NEUTRINO SWITCHYARD 120 EXPERIMENTAL AREAS

SECTION IV CHAPTER 09 OF THE FERMILAB SAD

Revision 0 March 14, 2024

This Chapter of the Fermilab Safety Assessment Document (SAD) contains a summary of the results of the Safety Analysis for the Neutrino Switchyard 120 Experimental Area of the Fermilab Main Accelerator that are pertinent to understanding the risks to the workers, the public, and the environment due to its operation.

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SAD Chapter Review

This Section 4, Chapter 3 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD), *Neutrino Switchyard 120 Experimental Areas*, was prepared and reviewed by the staff of the Particle Physics Directorate, Detector Development and Operations Department in conjunction with the Environment, Safety, and Health Division (ES&H) Accelerator Safety Department.

Signatures below indicate review of this Chapter, and recommendation that it be approved and incorporated into the Fermilab SAD.

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SAD Review Subcommittee Chair

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Revision History

Printed versions of this Chapter of the Fermilab SAD may not be the currently approved revision. The current revision of this Chapter can be found on ES&H DocDB #1066 along with all other current revisions of all Chapters of the Fermilab SAD.

Author	Rev. No.	Date	Description of Change
Evan Niner Richard Tesarek	0	January 17, 2024	• New chapter specific for Neutrino experimental areas, separated from S04.C03 • Update to match new SAD Layout • Incorporate Risk Matrix and hazard discussion • Include E1039 SpinQuest Experiment

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Acronyms and Abbreviations

ACGIH	American Conference of Governmental Industrial Hygienists
ACNET	Accelerator Control Network System
AD	Accelerator Directorate
AHJ	Authority Having Jurisdiction
ALARA	As Low As Reasonably Achievable
ANSI	American National Standards Institute
APS-TD	Applied Physics and Superconducting Technology Directorate
ARA	Airborne Radioactivity Area
ASE	Accelerator Safety Envelope
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
ASO	Accelerator Safety Orderreferring to DOE O 420.2D *Safety of Accelerators*)
^{7}Be	Beryllium-7
BLM	Beam Loss Monitor
BNB	Booster Neutrino Beam
BPM	Beam Position Monitor
BY	Boneyard
CA	Controlled Area
CA	Contamination Area
CAS	Contractor Assurance System
CC	Credited Control
CCL	Coupled Cavity Linac
CDC	Critical Device Controller
CERN	European Organization for Nuclear Research
CFM	Cubic Feet per Minute
CFR	Code of Federal Regulations (United States)
Ci	Curie
CLW	Co-Located Worker (the worker in the vicinity of the work but not actively participating)
cm	centimeter
CPB	Cryogenics Plant Building
CSO	Chief Safety Officer
CUB	Central Utility Building
CW	Continuous Wave
CX	Categorically Excluded
D&D	Decontamination and Decommissioning

DA	Diagnostic Absorber
DAE	Department of Atomic Energy India
DCS	Derived Concentration Standard
DocDB	Document Database
DOE	Department of Energy
DOT	Department of Transportation
DR	Delivery Ring
DSO	Division Safety Officer
DSS	Division Safety Specialist
DTL	Drift Tube Linac
DUNE	Deep Underground Neutrino Experiment
EA	Environmental Assessment
EA	Exclusion Area
EAV	Exhaust Air Vent
EENF	Environmental Evaluation Notification Form
EMS	Environmental Management System
EOC	Emergency Operations Center
EPA	Environmental Protection Agency
ES&H	Environment, Safety and Health
Fermilab	Fermi National Accelerator Laboratory (see also FNAL)
FESHCom	Fermilab ES&H Committee
FESHM	Fermilab Environment, Safety and Health Manual
FHS	Fire Hazard Subcommittee
FIRUS	Fire Incident Reporting Utility System
FNAL	Fermi National Accelerator Laboratory (see also Fermilab)
FODO	Focus-Defocus
FONSI	Finding of No Significant Impact
FQAM	Fermilab Quality Assurance Manual
FRA	Fermi Research Alliance
FRCM	Fermilab Radiological Control Manual
FSO	Fermilab Site Office
FW	Facility Worker (the worker actively performing the work)
GERT	General Employee Radiation Training
GeV	Giga-electron Volt
^{3}H	Tritium
HA	Hazard Analysis
HAR	Hazard Analysis Report
HCA	High Contamination Area

