"[15]. This report, which is prepared for each calendar year, contains an annual summary of monitoring results, subsequent exposure pathway analysis, and dose assessment, where applicable. Environmental sampling procedures are established in the Environmental Protection Procedures Manual[16]. Protection of groundwater resources is addressed in the Fermilab Ground Water Protection Management Plan[17]. Division/Section/Center environmental monitoring programs are utilized to track, trend, and evaluate process environmental discharges of air and water, along with accelerator operating intensities of the individual areas, for compliance with all applicable standards and in support of the laboratory environmental monitoring program.

I - 7 Quality Assurance

At Fermilab, quality assurance (QA) is used to maintain a high state of readiness, reliability, and sustainability of programs that support the Nation's efforts of using high-energy physics to advance our understanding of the fundamental nature of matter and energy. Fermilab uses a graded approach to define and integrate the appropriate level of quality controls based upon risk of the subject initiative or operation. Using a graded approach is paramount to an effective and efficient quality program to ensure that effort expended to maintain it provides value to the organization.

Fermilab's Integrated Quality Assurance program is composed of the Integrated Quality Assurance (IQA) program document, programmatic implementing procedures such as the Fermilab graded approach, and D/S/Cs' implementing procedures. The IQA provides a single, integrated approach for assuring quality throughout Fermilab. The IQA implements the tenets of this policy, and those set forth in the current revisions of the referenced documents.

The purpose of IQA is to implement DOE Order 414.1C and the Fermilab Director's Policy 10, Quality Assurance, and to improve Fermilab's overall performance at meeting or exceeding customer expectations. Additionally, this program will help sustain Fermilab's legacy and heritage of success.

The aim of the IQA is to define a QA program that ensures that Fermilab's products and services meet or exceed customers' expectations, provide the laboratory with requirements for the purpose of implementing and maintaining an Integrated Quality Assurance program throughout the laboratory, and provide a quality assurance system capable of monitoring, controlling, and continually improving the program's activities, processes, and systems.

The IQA establishes the requirements necessary to implement the Fermilab Director's Policy 10 and comply with DOE Order 414.1C[18]. This IQA applies to Fermi Research Alliance, LLC and all employees, contractors, subcontractors, and Fermilab users when performing work that affects the laboratory.

I - 8 Post-Operations Planning

It is Fermilab's policy as outlined in FESHM Chapter 8070 to maintain information necessary for future decontamination and decommissioning (D&D) of any or all of the laboratory facilities. This documentation is maintained by the ESH Section to provide adequate safeguards against injury or illness for employees, sub-contractors and the public or damage to the environment at such time that facilities are demolished.

Each D/S/C head is responsible for informing the ES&H Director, who is responsible for the Laboratory's master D&D files, concerning any activities affecting possible future D&D activities. This includes updating the Radiological Facility Use records on at least an annual basis to identify any hazardous materials, other chemicals, and radioactivity in their facilities that are not removable. "As built" drawings are maintained to show the location and inventory of contamination. The ES&H Director is notified of any changes of facility usage, for inclusion in the D&D files.

All actions taken to decontaminate a facility or to fix contamination prior to actual D&D work are documented by the laboratory organization that supervises the D&D work and transmitted to the ES&H Section prior to commencing actual D&D activities. Items to be documented include the means for accomplishing the D&D and may include, as necessary, regular environmental reviews, Radiological Facility Use reports, and activity-specific communications. Chemicals that should be included in the reports are found in FESHM Chapter 5052.

The Laboratory has comprehensive programs for the handling, storage, and disposal of both radioactive wastes and hazardous chemical wastes. The various waste programs are described in the FRCM and the FESHM.

I - 9 Acronyms

ACGIH	American Conference of Industrial Hygienists
AD	Accelerator Division
ADDP	Accelerator Division Department Procedure
ADSP	Accelerator Division ES&H Procedure
ALARA	As Low As Reasonably Achievable
ANSI	American National Standards Institute
ARR	Accelerator Readiness Review
ASE	Accelerator Safety Envelope
ASME	American Society of Mechanical Engineers
ASO	Accelerator Safety Order
CERN	European Organization for Nuclear Research
CFR	Code of Federal Regulations (United States)
CX	Categorically Excluded
D&D	Decontamination and Decommissioning
DOE	Department of Energy
D/S/C	Division/Section/Center
EA	Environmental Assessment
EENF	Environmental Evaluation Notification Form
ESH	Environment, Safety and Health
ESHEC	Environment, Safety and Health Executive Committee
ES&H	Environment, Safety and Health
ES&H/QA	Environment, Safety and Health / Quality Assurance
Fermilab	Fermi National Accelerator Laboratory
FESHCom	Fermilab Environment, Safety and Health Committee

FESHM	Fermilab ES&H Manual
FESS	Facilities Engineering Services Section
FESS-OPS	Facilities Engineering Services Section Operations Maintenance Group
FIRUS	Fermilab Incident Reporting and Utility System
FNAL	Fermi National Accelerator Laboratory
FRA	Fermi Research Alliance, LLC.
FRCM	Fermilab Radiological Control Manual
FSO	DOE Fermi Site Office
GeV	Giga or billion electron Volts
HA	Hazard Assessment
HSSD	High Sensitivity Air Sampling Detection
HVAC	Heating, ventilation and air conditioning system
ICW	Industrial Cooling Water
IES&HM	Integrated Environment, Safety & Health Management
ISMP	Integrated Safety Management Plan
ITNA	Individual Training Needs Assessment
IQA	Integrated Quality Assurance
LOTO	Lock out/Tag out
MI	Main Injector
MiniBooNE	Phase I Booster Neutrino Experiment
MINOS	Main Injector Neutrino Oscillation Search
NEC	National Electrical Code
NFPA	National Fire Protection Association
mrem/hr	Millirem per hour
mrem/yr	Millirem per year
MOU	Memorandum of Understanding

NEC	National Electrical Code
NEPA	National Environmental Policy Act
NESHAP	National Emissions Standard for Hazardous Air Pollutants
NuMI	Neutrinos at the Main Injector
ODH	Oxygen Deficient Hazard
OJT	On-the-Job Training
ORC	Operational Readiness Clearance
OSHA	Occupational Safety and Health Administration
PE	Professional Engineer
PET	Positron Emission Tomography
PIF	Project Information Form
PORC	Partial Operational Readiness Clearance
PPE	Personal Protective Equipment
PPD	Particle Physics Division
QA	Quality Assurance
RAW	Radioactive Water
RF	Radiofrequency Wave
RSO	Radiation Safety Officer
RWP	Radiological Work Permit
SA	Shielding Assessment
SAD	Safety Assessment Document
SEWS	Site-Wide Emergency Warning System
SF6	Sulfur Hexafluoride
TD	Technical Division
TDR	Technical Design Report
USEPA	United States Environmental Protection Agency

VESDA	Very Early Smoke Detection Apparatus
WSHP	Worker Safety and Health Program
WSS	Work Smart Standards

I - 10 References

[1] DOE O 420.2B, Safety of Accelerator Facilities, July 23, 2004.

[2] Fermilab Director's Policy Manual. - The current web link is: http://www.fnal.gov/directorate/Policy_Manual.html

[3] Fermilab ES&H Manual. - The current web link is: http://www-esh.fnal.gov/home/esh_home_page.page?this_page=800

[4] Fermilab Radiological Control Manual. - The current web link is: http://www-esh.fnal.gov/home/esh_home_page.page?this_page=900

[5] DOE G 420.2-1, Accelerator Facility Safety Implementation Guide for DOE O 420.2B, Safety of Accelerator Facilities, July 1, 2005.

[6] Fermilab Work Smart Standards Set. - The current web link is: https://esh-docdb.fnal.gov:440/cgi-bin/ShowDocument?docid=38

[7] Fermilab Emergency Response Plan – current version

[8] Fermi National Accelerator Laboratory (Fermilab) Worker Safety and Health Plan (WSHP), Revision 2, May 2009.

[9] Title 10 of the Code of Federal Regulations, Part 851 (10 CFR 851), Worker Safety and Health Program, June 28, 2006.

[10] Fermilab Integrated Safety Management Plan. - The current web link is: https://esh-docdb.fnal.gov:440/cgi-bin/ShowDocument?docid=455

[11] ADAP-11-0001, Accelerator Division Administrative Procedure, Beam Permits, Run Conditions, and Startup.

[12] Hazard Assessment Document – current version.

[13] Fermilab Engineering Standards Manual. - The current web link is: http://www-esh.fnal.gov:8001/FESM/Default.html

[14] Accelerator Division ODH Assessment, March, 1999.

[15] The Report to the Director on the Fermilab Environment. – The current web link is: http://www-esh.fnal.gov/pls/default/esh_home_page.page?this_page=12831

[16] Environmental Protection Procedures Manual, Fermilab ES&H Section Environmental Protection Group.

[17] Fermilab Ground Water Protection Management Plan. – The current web link is: http://www-esh.fnal.gov:8001/GWPMP_05_2008_Rev.pdf

[18] DOE O 414.1C, Quality Assurance, Issued June 17, 2005.