HCTT	Hazard Control Technology Team
HEP	High-Energy Physics
HFD	Hold for Decay
HLCF	High-Level Calibration Facility
HPR	Highly Protected Risk
Hr	Hour
HRA	High Radiation Area
HSSD	High-Sensitivity Air Sampling Detection
HVAC	Heating, Ventilation, and Air Conditioning
HWSF	Hazardous Waste Storage Facility
Hz	Hertz
IB	Industrial Building
IBC	International Building Code
ICW	Industrial Cooling Water
IEPA	Illinois Environmental Protection Agency
IEEE	Institute of Electrical and Electronics Engineers
INFN	Istituto Nazionale di Fisica Nucleare
IMPACT	Integrated Management Planning and Control Tool
IPCB	Illinois Pollution Control Board
IQA	Integrated Quality Assurance
ISD	Infrastructure Services Division
ISM	Integrated Safety Management
ITNA	Individual Training Needs Assessment
KeV	kilo-electron Volt
kg	kilo-grams
kW	kilo-watt
LBNF	Long Baseline Neutrino Facility
LCW	Low Conductivity Water
LHC	Large Hadron Collider
LLCF	Low-Level Calibration Facility
LLWCP	Low-Level Waste Certification Program
LLWHF	Low-Level Waste Handling Facility
LOTO	Lockout/Tagout
LPM	Laser Profile Monitor
LSND	Liquid Scintillator Neutrino Detector
LSO	Laser Safety Officer
m	meter
mA	milli-amp

MABAS	Mutual Aid Box Alarm System
MARS	Monte Carlo Shielding Computer Code
MC	Meson Center
MC&A	Materials Control and Accountability
MCR	Main Control Room
MEBT	Medium-Energy Beam Transport
MEI	Maximally Exposed Individual
MeV	Mega-electron Volt
MI	Main Injector
MINOS	Main Injector Neutrino Oscillation Search
MMR	Material Move Request
MOI	Maximally Exposed Offsite Individual *(Note: Due to the Fermilab Batavia Site being open to the public, the location of the MOI is taken to be the location closest to the accelerator that is accessible to members of the public.)*
MP	Meson Polarized
mrad	milli-radian
mrem	milli-rem
mrem/hr	milli-rem per hour
MT	Meson Test
MTA	400 MeV Test Area
MTF	Magnet Test Facility
^{22}Na	Sodium-22
NC	Neutrino Center
NE	Neutrino East
NEC	National Electrical Code
NEPA	National Environmental Policy Act
NESHAPS	National Emissions Standards for Hazardous Air Pollutants
NFPA	National Fire Protection Association
NM	Neutrino Muon
NMR	Nuclear Material Representative
NOvA	Neutrino Off-axis Electron Neutrino (ve) Appearance
NPH	Natural Phenomena Hazard
NRTL	Nationally Recognized Testing Laboratory
NIF	Neutron Irradiation Facility
NTSB	Neutrino Target Service Building (see also TSB)
NuMI	Neutrinos at the Main Injector
NW	Neutrino West
ODH	Oxygen Deficiency Hazard
ORC	Operational Readiness Clearance