Main Injector/Recycler

Revision 0
April 23, 2013

Author(s)
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Revision History

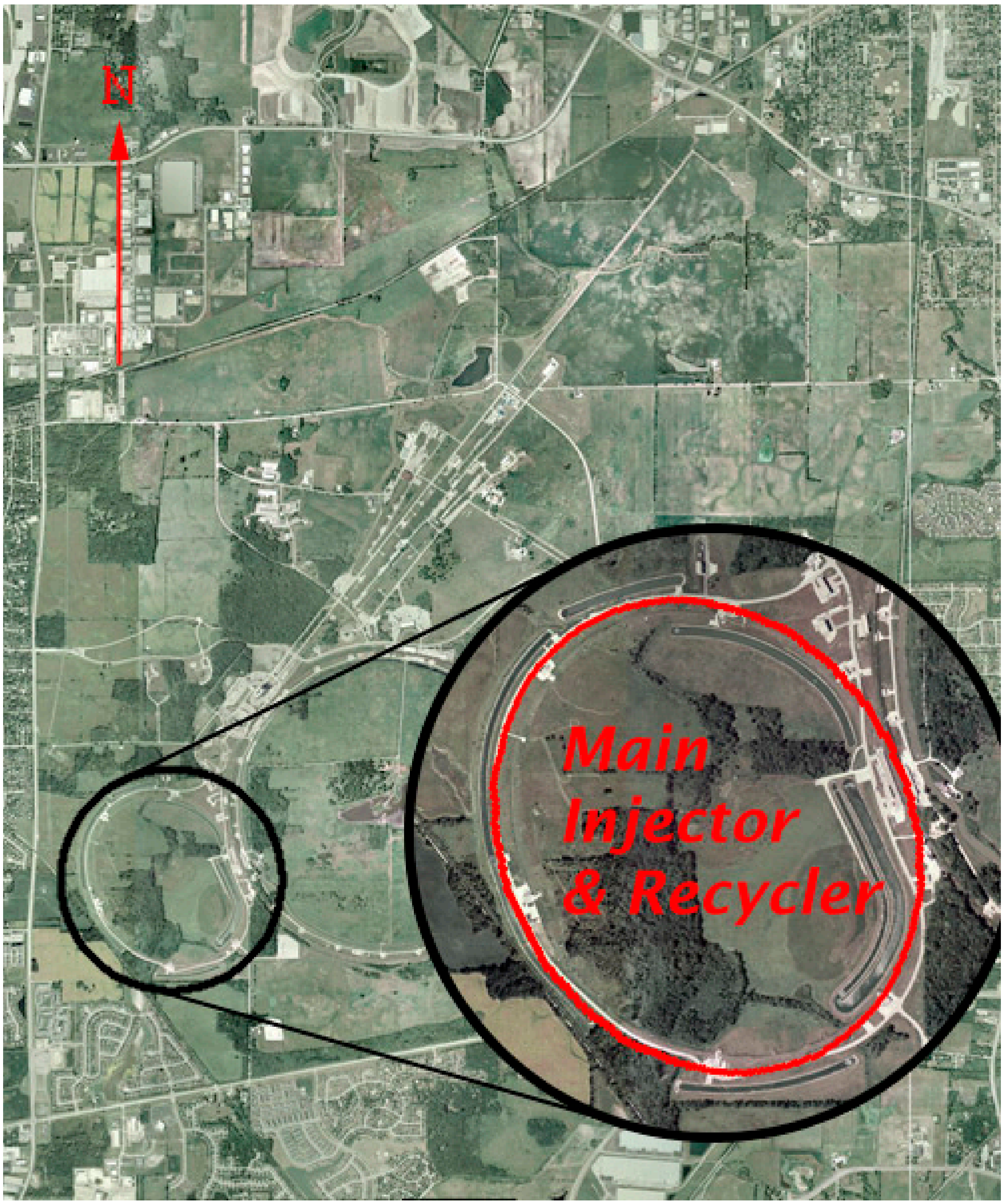
Author	Description of Change	Revision No. & Date
John E. Anderson Jr. David Capista	Initial release of the Main Injector/Recycler Chapter for the Fermi National Accelerator Laboratory Safety Assessment Document (SAD).	Revision 0 April 23, 2013

Table of Contents

II - 6 Main Injector (MI) /Recycler Area

II - 6.1 MI/Recycler Location on Fermi National Accelerator Laboratory (Fermilab) Site

The following aerial photograph shows the location of the MI/Recycler in relationship to the Fermilab site.



II - 6.2 Inventory of Hazards

The following table lists the identified hazards found in the MI/Recycler enclosure and support buildings. All hazards with an asterisk (*) have been addressed in Chapters 1-10 of the Fermilab Safety Assessment Document (SAD) and are not addressed in this section of the SAD.

Radiation Ionizing radiation Residual activation Groundwater activation Surface water activation Air activation Soil interactions Radioactive waste	**Kinetic Energy** Power tools * Pumps and motors *
Toxic Materials Lead shielding * Beryllium components *	**Potential Energy** Crane operations * Compressed gases * Vacuum / pressure vessels * Vacuum Pumps *
Flammable & Combustible Materials Cables *	**Magnetic Fields** Fringe fields *
Electrical Energy Stored energy exposure * High voltage exposure * Low voltage, high current exposure *	**Gaseous Hazards** Confined spaces *
Thermal Energy	**Access / Egress** Life Safety Egress *

II - 6.3 Introduction

This Section II, Chapter 6 of the Fermi National Accelerator Laboratory (Fermilab) SAD covers the MI Accelerator, Recycler Ring, and beam absorber areas. The chapter has been prepared by the staff of the Fermilab Accelerator Division (AD) MI Department.

II - 6.3.1 *Purpose of the MI/Recycler Area*

The MI provides a primary proton beam to various end-users from 8 Giga-electron volt (GeV) and at higher energies up to120 GeV in support of the Fermilab high energy physics (HEP) programs. While the accelerator is capable of 150 GeV operations, there are no current plans to utilize energies above 120 GeV. The MI provides 5.16×10^{13} protons/pulse, at a 1.333 second cycle time, for an hourly intensity of 1.39×10^{17} protons at 120 GeV. Beam used for studies purposes in the MI beam line is sent to the MI-40 abort absorber.

The Recycler has been repurposed from its original design as an antiproton storage ring. In its current operational mode, the Recycler is used to collect and transport 8 GeV protons from the Booster accelerator to the MI. Protons from the Recycler are sent directly to the MI via a transfer line in the MI30 straight section. The Recycler is capable of operating at up to 2.25×10^{17} protons/hr at 8 GeV. Beam used for studies purposes in the Recycler is sent to the MI-40 abort absorber.

II - 6.3.2 *Description of the MI/Recycler Area*

The MI/Recycler accelerators are located south of the Wilson Hall. The MI/Recycler accelerator enclosure consists of: an injection line, two circular machines approximately 3319 meters in circumference, two extraction beam lines, a beam abort absorber, and 10 support service buildings. The 8 GeV injection line from the Booster accelerator connects to three areas: the Booster Neutrino beam line, the MI, and the Recycler. Beam can be extracted from the MI enclosure to the Neutrino beam line, the switchyard beam line, the Muon campus, or the MI-40 abort absorber.

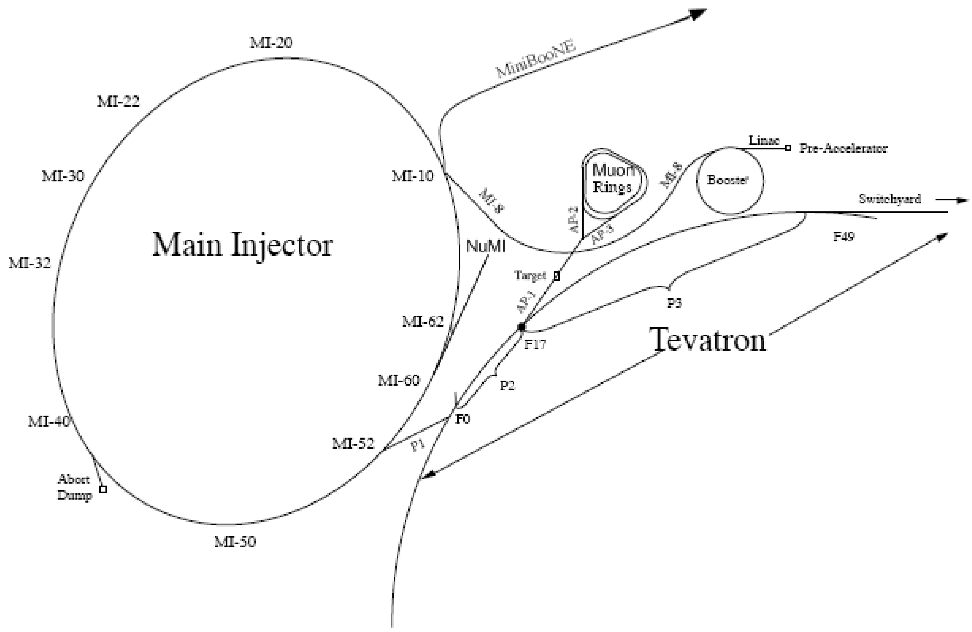


Figure 1 Main Injector Accelerator Layout and Associated Beam Lines

II - 6.3.3 *Operating Modes*

The MI and Recycler are multipurpose machines and have many operating modes. The MI-8 beam line is used to inject beam into one of three areas; the Recycler which accumulates Booster protons for delivery to the MI; the MI which supplies protons to the Fermilab HEP experimental program; or the Booster Neutrino beam line. Both the MI and Recycler machines have beam study cycles that direct beam to the MI-40 abort absorber.

Beam is delivered from the Booster to the MI-8 beam line and passes two switch magnets that further direct the Booster beam to the Booster Neutrino beam line, the Recycler, or to the MI. Booster beam is sent to the MI-8 beam line at a maximum rate of 15 Hertz (Hz), supplying one Booster batch of beam each cycle. Beam can be directed to any of the three beam lines, Booster Neutrino beam line, the Recycler, or to the MI on any given Booster batch.

The Recycler is a fixed energy machine in which its bending magnets are based on permanent magnet technology and can only capture, store and accumulate Booster protons. A maximum of 12 Booster batches are possible for capture and storage in this machine. Once the Booster beam is injected into the Recycler, it will be either sent to the MI or to the MI-40 abort.

The MI accepts beam from either the Booster or the Recycler. When the MI is accepting beam directly from the Booster, the fill time is dominated by the 15 Hz cycle time of the Booster. When beam is transferred from the Recycler, the MI can be filled in a single turn. For high power operations, these two machines work in tandem where the Recycler will fill with 12 Booster batches, while the MI is ramping and extracting. Beam from the Recycler will be transferred to the MI in a single turn, starting the cycle over again. Operation in this manner eliminates the fill time for the MI thus reducing the MI cycle time.

Beam from the MI can be delivered to several experimental areas. The highest power beam is sent to the NOvA target at an energy of up to 120 GeV. The MI also supports Switchyard slow spill which is 120 GeV beam delivered to the Meson and Neutrino experimental areas over a several second duration. Beam to the Muon campus can be either 8 GeV or up to 120 GeV. Various study cycles are supported in the MI and Recycler that will deliver beam to the MI-40 abort absorber. The MI study cycles can be at energies between 8 GeV and 150 GeV where the Recycler beam energy is fixed at 8 GeV.

The MI is assessed to provide 5.16×10^{13} protons/pulse, with a 1.333 second cycle time, delivering up to 1.39×10^{17} protons/hr at 120 GeV. The MI operates 95% efficient with approximately 80% of the “lost” protons absorbed at collimators and 20% “kicked” to the MI-40 abort absorber.

The Recycler is assessed to provide 2.25×10^{17} protons/hr at 8 GeV. The Recycler is 99% efficient with beam losses during Booster injection sent to the MI-40 abort absorber by gap clearing kicker magnets.

II - 6.4 Safety Assessment

The unique beam line specific hazards for the MI and Recycler area are analyzed in this section. The radiological hazards include ionizing radiation, residual activation, groundwater and surface water activation, air activation, soil interactions, and radioactive waste.

II - 6.4.1 *Radiological Hazards*

The MI/Recycler beam lines present radiological hazards in the form of prompt and residual ionizing radiation from particle beams, residual radiation due to activation of beam line components, and environmental radioactivity in the form of potential groundwater, surface water, air and soil activation resulting from the operation of the beam transport systems.

Detailed shielding assessments and post assessment documents address these hazards [1, 2]. The assessments provide a detailed analysis of the MI/Recycler facility demonstrating the required shielding, controls and interlocks to comply with the Fermilab Radiological Control Manual (FRCM) [3]. Residual activation of components has a substantial impact on the ability to occupy the MI/Recycler enclosure where recurring access is required for routine maintenance.

The shielding assessments for the MI and Recycler begin at the MI and Recycler injection points at Cell 100 near the MI-10 service building. The assessments include both rings as well as the Recycler to MI transfer line. The shielding assessments include the P150 extraction line beginning at the Extraction Lambertson magnet (I:Lam52) and progressing toward switchyard. The shielding assessments end at the P150 shield wall that separates the MI and Tevatron F-Sector enclosures, and the MI-40 absorber.

The assessments consider groundwater and surface water activation, lists surface water discharge points and monitoring locations; calculates air activation, estimates annual release, and release points; considers muon production; considers longitudinal and transverse shielding requirements; summarizes labyrinth and penetration calculations; calculates residual dose rates; and specifies active shielding controls and monitoring.

II - 6.4.1.1 Ionizing Radiation

Prompt ionizing radiation is the principle radiation hazard when beam is transported through the MI and Recycler beam lines. In order to protect workers and the general public, the enclosures and beam pipes are surrounded either by sufficient amounts of shielding (soil, concrete, or iron), and/or networks of interlocked detectors to keep any prompt radiation exposure within acceptable levels.

Detailed shielding assessments have been compiled and reviewed by the Fermilab Shielding Review Subcommittee to address these concerns. The assessments provide a detailed analysis of the beam line, demonstrating the required overburden or soil shielding, use of signs, fences, and active interlocks to maintain any prompt radiation within acceptable levels.

Shielding assessments for the MI and Recycler beam lines have included analyses of injection, circulation, extraction, and absorption areas. The assessments require that:

- *All penetrations must be filled with shielding as specified.*
- *All movable shielding blocks must be installed as specified.*
- *The average beam intensity in the MI shall not exceed 1.39x10^{17} protons/hr.*
- *The average beam intensity in the Recycler shall not exceed 2.25x10^{17} protons/hr.*
- *The radiation safety interlock system must be certified as working.*
- *Radiation detectors around the MI/Recycler enclosure are installed and interlocked to the radiation safety interlock system.*

II - 6.4.1.2 Residual Activation

Five radiation surveys dating from July 18, 2010 to May 1, 2012 taken within hours after stopping beam operations were used to estimate future residual dose rates for the MI/Recycler area. Residual dose rates of 80-100 milli-rem/hr (mrem/hr) had been regularly found at MI injection and extraction regions in previous operations. For 700 kilo-Watt (kW) operations, these regions are expected to be at the 150-200 mrem/hr level. Collimation locations, recently surveyed at 500-1500 mrem/hr, are expected to be in the 900-2600 mrem/hr range with 700 kW operations.

Since the Recycler has been repurposed from its designed use as an antiproton accumulator, the repurposed operations will result in greater residual activity than previously. The Recycler residual dose rates are expected however to be smaller than those associated with the MI. The MI is a machine with larger losses that can be present at higher energies than those from the Recycler. Since the MI and the Recycler share the same enclosure, the dominant residual dose rates for the enclosure will be from the MI [1].

Each of the MI/Recycler service buildings include large Low Conductivity Water (LCW) supply and return headers. Significant MI beam loss can result in the production of short-lived radioisotopes within the LCW system. Significant beam loss in the Recycler can also result in the production of short-lived radioisotopes within the LCW system even though most Recycler elements are air-cooled and do not require the LCW. These short-lived radioisotopes can result in doses above normal background when transported to the service buildings via the LCW piping.

Radiation detectors have been installed to monitor the dose rates near the return piping at each of the MI service buildings. Although no significant dose rates associated with normal operation of the MI have been observed since the detectors were installed, these detectors are interlocked to protect against unintentional beam loss.

When the MI/Recycler is not in operation, the enclosure area will remain radioactive and access to these components will be tightly controlled with the level of control dependent on the level of residual radiation. The control measures include training and training verification, centralized access authorization, and key entry. Controls required for different levels of residual radiation are specified in the FRCM [3], and are detailed in the Radiological Work Permit (RWP) for the work to be performed.

In most situations, general RWPs for accesses will suffice. A job-specific RWP and an as-low-as-reasonably-achievable (ALARA) plan will be required for work on any highly activated equipment with a potential individual exposure greater than 200 mrem or potential job exposure greater than 1000 person mrem. These tasks will be supervised by members of the AD Radiation Protection Group under the direction of the AD Radiation Safety Officer (RSO).

II - 6.4.1.3 Groundwater and Surface Water Activation

The MI beam losses occur at the injection/extraction locations, distributed around the beam line, and at the abort absorber at MI-40. Radiation surveys of injection/extraction locations indicate that losses are highest at the collimators near MI-30. The interaction of the beam with water molecules produces tritiated water. The majority of potentially activated water is collected in drains around the MI and discharged to the site-wide Industrial Cooling Water system, which contains the tritiated water to the Fermilab site.

The 700 kW MI release estimate for surface and groundwater shows that the annual distributed beam loss of 2.51×10^{19} protons will produce combined ^{3}H (tritium) and ^{22}Na (sodium-22) concentrations that are 45.0% of the surface water limits and a negligible fraction of the groundwater limits respectively [1]. The 6.28×10^{18} protons sent to the MI-40 abort produce combined ^{3}H and ^{22}Na concentrations that account for 0.3% of the surface water limit and a negligible fraction of the groundwater limits [1].

The assessment of releases to groundwater and surface water are based upon a beam intensity of 6.28×10^{20} protons per year injected into the Recycler Ring. Up to 0.3% of the total beam may be lost in the Recycler Ring, which is equivalent to a distributed loss of 1.88×10^{18} protons per year. It is also estimated that a maximum of 1.5% of the total beam will be sent to the MI-40 abort absorber during gap-clearing, which is equivalent to 9.42×10^{18} protons per year.

Annual estimates for groundwater and surface water for a distributed beam loss of 1.88×10^{18} protons from the Recycler will produce combined ^{3}H and ^{22}Na concentrations that account for 3.4% of the surface water limit and a negligible groundwater concentration [2]. Annual estimates for the 9.42×10^{18} protons sent to the MI-40 abort will produce combined ^{3}H and ^{22}Na concentrations that account for only 0.4% of the surface water limit and a negligible groundwater concentration [2].

The combined annual MI/Recycler concentration estimates and release fractions for ^{3}H and ^{22}Na surface water and groundwater releases are given in Table 1.

Table 1: Combined Annual MI and Recycler Surface Water and Groundwater Release Fractions

Description	**Annual Concentration Limits ((pico Curie (pCi)/millilitre (ml))**		**Annual Concentration Estimate (pCi/ml)**		**Fraction of Annual Limit**
	^{3}H	**^{22}Na**	**^{3}H**	**^{22}Na**	**$^{3}H + ^{22}Na$**
Surface Water (Distributed)	1900	10	51.6	4.84	5.11×10^{-1}
Groundwater (Distributed)	20	0.4	3.44×10^{-5}	6.88×10^{-10}	1.72×10^{-6}
Surface Water (Abort)	1900	10	0.77	0.07	7.4×10^{-3}
Groundwater (Abort)	20	0.4	8.9×10^{-8}	1.81×10^{-12}	4.45×10^{-9}

Groundwater is sampled routinely as part of the Fermilab Environment, Safety, Health, and Quality Section Environmental Monitoring Program. The sump discharges and pond surface waters are routinely sampled as part of the AD Routine Monitoring Program (ADDP-SH-1003).

II - 6.4.1.4 Air Activation

The concentration of radionuclides in the MI/Recycler enclosure is below the limit of detection due to very large amounts of air flowing in and out of the MI/Recycler enclosure. The annual emission calculation is based on the annual proton beam loss rates which reflect the output of the Beam Budget Monitor system and various Accelerator Controls Network (ACNET) data loggers. MI emissions are reported as an unmonitored source in the Fermilab Radionuclide Air Emissions Annual Reports [4] provided to the DOE Fermi Site Office for transmission to State and Federal regulatory agencies in accordance with Regulations.

The yearly scaled estimates for 700 kW operation based on the same 4.2% beam loss are 3.0×10^{19} protons from a total of 7.0×10^{20} protons delivered, resulting in an estimated 20.4 Ci being released from the MI. The release of 20.4 Ci in a year from the MI is 1% of the Fermilab allowable total average activity release specified in the Fermilab Lifetime Operating Air Pollution permit issued by the Illinois Environmental Protection Agency (IEPA).

The Recycler beam will be transmitted cleanly. Beam will be intentionally absorbed only at the MI-40 absorber. The MI-40 absorber will be used for kicker gap clearing during injection from the Booster and for aborting the beam if the established beam permit is lost. Gap clearing losses are estimated to be at 1-1.5% [2]. The MI-40 absorber room ventilation stack is locked-off with a RSO padlock and is not allowed to operate during beam transport. Any air activation that might occur due to incidental losses of circulating beam is expected to be minimal.

The reported 2010 release for the MI enclosure was 11.4 Ci [5]. This release resulted from an annual loss of 1.68×10^{19} protons or 6.79×10^{-19} Ci/proton. If the same production rate is assumed for the repurposed Recycler operations, then an estimated 6.4 Ci/yr will be released for an estimated number of 9.42×10^{18} lost protons/yr [2]. Recycler releases are expected to be less than 0.5% of the overall integrated Fermilab Lifetime Operating Air Pollution permit issued by the IEPA. There are no intended air-release points.

II - 6.4.1.5 Particle Interactions in Soil

Muons resulting from MI/Recycler operations penetrate into the soils surrounding the MI/Recycler enclosure. Most of the muons created by beam line losses of 120 GeV MI protons remain below grade since the majority of the MI lies in a horizontal plane. There is one location however with a 24-milliradian vertical bend for extraction into the P150 beam line at MI-52. The 120 GeV protons lost at that location could produce muons above grade.

The steepest upward trajectory in the MI beam line occurs between quadruple magnets Q701 and Q702 [1]. Muons from the Q701-Q702 region represent the greatest opportunity for muon exposure to personnel above grade. While there are downstream portions of the P150 line that also rise vertically, the upward trajectory is at a shallower angle. Since muons generated from losses along these other downstream locations of the MI beam line will encounter a longer path through soil, these locations are of less significance.

The range of 60 GeV muons in soil of density 2.0 grams/cm^3 is approximately 361 feet [6]. A distance of 400 feet of soil is adequate to range out muons with energies below 60 GeV. The flux of muons at energies higher than 60 GeV in the MI is negligible [7].

The path of secondary particles that enter the P150 tunnel intersects the ceiling of the enclosure about 320 feet downstream of Q701 in the P150 beam line. The muons travel about 480 feet downstream beneath the F0 Service Building to emerge near the Tevatron ring road or cooling pond. The bank of the Tevatron cooling pond is at the end of this path where the level of soil drops away. A conservative estimate of the range of the secondary particles is about 400 feet assuming soil shielding of density 2.24 grams/cubic centimeter (cm^3).

The Recycler beam also operates in a horizontal plane. The Recycler does not have any significant upward vertical bends. Any muons generated by Recycler losses will therefore remain below grade until the muons are absorbed. No Recycler muons will have energy greater than 8 GeV. The range of 8 GeV muons in soil of density 2.0 grams/ cm^3 is approximately 66 feet [6]. The Recycler muons are thus absorbed in the soil.

At injection, protons from the Booster are conveyed by the MI-8 injection line and are deflected upward by 32.8 milliradians near Cell 848. Losses here could give rise to muons that penetrate the ceiling about 168 feet downstream of the bend. In the vicinity of the Recycler tunnel, grade elevations are 740 feet or more and the berm is higher. Consequently there are 560 feet or more of soil in the path of any muons from Recycler operations before emerging at grade level. In traversing the soil above the ceiling, muons will travel 66 feet and be entirely absorbed before the muons have ascended no more than 2.0 feet vertically.