OSHA	Occupational Safety and Health Administration
pCi	pico-Curie
pCi/mL	pico-Curie per milliliter
PE	Professional Engineer
PIN	Personal Identification Number
PIP	Proton Improvement Plan
PIP-II	Proton Improvement Plan-II
PHAR	Preliminary Hazards Analysis Report
PPD	Particle Physics Directorate
PPE	Personnel Protective Equipment
QA	Quality Assurance
QAM	Quality Assurance Manual
RA	Radiation Area
RAF	Radionuclide Analysis Facility
RAW	Radioactive Water
RCT	Radiological Control Technician
RF	Radio-Frequency
RFQ	Radio-Frequency Quadrupole
RIL	RFQ Injector Line
RMA	Radioactive Material Area
RMS	Root Mean Square
RPCF	Radiation Physics Calibration Facility
RPE	Radiation Physics Engineering Department
RPO	Radiation Physics Operations Department
RRM	Repetition Rate Monitor
RSI	Reviewed Safety Issue
RSIS	Radiation Safety Interlock System
RSO	Radiation Safety Officer
RWP	Radiological Work Permit
SA	Shielding Assessment
SAA	Satellite Accumulation Areas
SAD	Safety Assessment Document
SCF	Standard Cubic Feet
SCFH	Standard Cubic Feet per Hour
SEWS	Site-Wide Emergency Warning System
SNS	Spallation Neutron Source
SR	Survey Riser
SRF	Superconducting Radio-Frequency

SRSO	Senior Radiation Safety Officer
SSB	Switchyard Service Building
SSP	Site Security Plan
SWIC	Segmented Wire Ionization Chambers
TLM	Total Loss Monitor
TLVs	Threshold Limit Values
TPC	Time Projection Chamber
TPES	Target Pile Evaporator Stack
TPL	Tagged Photon Lab
TSB	Target Service Building (see also NTSB)
TSCA	Toxic Substances Control Act
TSW	Technical Scope of Work
T&I	Test and Instrumentation
UPB	Utility Plant Building
UPS	Uninterruptible Power Supply
USI	Unreviewed Safety Issue
VCTF	Vertical Cavity Test Facility
VHRA	Very High Radiation Area
VMS	Village Machine Shop
VMTF	Vertical Magnet Test Facility
VTS	Vertical Test Stand
WSHP	Worker Safety and Health Program
µs	micro-second

IV-9. Neutrino Switchyard 120 Experimental Areas

IV-9.1. Introduction

This Section 4 Chapter 9 of the Fermilab SAD covers the Neutrino Switchyard 120 Experimental Area segment of the Fermilab Main Accelerator.

IV-9.1.1 Purpose/Function

The Neutrino Muon (NM) 4 enclosure experimental hall, located along the Fermilab neutrino line, currently houses the long-term E1039 SpinQuest experiment. The neutrino beamline is configured to deliver protons to the experiment.

IV-9.1.2 Current Status

The Neutrino Switchyard 120 Experimental Areas segment of the Fermilab Main Accelerator is currently:

- **Neutrino Muon 4: Operational**

IV-9.1.3 Description

The NM4 enclosure experimental hall is served by the Neutrino fixed-target beamline. The enclosure houses long-term fixed-target experiments. The Neutrino line currently hosts the E1039 SpinQuest experiment at the NM4 enclosure experimental hall.

The NM4 hall contains two levels. The upper level is a ground level and has a cryogenics platform and catwalk with a large high-bay staging area connected to an external roll-up door. There is a rail crane to facilitate moving equipment in the space or between levels. The lower level contains E1039 experimental components including a target cave, several magnets, and other detector components. Many of these elements have been repurposed from previous experiments. The target cave for the E1039 experiment, which houses a cryostat with an anhydrous ammonia target, cannot be reached from inside NM4 due to radiological shielding. It is accessed via a ladder inside NM3, which is the adjacent upstream enclosure. The cryogenics platform on the upper level produces liquid helium to circulate into the target cryostat to cool the solid ammonia target and to operate a super-conducting magnet. Figures 1-3 show some of the E1039 layout configuration in the NM4 hall.