Downstream of the first vertical bend is a second vertical bend, reducing the angle of the rising beam from 32.8 milliradians to 19.2 milliradians. This shallower angle would offer an even longer path through soil for muons which would rise less than 0.8 feet vertically in traveling 66 feet.

The soil surrounding MI/Recycler enclosure including that at the MI-40 absorber will be sampled during decommissioning to document activation levels, as required by the Fermilab ES&H Manual (FESHM) [8].

II - 6.4.1.6 Radioactive Waste

MI/Recycler radioactive waste hazards and waste disposal will be managed within the program established for the Fermilab accelerator complex and as prescribed in the FRCM. Waste minimization is an objective of the equipment design and operational procedures. Although production of radioactive material is not an operational function of the MI/Recycler area, beam loss and, in the case of some beam diagnostics devices, intentional interception of the beam will result in activation of beam line elements. Reuse of activated items will be carried out when feasible. Activated items that cannot be reused will be disposed of as radioactive waste in accordance with the FRCM requirements.

II - 6.5 Credited Controls

II - 6.5.1 *Passive Controls*

Passive controls are accelerator elements that are part of the physical design of the facility that require no action to function properly. These passive controls are fixed elements of the beam line that take direct human intervention to remove. The MI/Recycler area enclosure is designed as a concrete and earth covered radiation shield to protect personnel from radiological exposure during beam operations.

II - 6.5.1.1 Permanent Shielding

The MI/Recycler shielding requirements for 700 kW operations have been documented which scale from the Standard Reitzner Category Table developed from MARS [9] simulations of thick shielding [1, 2].

The MI Standard Category Table is based on a model with the beam located 3 feet from the tunnel ceiling. Since MI ceiling heights vary but are typically 5.7 feet or more above the beam, the MI table will thus overestimate shielding requirements.

The MI longitudinal shielding summary indicates that all longitudinal ranges provide adequate shielding for 700 kW operations [1]. The shielding summary for the abort line indicates no failures[1]. All transverse locations provide adequate shielding and conform to guidance specified in the FRCM.

The MI has no thinly-shielded sections where neutron skyshine would potentially be a problem at large distances from the source. A calculation has been performed due to its proximity to the site boundary [1]. The Illinois Prairie Path represents the closest off-site location to the MI at approximately Cell 320 and is 85 meters away. Calculations show that if all MI beam is continuously lost on a magnet at this location for one year, the skyshine contribution to site boundary dose would be 1.6 mrem/yr for continuous occupancy. The Fermilab site boundary dose limit is 10 mrem/yr.

The Recycler Standard Category Table for the stated operating parameters is based upon the following models; beam incident on a magnet 3 feet from the enclosure wall, a beam pipe 3 feet from the enclosure wall, and a pipe buried in soil. The Recycler is typically only 1.5 feet below the enclosure ceiling. A model with beam incident on a buried pipe was selected since other models would tend to underestimate the required shielding.

The Recycler longitudinal shielding summary indicates that all longitudinal ranges provide adequate shielding and are within FRCM requirements for operations up to 2.25×10^{17} protons/hr [2]. The shielding summary for the abort line indicates no failures [2]. All transverse locations provide adequate shielding and conform to guidance specified in the FRCM.

The Recycler Ring has no thinly-shielded sections where neutron skyshine would potentially be a problem at large distances from the source. A calculation has been performed due to its proximity to the site boundary [2]. The Illinois Prairie Path again represents the closest off-site location to the Recycler Ring at approximately 85 meters away from Cell 320. Calculations show that if all Recycler beam is continuously lost on a magnet at this location for one year, the skyshine contribution to site boundary dose would be 0.2 mrem/yr for continuous occupancy. The Fermilab site boundary dose limit is 10 mrem/yr.

II - 6.5.1.2 Labyrinth and Penetration Shielding

The details of the MI labyrinth and penetration assessments have been documented [1]. The shielding summary details the mitigations necessary for each penetration to comply with the requirements of the FRCM. Individual analyses of penetrations for electrical power distribution conduits and sump discharge piping have not been performed. Limiting cases for each type of penetration have been analyzed to determine that all locations fall within dose rate requirements established in the FRCM.

Recycler labyrinth and penetration assessments have been documented [2]. The Recycler shielding summary typically represents configurations necessary to mitigate doses from MI losses alone. In most cases, the MI mitigation requires additional shielding over and above the shielding required for Recycler mitigation. Therefore, solutions developed to mitigate doses as a result of the MI shielding assessment are generally adequate to protect against Recycler losses for operation at 2.25×10^{17} protons/hr [2].

There are a few locations where Recycler losses generate a higher dose than MI losses [2]. An example is the large penetration K145B in Room 117 at the south end of the MI-60 service building. In these cases, the solutions reflect the shielding requirements for Recycler operation [2].

II - 6.5.1.3 Movable Shielding

The Main Injector enclosure has four areas where movable shielding is used. Two of these areas are shield walls that have been constructed to separate the MI enclosure from the Tevatron enclosure in the middle of the A150 and P150 transfer line areas. The other two areas are in the Tevatron enclosure where movable shielding has been added to attenuate doses from Recycler losses that could pass through the short circuit emergency exit stairwell that connects between the MI and Tevatron tunnels near the MI-60 region. In all four cases, the shielding has been clearly labeled and secured in place by the AD RSO.

II - 6.5.2 *Active Controls*

Active engineered controls are systems designed to reduce the risks from accelerator operations to acceptable levels. These automatic systems limit operations, shutdown operations, or provide warning alarms when operating parameters are exceeded. The active controls in place for the MI/Recycler area are presented.

II - 6.5.2.1 MI/Recycler Beam Loss Controls

The AD MI Department has documented ten different machine control systems that limit beam losses in the MI/Recycler [10]. The machine controls make up nine systems that fall into four categories; systems that detect beam losses, systems that prevent beam losses, systems that reduce the probability or frequency of beam losses, and software based administrative alarms.

Three of the machine controls create two separate systems that detect excessive beam losses. The Beam Loss Monitor (BLM) system in conjunction with the Beam Permit System detects excessive beam losses through several hundred ionization chambers distributed around the MI/Recycler ring.

The LCW Activation Monitoring, an element of the second system, detects beam loss at or near LCW-cooled elements. Radiation monitors are located adjacent to the LCW piping at each service building. Uncontrolled losses will trip the radiation monitors and disable the Radiation Safety System preventing further beam injection. Seven interlocked detectors are required to monitor LCW piping within service buildings at MI/Recycler area locations MI-10, MI-20, MI-30, MI-40, MI-50, MI-52, and MI-62.

Three machine control systems, the Power Supply Regulation and Permits System and the MI/Recycler Vacuum Interlocks System in conjunction with the Beam Permit System, prevent beam losses from occurring. These machine control systems monitor critical power supplies and vacuum systems preventing further beam from being injected if faults are detected.

Four additional machine controls including the Beam Switch Sum Box, the Time Line Generator, the MI/Recycler Transfer Permit, and the MI/Recycler Orbit Controls insure that the necessary machines are ready to transport beam. These systems determine if the necessary machines are ready to transport beam and maintain the beam near the center of the machine's aperture thus reducing the probability or frequency of beam losses.

The MI/Recycler Alarms and Limits combine software monitoring of devices and monitoring controls. Machine devices are monitored by the ACNET System and device problems are posted on alarm screens in the Main Control Room based upon an established set of limits and priorities for each device.

The combination of these systems provides a defense-in-depth strategy to greatly limit the duration of accidental beam losses. The analysis of these systems and an operating experience review over the past 10 years provided the basis for determining the credible beam loss accident event for the MI and Recycler. Based on this review by the Beam Loss Scenarios Panel, the Fermilab Director approved a two category reduction for the accident condition postings for the MI/Recycler area [11].

II - 6.5.2.2 Radiation Safety Interlock System

The MI/Recycler area is one of the two Booster Radiation Safety Interlock System operating modes. The characteristics of the system are described in Chapter I of the Fermilab SAD.

The MI/Recycler enclosure is approximately 3300 meters in circumference. Spaced around the ring are eight service buildings with interlocked enclosure access points and an additional interlocked equipment access labyrinth at the MI-60 service building. Sixteen interlocked emergency exit stairs that lead directly to the surface are spaced around the ring to minimize the distance between exit points. The enclosure is separated into five separate interlocked boundaries to assist with Search and Secure operations. The interlock system inhibits transport of beam beyond the Booster absorber in the Booster enclosure except when the MI, Tevatron F Sector, Muon Campus Transport, MI-12A, and MI-31 Stub enclosures are properly secured and locked, and the area radiation monitors are made up.

The Radiation Safety Interlock system inhibits beam by controlling redundant critical devices. In the case of the MI operating mode, the primary critical devices are the Booster Extraction Lambertson (ACNET designation B:LAM), and the Horizontal Bend Magnet Power Supply (ACNET designationB:MH1). In the event of a critical device failure, the system has a failure mode function that will reach back and disable the upstream Linac Radiation Safety Interlock System.

Trained and qualified personnel from the AD Operations Department are required to search and secure the enclosure before permits from the radiation safety interlock system may be reestablished following any personnel access to the enclosure, except under strictly specified controlled access conditions. The Radiation Safety Interlock Systems including requirements for hardware and system testing, inventory of interlock keys, search and secure procedures for the beam line enclosure, controlled access procedures, personnel training requirements, and procedures for maintenance of interlock systems, are in conformance with the requirements stated in the FRCM.

II - 6.5.3 *Administrative Controls*

All MI/Recycler area operations with the potential to affect the safety of employees, researchers, or the public or to adversely affect the environment are performed using approved laboratory, division, or department procedures. These procedures are the administrative controls that encompass the human interactions that define safe accelerator operations.

II - 6.5.3.1 Beam Permits and Run Conditions

In accordance with AD Administrative Procedure on Beam Permits, Run Conditions, and Startup (ADAP-11-0001), beam will not be transported to the MI/Recycler without an approved Beam Permit and Run Condition. The Beam Permit specifies beam power limits as determined and approved by the AD Head in consultation with the AD ES&H Department Head, AD RSO, AD Operations Department Head, and AD External Beams Department Head. The run conditions list the operating modes and safety envelope for the MI/Recycler beam line. Run conditions are issued by the AD ES&H department, and are signed by the AD Operations Department Head, AD RSO, and AD Division Head.

In order to run beam to the MI/Recycler beam line, the MI Enclosure, Tevatron F Sector, Muon Campus Transport, MI-12A, and MI-31 Stub must be secure, seven interlocked detectors used to monitor LCW piping within MI-10, MI-20, MI-30, MI-40, MI-50, MI-52, and MI-62 Service Building locations and five interlocked detectors to monitor prompt radiation at three locations in the MI-60 Service Building must be active.

II - 6.5.3.2 Summary of Beam Operating and Safety Envelope Parameters

The MI/Recycler has been assessed from the standpoint of beam operating and safety envelope parameters. The MI was assessed for beam operating parameters of $5.16\text{x}10^{13}$ protons/pulse, $1.39\text{x}10^{17}$ protons/hr with a 1.333 second cycle time (2700 pulses/hr) at 120 GeV. The Recycler beam operating parameters used in this assessment are of $8.34\text{x}10^{13}$ protons/pulse, $2.25\text{x}10^{17}$ protons/hr with a 1.333 second cycle time (2700 pulses/hr) at 8 GeV.

Accelerator operational approvals shall be obtained by following the AD Procedure on Beam Permits, Run Conditions, and Startup (ADAP-11-0001), administered by the AD ES&H Department and AD Head. Beam Permit and Run Condition documents shall identify the beam power and operating parameters allowed within the current Accelerator Safety Envelope. The

Beam Permit specifies beam power limits as determined and approved by the AD Head in consultation with the AD ES&H Department Head, AD RSO, AD Operations Department Head, and AD Main Injector Department. The Run Condition for the MI/Recycler area describes the operating configuration as reviewed by the AD RSO, AD Operations Department Head, and as approved by the AD Head.

II - 6.6 Summary and Conclusion

Specific hazards associated with commissioning and operation of the MI/Recycler area enclosure are identified and assessed in this chapter of the Fermilab Safety Assessment Document. The designs, controls, and procedures to mitigate MI/Recycler specific hazards are identified and described. In addition to these specific safety considerations, the MI/Recycler area is subject to the global and more generic safety requirements, controls and procedures outlined in Section I of this Fermilab Safety Assessment Document.

The preceding discussion of the hazards presented by MI/Recycler operations and the credited controls established to mitigate those hazards demonstrate that the area can be operated in a manner that will produce minimal hazards to the health and safety of Fermilab workers, visiting scientists, members of the public, as well as to the environment.

II - 6.7 Glossary, Acronyms

ACNET	Accelerator Control Network System
AD	Accelerator Division
ALARA	As Low As Reasonably Achievable
BLM	Beam Loss Monitor
Ci	Curie
ES&H	Environment, Safety and Health
Fermilab	Fermi National Accelerator Laboratory
FESHM	Fermilab Environment, Safety, and Health Manual
FRCM	Fermilab Radiological Control Manual
GeV	Giga-electron volt
HEP	High Energy Physics
Hr	Hour
Hz	Hertz
IEPA	Illinois Environmental Protection Agency
kW	kilo-watt
LCW	Low Conductivity Water
MI	Main Injector
mrem/hr	milli-rem per hour
NOvA	Neutrino Off-axis Electron Neutrino (νe) Appearance
NuMI	Neutrino at Main Injector
RSO	Radiation Safety Officer
RWP	Radiation Work Permit
SA	Shielding Assessment
SAD	Safety Assessment Document

II - 6.8 References

[1] **Main Injector Incremental Shielding Assessment 700 kW,** W. Schmitt, W. Higgins, M. Vincent, R. Zimmermann, August 2012.

[2] **Recycler Ring Incremental Shielding Assessment 2.25x10^{17} protons/hour,** W. Schmitt, W. Higgins, M. Vincent, R. Zimmermann, October 2012.

[3] **Fermilab Radiological Control Manual**. - The web link is: http://esh.fnal.gov/xms/FRCM

[4] **Fermilab Radionuclide Air Emissions Annual Report**. - https://esh-docdb.fnal.gov:440/cgi-bin/ShowDocument?docid=2073

[5] **Calendar Year 2010 Radionuclide Air Emissions Annual Report for Fermilab. -** https://esh-docdb.fnal.gov:440/cgi-bin/ShowDocument?docid=1735

[6] **Radiation Physics for Personnel and Environmental Protection**, D. Cossairt, TM-1834

[7] **Summary of Shielding Estimates for LBNE Transport Line Hadrons & Muons**, K. Vaziri, LBNE-doc-3759-v1, May 18, 2011.

[8] **Fermilab Environment Safety & Health Manual**. - The web link is: http://esh.fnal.gov/xms/FESHM

[9] N.V. Mokhov, **"The MARS Code System User's Guide"**, Fermilab-FN-628 (1995);N.V. Mokhov, O.E. Krivosheev, **"MARS Code Status"**, Proc. Monte Carlo 2000 Conf., p. 943, Lisbon, October 23-26, 2000; Fermilab-Conf-00/181 (2000).

[10] **Main Injector and Beam Loss Controls**, D. Capista, July 2012.

[11] **Approval to Reduce Accident Condition Postings by two categories for the Main Injector and Recycler. -** https://esh-docdb.fnal.gov:440/cgi-bin/ShowDocument?docid=1935

Neutrinos at the Main Injector (NuMI) Beam Line

Revision 0
June 3, 2013

Author(s)

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Revision History

Author	Description of Change	Revision No. & Date
John E. Anderson Jr. Craig Moore	Initial release of the NuMI Beam Line Chapter for the Fermi National Accelerator Laboratory Safety Assessment Document (SAD)	Revision 0 June 3, 2013

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II-9 NuMI Beam Line

II – 9.1 NuMI Beam Line Location on the Fermi National Accelerator Laboratory (Fermilab) Site

The following aerial photograph shows the location of the NuMI Beam Line in relationship to the Fermilab site.

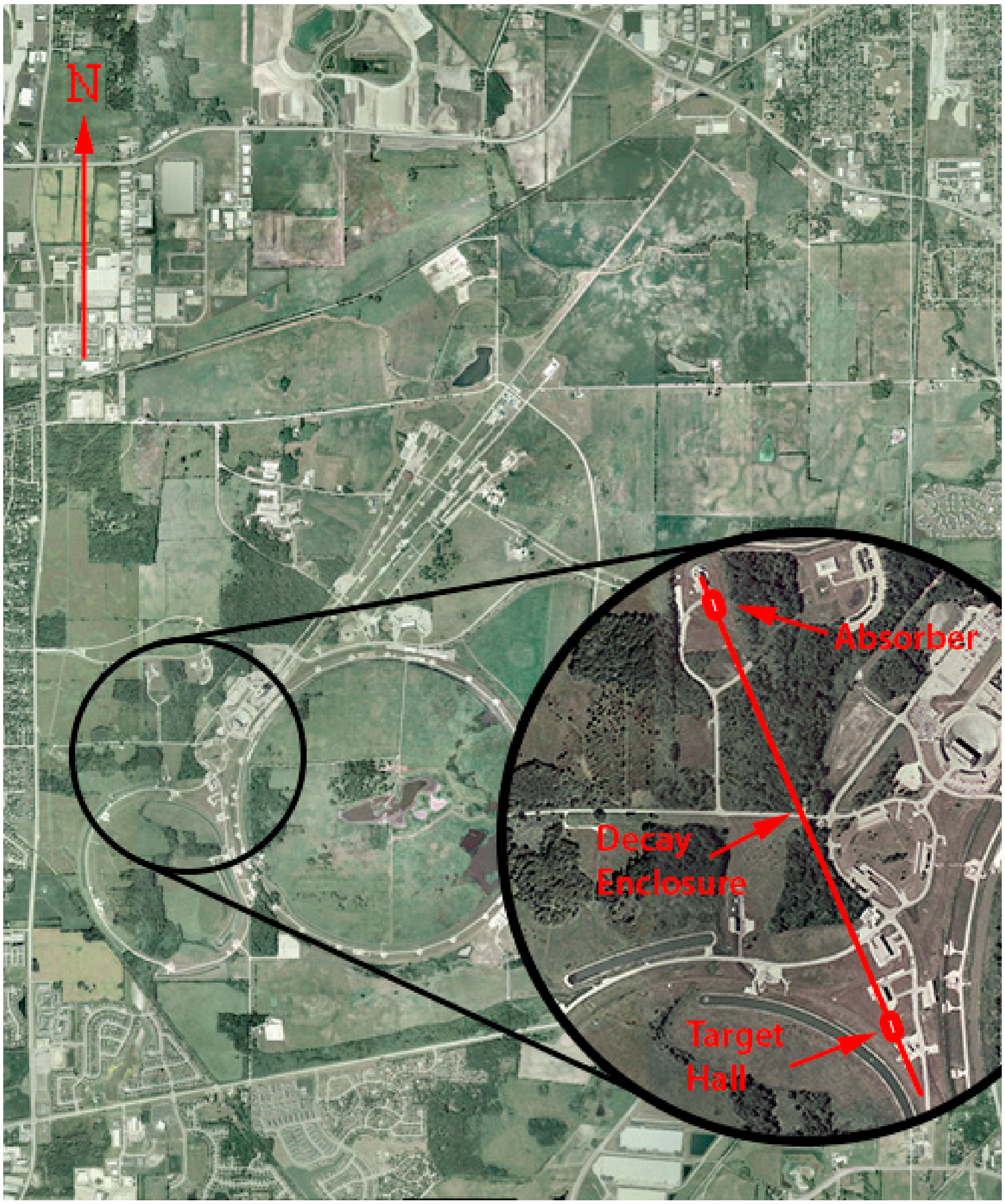

Figure 1 View of the Fermilab site showing the NuMI Beam Line location.

II – 9.2 Inventory of Hazards

The following table lists the identified hazards found in the NuMI Beam Line and support buildings. All hazards with an asterisk (*) have been discussed in Chapters 1-10 of the Fermilab Safety Assessment Document (SAD) and are not covered further in this section.

Radiation Ionizing radiation Residual activation Ground water activation Air activation Radioactive waste	**Kinetic Energy** Power tools ***** Pumps and motors *
Toxic Materials Lead shielding * Beryllium components *	**Potential Energy** Crane operations * Compressed gases * Vacuum pumps *
Flammable & Combustible Materials Cables * Flammable gasses*	**Magnetic Fields** Fringe fields *
Electrical Energy Stored energy exposure High voltage exposure* Low voltage, high current exposure *	**Gaseous Hazards** Confined spaces *
Thermal Energy	**Access / Egress** Life safety/emergency egress

II – 9.3 Introduction

This Section II, Chapter 9 of the Fermilab SAD addresses the NuMI Beam Line. The NuMI Beam line runs from a lined and unlined Carrier Tunnel that begins at the NuMI stub in the Main Injector and includes the target hall, decay tunnel, hadron absorber enclosures, access tunnel, and muon alcoves as well as the respective surface and underground service buildings.

II – 9.3.1 Purpose of the NuMI Beam Line

The purpose of the NuMI Beam Line is to produce an intense beam of neutrinos for physics experiments designed to detect and study neutrino oscillations. The NuMI Beam Line extracts a 120 Giga-electron volt (GeV) beam of protons from the Main Injector (MI) and directs a high intensity beam of neutrinos to near-detectors at Fermilab and far-detectors at Soudan, Minnesota and Ash River, Minnesota.

II – 9.3.2 Description of the NuMI Beam Line

The NuMI Beam Line receives an extracted beam of 120 GeV protons from the MI. The extracted beam strikes a target to produce short-lived hadrons. Neutrino horns focus the hadrons before the hadrons enter the NuMI decay pipe. A fraction of the hadrons in the decay pipe decay to neutrinos and muons as they travel through the decay pipe. At the end of the decay pipe, the remaining hadrons are absorbed in the hadron absorber.