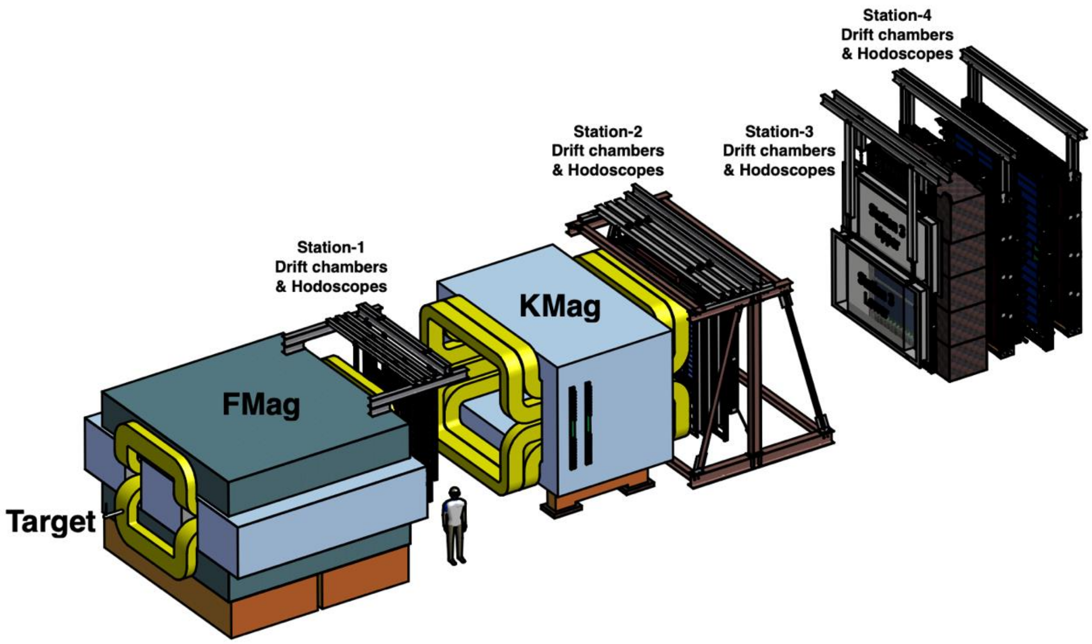

Figure 1. The spectrometer layout in the lower level of NM4, which was repurposed from the SeaQuest experiment for E1039 SpinQuest. Beam is traveling from left to right in the image. FMag and KMag are two large electromagnets. FMag is a closed-aperture solid iron magnet to focus muons downstream and absorb beam protons that did not interact with the target. KMag is a large open-aperture magnet to measure muon momenta.