The native rock in place downstream of the hadron absorber absorbs the muons produced with the neutrinos in the decay region. Muon monitors along the beam line monitor the direction of the beam by measuring muon distributions. Figure 2 depicts the process for production of the neutrino beam.

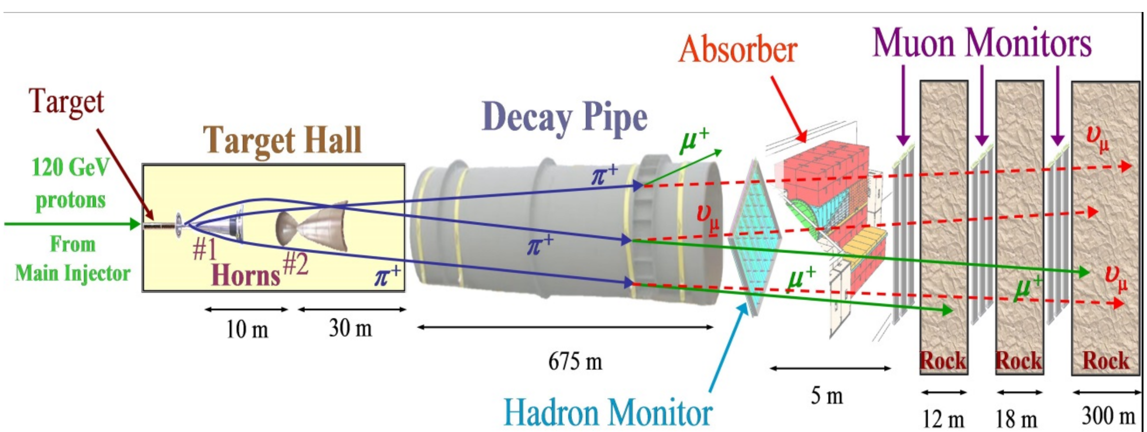

Figure 2. Process for production of the NuMI neutrino beam

Research and support facilities constructed for the NuMI Project also include access shafts, support rooms, and a bypass tunnel for the rock region downstream of the absorber. The main components of the NuMI Beam Line include:

- An underground lined Carrier Tunnel starting at the NuMI stub in the MI;
- An underground unlined Carrier Tunnel;
- Underground Pre-Target/Target enclosure;
- An underground Decay Tunnel;
- An underground Hadron Absorber Enclosure and Access Tunnel with Muon Alcoves; and
- Surface MI-65 and Main Injector Neutrino Oscillation Search (MINOS) Service Buildings

The NuMI Beam Line instrumentation assures that the beam is on target and directed to the near and far detectors by maintaining beam losses to a minimum level. This outcome is accomplished through the use of position information to assure that the beam is in the center of its vacuum chamber with profiles to allow unexpected beam tails and halo to be observed, sensitive loss measurements to allow beam problems to be immediately addressed, and intensity measurements to monitor large beam losses.

The NuMI Profile Monitors are secondary emission monitors designed to place minimal material in the beam. Toroids or beam current transformers are used in the NuMI Beam Line for intensity measurements. Total Loss Monitors used in the NuMI Beam Line provide continuous coverage from the NuMI extraction enclosure through the final targeting elements.

II – 9.3.3 Operating Modes

The NuMI Beam Line transports 120 GeV MI protons at a maximum intensity of 5.4×10^{13} protons every 1.333 seconds. This transport rate amounts to 1.46×10^{17} protons/hr.

Figure 3 depicts the major elements of the NuMI Beam Line:

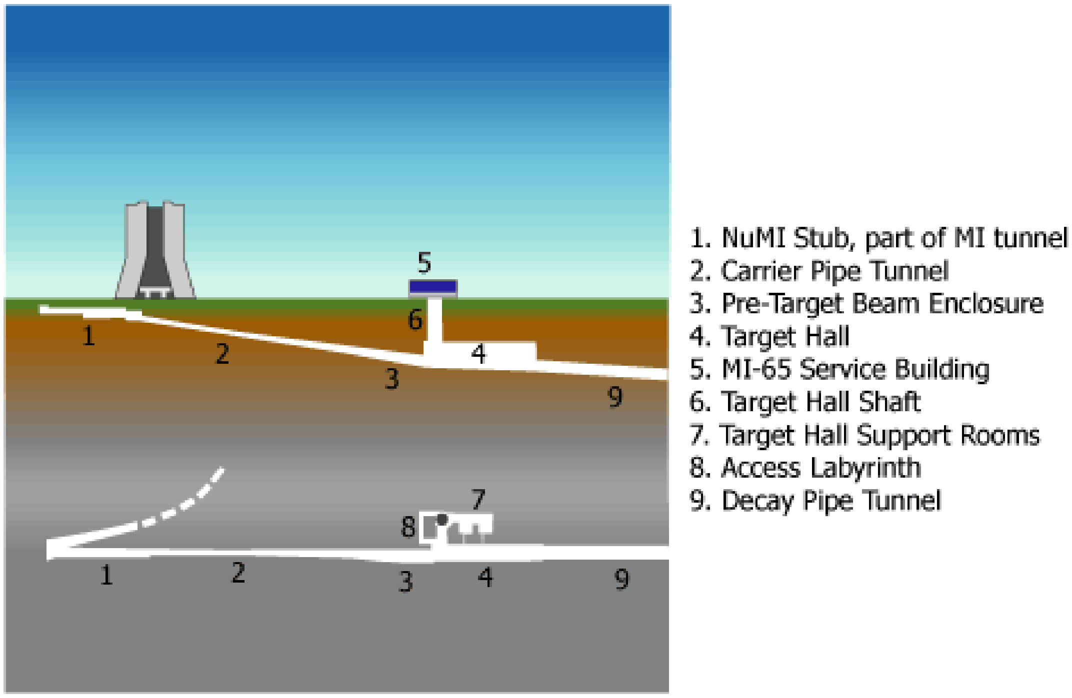

Figure 3 Major elements of the NuMI Beam Line.

II – 9.4 Safety Assessment

The unique beam line specific hazards for the NuMI area are analyzed in this section. The radiological hazards include ionizing radiation, residual activation, groundwater and surface water activation, air activation, and radioactive waste. In addition to the radiological hazards, the NuMI Beam Line has a unique electrical hazard, life safety emergency egress, and flooding hazards that are addressed.

II – 9.4.1 Radiological Hazards

The NuMI Beam Line presents radiological hazards in the form of prompt and residual ionizing radiation from particle beams, residual radiation due to activation of beam line components, and environmental radioactivity in the form of potential groundwater, surface water, and air activation resulting from the operation of the beam transport systems.

A detailed shielding assessment and post assessment documents address these hazards [1]. The assessments provide a detailed analysis of the NuMI Beam Line facility demonstrating the required shielding, controls and interlocks to comply with the Fermilab Radiological Control Manual (FRCM) [2].

The NuMI Beam Line begins at the location of the first NuMI extraction kicker magnet in the MI at cell 602. The assessment continues through the MI ring to the NuMI Stub, the Carrier Tunnel, the Target Hall, the decay pipe, the hadron absorber, and the muon alcoves. The assessment includes the MI-65 and MINOS access shaft areas and the Target Hall support rooms.

The assessment considers groundwater and surface water activation, lists surface water discharge points and monitoring locations; calculates air activation, estimates annual release, and release points; considers muon production; considers longitudinal and transverse shielding requirements; summarizes labyrinth and penetration calculations; calculates residual dose rates; and specifies active shielding controls and monitoring.

II – 9.4.1.1 Ionizing Radiation

Prompt ionizing radiation is the principle radiation hazard when beam is transported through the NuMI Beam Line. In order to protect workers and the general public, the enclosures and beam pipes are surrounded either by sufficient amounts of shielding (soil, concrete, or iron), and/or networks of interlocked detectors to keep any prompt radiation exposure within acceptable levels.

A detailed shielding assessment has been compiled and reviewed by the Fermilab Shielding Review Subcommittee to address these concerns. The assessment provides a detailed analysis of the beam line, demonstrating the required overburden or soil shielding, use of signs, fences, and active interlocks to maintain any prompt radiation within acceptable levels.

The shielding assessment for the NuMI Beam Line has included analyses of injection, targeting, decay, and absorption areas. The assessment covers prompt dose rates associated with the secondary beam line, labyrinths and penetrations, the Hadron Absorber labyrinth, the radioactive water system (RAW) room, and muons in the bypass tunnel. Since the majority of the NuMI Beam Line is deep underground, there are only a few areas where the issue of prompt radiation from NuMI operations is a concern. These areas include the MI/NuMI Stub, the power supply room/upstream shaft area and the bypass tunnel. The NuMI Beam Line shielding assessment requires that:

- *Certain penetrations are filled with shielding as specified;*
- *All movable shielding blocks are installed as specified;*
- *All interlocked detectors are installed as specified;*

- *The radiation safety interlock system is certified as working.*

The NuMI Shielding Assessment concludes:

- *The facility is in conformance with all FRCM requirements and can be operated safely with the following beam parameters:*
  - *Maximum operating intensity is 1.46 x 10^{17} protons per hour;*
  - *Maximum energy is 120 GeV.*

II – 9.4.1.2 Residual Activation

The shielding assessment estimates residual activation of NuMI Beam Line components. The beam line is designed to keep residual dose rates in the primary beam region below100 milli-rem per hour (mrem/hr) and below 30 mrem/hr in the Hadron Absorber Hall where personnel have access. Radiological surveys taken over the past six years of operation with 120 GeV protons show dose rates in the primary beamline region and in the accessible areas of the Hadron Absorber Hall of less than 15 mrem/hr.

The shielding assessment estimates residual activation of NuMI Target Chase components. The standard residual dose rate values quoted are for a 30-day irradiation and a 1 day cool down, designated (30d, 1d). Estimated values for (30d, 1d) at operations of 700 kilowatt (kW) beam power are 6 rem/hr for the Target, 400 rem/hr for Horn 1, and 33 rem/hr for Horn 2.

When the NuMI Beam Line is not in operation, the enclosure area will remain radioactive and access to these components will be tightly controlled with the level of control dependent on the level of residual radiation. The control measures include training and training verification, centralized access authorization, and key entry. Controls required for different levels of residual radiation are specified in the FRCM, and are detailed in the Radiological Work Permit (RWP) for the work to be performed.

In most situations, general RWPs for accesses will suffice. A job-specific RWP and an as-low-as-reasonably-achievable (ALARA) plan will be required for work on any highly activated equipment with a potential individual exposure greater than 200 mrem or potential job exposure greater than 1000 person-mrem. These tasks will be supervised by members of the Accelerator Division (AD) Environment, Safety, and Health (ES&H) Radiation Safety Group under the direction of the AD Radiation Safety Officer (RSO).

II – 9.4.1.3 Groundwater and Surface Water Activation

Operation of the NuMI Beam Line will activate water in the vicinity of the NuMI Beam Line tunnel. The majority of the activation occurs within a few meters of the beam line tunnel wall. Groundwater modeling of the subsurface hydrologic systems suggests that the NuMI tunnel functions as a well that captures nearby groundwater [1].

Water flowing into the NuMI tunnel is pumped to the surface from the sump at the base of the MINOS Access Shaft. The shielding assessment estimates that with $6x10^{20}$ protons on target each year, the ^{3}H (tritium) and ^{22}Na (sodium-22) concentrations of the sump water will be 35 pico Curie (pCi)/milliliter (ml) for ^{3}H with no detectable ^{22}Na, approximately 2% of the surface water discharge limits. At the surface, the water is discharged to a holding tank for use in the Fermilab Industrial Cooling Water (ICW) system, which confines the tritiated water to the Fermilab site.

The NuMI horns, decay pipe, and the hadron absorber are cooled by water. The water in these cooling systems will become activated with ^{3}H, and to a lesser extent ^{7}Be (beryllium-7). The controls, interlocks and alarms designed for these systems prevent catastrophic losses and damage to the equipment [1]. The release of RAW from any of the NuMI cooling systems does not cause any significant increase to the concentration of radionuclides in the discharge to the ICW system [1].

AD ES&H Radiation Safety Group monitors beam line losses to maintain water activation and residual dose rates in the tunnel below limits defined in the FRCM as part of the Fermilab environmental monitoring program. Water is sampled periodically at monitoring well S-1274 located down-gradient of the lined section of the Carrier Tunnel and a holding tank located near the MINOS Service Building. The NuMI Beam Line sumps are sampled periodically in accordance with Fermilab monitoring procedures and tested for radionuclides.

Releases of ^{3}H and ^{22}Na constitute the radionuclides of most significant concern from the standpoint of groundwater and surface water activation. Table 1 presents documented and monitored levels of radionuclides associated with the NuMI beamline and associated regulatory limits.

10.75×10^{20} protons on target	Monitoring Well Measured Concentrations	Regulatory Limits*
^{3}H	< 0.2 pCi/ml	20 pCi/ml Groundwater 1900 pCi/ml Surface Water
^{22}Na	< 0.03 pCi/ml	0.4 pCi/ml Groundwater 10 pCi/ml Surface Water
* ^{3}H Regulatory Limit from 40CFR141 Federal Drinking Water Standards. ^{22}Na Regulatory Limits from the DOE STD-1196-2011 Derived Concentration Standards.		

Table 1: Release Concentrations and Regulatory Limits associated with NuMI Beam Line-produced radionuclides in groundwater and surface water.

II – 9.4.1.4 Air Activation

Federal regulations and the Fermilab Lifetime Operating Air Pollution permit issued by the Illinois Environmental Protection Agency (IEPA) govern releases of airborne radionuclides. The regulations limit the equivalent dose delivered to a member of the public to 10 mrem/year [3, 4]. Fermilab has established a secondary goal of keeping the maximum equivalent dose at the site boundary due to air emissions under 0.1 mrem/yr.

The methodology used to assess NuMI air activation concerns has been documented in the shielding assessment [1]. Delayed ventilation is used at NuMI to reduce radioactive air emissions. The vast majority of the radioactivity produced is short-lived. A delay time of one hour from production of the radionuclides to release will reduce the levels of radioactivity by roughly one order of magnitude at the stack release point.

There are six NuMI Beam Line exhaust air vents (EAV). EAV1 is the vent for the Carrier Tunnel and Pre-Target area. EAV2, Target Pile Evaporator Stack (TPES), and Survey Riser (SR) SR3 are the exhaust vents for the Target Hall area and upstream decay region. EAV3 is the exhaust vent for the Hadron Absorber area and downstream decay region. The highest levels of air activation are from the Target Hall/upstream decay region (EAV2, TPES, and SR3) and the Hadron Absorber/downstream decay region (EAV3). The air from EAV1, EAV2, TPES, SR3 and

EAV3 is routinely monitored by the Environment, Safety, Health, & Quality (ESH&Q) Section to insure air emissions stay well below 0.1 mrem/yr level at the site boundary.

During the early operation of the NuMI Beam Line, increases in tritium concentration were observed in the water discharged from the NuMI sumps to the Fermilab ICW system. The increase in tritium concentrations in the water discharged from the NuMI sumps has been directly correlated to humidity levels inside the NuMI Target Hall and target chase. Dehumidification systems have been installed to reduce the humidity levels in air within the Target Hall and target chase.

A condensate collection system has been installed to collect tritiated water condensed on the cooling coils of the NuMI target chase air cooling and desiccant re-circulation systems. The water is pumped from a holding tank in the NuMI Beam Line tunnel to a holding tank located in the southwest corner of the MI-65 service building. The water from the holding tank is gravity fed to an evaporation unit where the evaporated water is exhausted out the TPES through the roof of the MI-65 service building.

A high velocity fan on the roof of MI-65 mixes outside air with the exhausted moist air from the evaporator. This mixing prevents condensation of the evaporated water on the MI-65 service building roof and area surrounding the building. Tritium released through the MI-65 exhaust stacks contributes less than 1 micro-rem /year to Fermilab site boundary dose [1].

Secondary particles and un-interacted protons within the beam line will also interact with helium in the NuMI decay pipe to produce tritium and other radionuclides. Monte Carlo Shielding Computer Code (MARS) [5] simulations predict that about 0.12 Ci of tritium will be produced in the helium and 9 Ci of tritium will be produced in the decay pipe steel for every 1 $x10^{20}$ protons on target. Approximately half of the tritium in the decay pipe steel or 5 Ci of tritium are expected to leak from the steel into the helium. However, measurements of the decay pipe tritium contents showed no evidence of tritium migration from the decay pipe steel into the helium. This is attributed to the lack of air and moisture inside the decay pipe.

After ten years of running with helium in the decay pipe, irradiation of 5×10^{21} protons on target, the airborne activation in the Target Hall from a decay pipe window failure would result in a dose rate of 12 mrem/hr, well below the FRCM limit of 100 mrem in one hour. The release of all the tritium accumulated in the decay pipe helium into the air will contribute less than 0.1 micro-rem to the Fermilab site boundary dose.

The NuMI Beam Line shielding assessment calculates the annual maximum anticipated equivalent dose to an individual located at the Fermilab site boundary to be 0.025 mrem from all emission sources.

II – 9.4.1.5 Radioactive Waste

Tritiated water from the Target Chase and Absorber Hall air chiller condensate is evaporated. Fermilab reports the amount of ^{3}H evaporated in Fermilab Radionuclide Air Emissions Annual Reports [6] provided to the DOE Fermi Site Office for transmission to State and Federal regulatory agencies in accordance with 40 CFR Part 61 Subpart H, National Emission Standards for Emissions of Radionuclides Other Than Radon from Department of Energy Facilities. Tritiated RAW is solidified and disposed of as solid low level radioactive waste.

Some used components will be stored in the Target Hall storage area until preparations are made for safe storage at the C0 assembly building, another location on site, or for disposal. Other items that can be taken up the access shaft are characterized and disposed of as solid low-level radioactive waste.

NuMI radioactive waste hazards and waste disposal are managed within the program established for the Fermilab accelerator complex and as prescribed in the FRCM. Waste minimization is an objective of the equipment design and operational procedures. Although production of radioactive material is not an operational function of the NuMI area, beam loss and, in the case of some beam diagnostics devices, intentional interception of the beam will result in activation of beam line elements. Reuse of activated items will be carried out when feasible. Activated items that cannot be reused will be disposed of as radioactive waste in accordance with the FRCM requirements.

II – 9.4.2 Electrical Stored Energy Exposure

Operation of the neutrino focusing horns poses electrical hazards from the stripline connections between power supply capacitor bank and the horns and the 60 kilo Jules of stored energy in the power supply capacitor bank. The Target Hall Power Supply Room horn stripline is an electromagnetic transmission line constructed of a series of aluminum conductors that carry the very high current needed to pulse the focusing horns in the target chase. Access to the stripline is controlled by the NuMI radiation safety interlock system and the stripline is located behind a fence.

The power supply capacitor bank is designed, installed, operated and maintained in accordance with Fermilab Environment, Safety, and Health Manual (FESHM) requirements. Performing Lock out Tag out (LOTO) is required before performing maintenance on devices connected to hazardous energy sources.

II – 9.4.3 Life Safety Emergency Egress

Life safety considerations have been used to set the Target area occupancy limit to 50 persons with a subsidiary limitation of four occupants in the downstream area of the Carrier Tunnel region during installation and maintenance activities. There is an 8-person limit at the Target underground area during normal operations.

Occupancy limits and tracking of those in the underground area are maintained through a badging process that requires a NuMI underground access badge when entering the underground areas. The individual entering the underground leaves their Fermilab badge at the entrance to the respective NuMI access shaft. A NuMI underground badge is then assigned to each individual. Upon completing their time underground, the individual returns the NuMI underground badge and retrieves their Fermilab badge providing for an accurate head count of those underground.

Methods of emergency egress have been established for each of the NuMI Beam Line areas:

- Exiting from the NuMI stub is through the usual MI emergency egress system. A secondary route is through the Carrier Tunnel to the Target Access Shaft staircase;
- Exiting from the Carrier Tunnel is either upstream via the MI, or downstream via the Target Access Shaft staircase;
- Primary exiting from the Target Hall and support rooms is through the Target Access Shaft staircase;
- Secondary Target Hall exiting is through the decay tunnel walkway to the MINOS Access Shaft and up the enclosed MINOS elevator;
- Tertiary exiting route from the Target Hall is through the Carrier Tunnel and the MI;

- The primary exit from the Absorber areas is through the isolated MINOS Access Shaft elevator; and
- The secondary exit from the Absorber area is through the Decay Tunnel walkway upstream to the Target area and out the Target Hall Access Shaft staircase.

National Institute of Occupational Safety and Health approved escape packs are provided adjacent to the shaft elevators to provide 10 minutes of breathing air to personnel during emergency egress. All personnel working in the underground facilities are required to take Fermilab Underground Safety Training as well as appropriate radiation training, and LOTO II training.

Egress through the MINOS area is addressed in MINOS Hall Detectors Section III, Chapter 5.

II – 9.4.4 Flooding

Incoming groundwater from the length of the NuMI tunnels collects in the MINOS Access Shaft sump pit. The water is pumped to the surface. If the pumping system is non-operational, approximately one hour can pass before the water will reach the MINOS Access Shaft floor level defining the beginning of a flooding condition. This hazard is addressed in the MINOS Hall Detectors Section III, Chapter 5.

II – 9.5 Credited Controls

II – 9.5.1 Passive Controls

Passive controls are accelerator elements that are part of the physical design of the facility that require no action to function properly. These passive controls are fixed elements of the beam line that take direct human intervention to remove. The NuMI Beam Line is designed to optimize the effect of these passive controls with permanent concrete and earth-covered radiation shields that use a combination of permanent shielding, movable shielding, and penetration shielding to protect personnel from radiological exposure during beam line operations.

II – 9.5.1.1 Permanent Shielding including Labyrinths and Penetrations

The permanent shielding encompasses the structural elements surrounding the beam line components. The NuMI concrete structure is contiguous with the MI beam line. Labyrinths and penetrations in the NuMI tunnels and halls have been assessed for radiation dose rates under normal operating and accident conditions. The areas assessed in the Shielding Assessment include the following:

- Survey Risers 1, 2, and 3;
- Exhaust Stacks EAV1, EAV2 and EAV3;
- Target Hall Labyrinth;
- Target Hall Equipment Door;
- Horn Stripline Penetration;
- RAW System Penetration;
- Hadron Absorber Access Labyrinth;
- Muon Alcoves 2, 3 and 4 gates;
- RAW Room Door;
- Target Chase Air Cooling Labyrinth;
- MINOS Access Shaft and EAV4; and
- Muon Alcove Bypass Tunnel.

The largest potential NuMI Beam Line radiological losses under both normal operating and accident conditions are at Survey Risers SR1 and SR2. Permanent shielding at these locations reduces the potential dose rate to 0.1 mrem/hr under both normal and accident conditions.

II – 9.5.1.2 Movable Shielding

Assessments of movable Target Hall shielding components have been made foremost for access to the Target Hall and the handling of irradiated components within the Target Hall. A movable concrete door is put in place during beam operations to preclude access to the Target Hall from the NuMI access shaft area. MARS calculations predict a dose rate on the Target Hall side which corresponds to less than 1 micro-rem/hr penetrating through the gaps in the shield door [1]. Measurements of the dose rate immediately outside the door would be less than 1 mrem/hr due to leaking air through the penetrations and combination of other small sources. These areas are considered Controlled Areas.

Measurements of NuMI residual radiation dose rates for Target Hall components have been made whenever a Target Hall component was taken from the NuMI Target Chase. NuMI Target Hall component shielding is housed within a permanent concrete liner. The movable shielding components include steel blocks, T- blocks and R-blocks. Movable shielding components are placed by crane operation in the Target Hall as a step in accessing, repairing or replacing NuMI Target Chase components. Figure 3 shows the movable components of Target Hall component shielding.

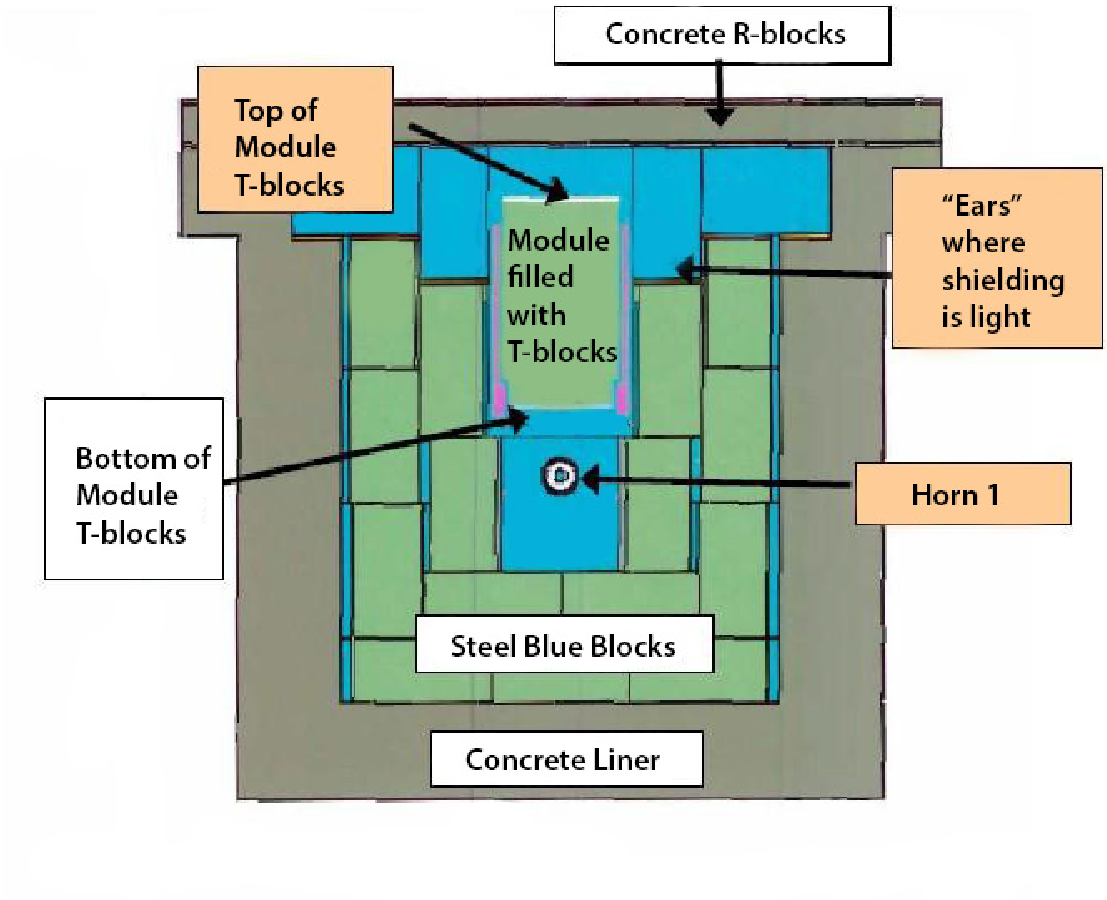

Figure 9. Cross Section of the NuMI Target Hall component region.

NuMI component handling is done remotely. Resultant radiation fields following relocation of the movable Target Hall shielding does not pose a hazard to workers. Continual attention is devoted to ensure that component access, repair, or replacement activity dose rate levels are maintained within FRCM acceptable limits.

II – 9.5.2 Active Controls

Active engineered controls are systems designed to reduce the risks from accelerator operations to an acceptable level. These are automatic systems that limit operations, shut down operations, or provide warning alarms when operating parameters are exceeded. The active controls in place for the NuMI Beam Line are discussed below.

II – 9.5.2.1 Radiation Safety Interlock System

The NuMI Beam Line employs a Radiation Safety Interlock System (RSIS). The characteristics of the system are described in Chapter I of the Fermilab SAD.

The NuMI Beam Line connects the MI RSIS and the NuMI RSIS. The boundary between the two systems is the door located at the mid-point of the NuMI Carrier Tunnel. The lined section of the Carrier Tunnel is a separately interlocked area to avoid the necessity of routine search and secure of this area. This lined section of the Carrier Tunnel is not accessible when the MI is operating.

The downstream end of the Carrier Tunnel is part of the NuMI RSIS and access to this region disables the NuMI critical devices. The primary critical devices are the NuMI Extraction Lambertson string (ACNET designation I:LAM60 & I:LAM61), and the Horizontal/Vertical Bend Magnet string (ACNET designation I:HV101A, B, & C). In the event of a critical device failure, the system has a failure mode function that will reach back and disable the upstream Booster RSIS. The NuMI RSIS prevents personnel access to Pre-Target, the Target Hall area, Decay Pipe tunnel, Hadron Absorber area and Muon Alcoves with beam enabled Access is not allowed to these areas unless the critical devices are disabled.

There are interlocked detectors in the Carrier Tunnel region to minimize losses along the primary beam, and power supply room. These detectors disable the critical devices when set points are exceeded.

The RSIS for the NuMI Beam Line includes the underground enclosures with the exception of the following areas that are accessible during routine operations:

- MI-65 Target Access Shaft Including Stairwell and Elevator;
- MI-65 Below Ground Elevator and Landing Area;
- Target Hall Power Supply Room;

- Absorber Access Tunnel up to the Absorber Area Door; and
- MINOS Access Shaft including elevators.

These areas are designated Controlled Areas.

Trained and qualified personnel from the AD Operations Department are required to search and secure the enclosure before permits from the RSIS may be reestablished following any personnel access to the enclosure, except under strictly specified controlled access conditions. The RSIS requirements including requirements for hardware and system testing, inventory of interlock keys, search and secure procedures for the beam line enclosure, controlled access procedures, personnel training requirements, and procedures for maintenance of interlock systems are in conformance with the FRCM.

II – 9.5.3 Administrative Controls

All NuMI Beam Line operations with potential to impact the safety of employees, researchers, or members of the public or to adversely impact the environment are performed using approved laboratory, division or department procedures. These procedures are the administrative controls that encompass the human interactions and form the foundation for safe accelerator operations. The administrative procedures and programs considered necessary to ensure safe accelerator operations are discussed.

II – 9.5.3.1 Beam Permits and Run Conditions

In accordance with AD Administrative Procedure on Beam Permits, Run Conditions, and Startup (ADAP-11-0001), beam will not be transported to the NuMI Beam Line without an approved Beam Permit and Run Condition. The Beam Permit specifies beam power limits as determined and approved by the AD Head in consultation with the AD ES&H Department Head, AD RSO, AD Operations Department Head, and AD External Beams Department Head. The run conditions list the operating modes and safety envelope for the NuMI Beam Line. Run conditions are issued by the AD ES&H Department, and are signed by the AD Operations Department Head, AD RSO, and AD Division Head.

In order to run beam to the NuMI Beam Line, the Pre-Target, Target Hall, Decay Pipe tunnel, Hadron Absorber area and Muon Alcoves must be secure. The radiation monitors in the Carrier Tunnel and power supply room must be active.

II – 9.5.3.2 Summary of Beam Operating and Safety Envelope Parameters

The NuMI Beam Line has been assessed from the standpoint of beam operating and safety envelope parameters. The beam operating parameter assessment was performed for 120 GeV MI protons transported to the NuMI target at a maximum intensity of 5.4×10^{13} protons every 1.333 seconds (1.46×10^{17} protons/hr).

II – 9.6 Summary & Conclusion

Specific hazards associated with commissioning and operation of the NuMI Beam Line are identified and assessed in this chapter of the Fermilab SAD. The designs, controls, and procedures to mitigate NuMI Beam Line-specific hazards are identified and described. The NuMI Beam Line is subject to the global and more generic safety requirements, controls and procedures outlined in Section 1 of the Fermilab SAD.

The preceding discussion of the hazards associated with NuMI Beam Line operations and the credited controls established to mitigate those hazards demonstrate that the NuMI Beam Line can be operated in a manner that will produce minimal risk to the health and safety of Fermilab workers, researchers, the public, as well as to the environment.

II – 9.7 Glossary, Acronyms

AD	Accelerator Division
ALARA	As Low As Reasonably Achievable
^{7}Be	Beryllium-7
EAV	Exhaust Air Vent
ES&H	Environment, Safety and Health
ESH&Q	Environment, Safety, Health and Quality
Fermilab	Fermi National Accelerator Laboratory
FESHM	Fermilab Environment, Safety, and Health Manual
FRCM	Fermilab Radiological Control Manual
GeV	Giga electron volts
^{3}H	Tritium
ICW	Industrial Cooling Water
LOTO	Lock out Tag out
MARS	Monte Carlo Shielding Computer Code
MI	Main Injector
MINOS	Main Injector Neutrino Oscillations Search
micro-rem/hr	micro-rem per hour
mrem/hr	milli-rem per hour
^{22}Na	Sodium-22
NuMI	Neutrinos at the Main Injector
pCi/ml	picoCurie/milliliter
RAW	Radioactive Water System
RSIS	Radiation Safety Interlock System
RSO	Radiation Safety Officer
RWP	Radiation Work Permit
SAD	Safety Assessment Document
SR	Survey Riser
TPES	Target Pile Evaporator Stack

II – 9.8 References

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[3] Title 40, Code of Federal Regulations, 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.

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