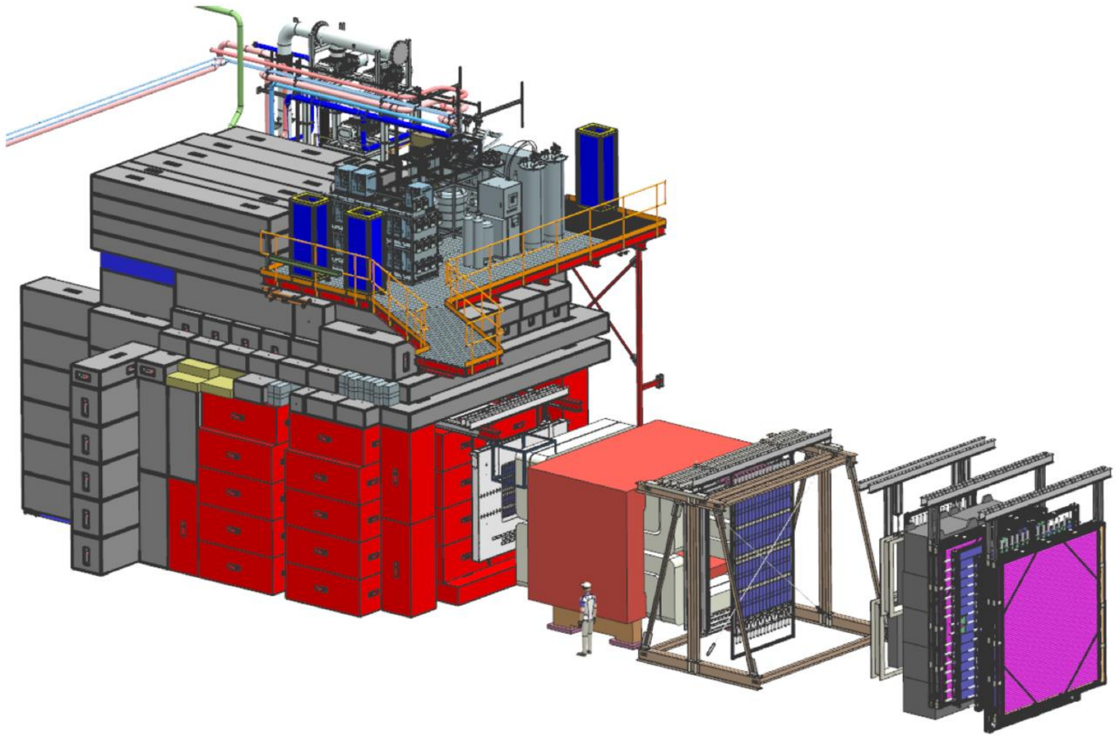

Figure 2. The target cave and spectrometer looking from downstream. The red shielding blocks are surrounding FMag. Pictured on the upper level is the cryogenics platform for manufacturing liquid helium installed for E1039.

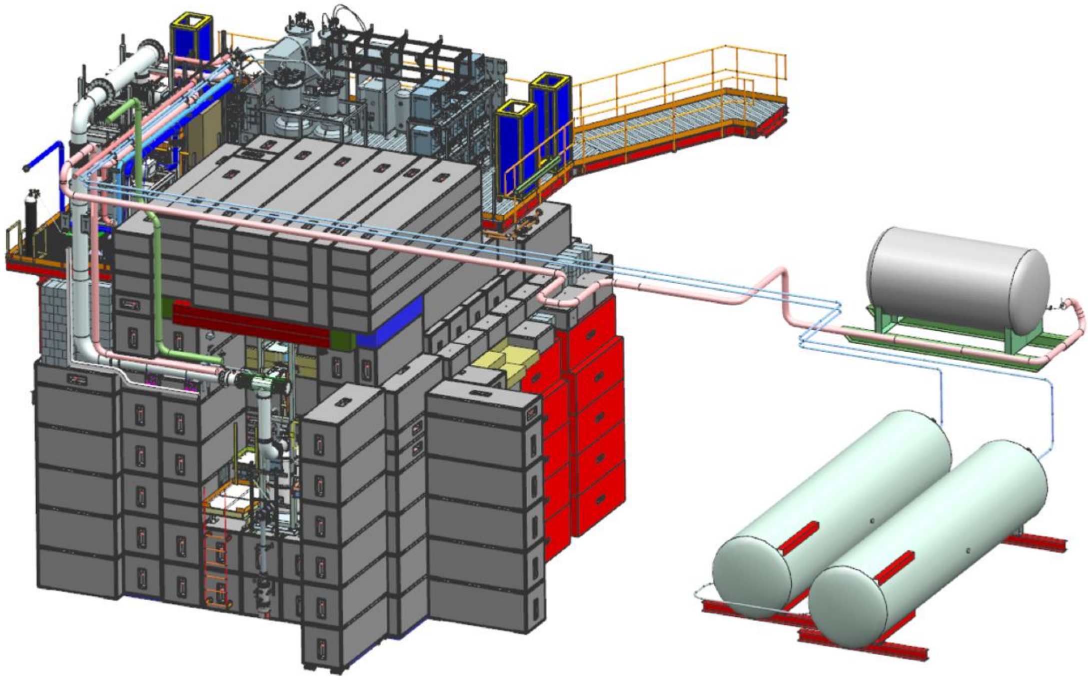

Figure 3. The target cave shown from the upstream end, with the SpinQuest target system shown in place in the alcove (opening in the upstream face of the target cave). The connecting storage tanks for helium gas and a liquid nitrogen dewar are outside of the NM4 building.

The character of the hazards associated with E1039 and other experiments in the NM4 hall are similar, but may vary in magnitude, which has been the case with prior experiments, and will likely be the case in the future. New experiments and/or additions to the existing setup are screened for hazards first through submitting a Technical Scope of Work (TSW) for review and approval by subject matter experts (SMEs) and senior lab management. When the experiment arrives onsite, it is again reviewed prior to operation through the Operational Readiness Clearance (ORC) [2] process coordinated by the ORC chairperson for the respective area prior to approval. Such experiments would be similar in ES&H impact to those described here. Depending on the scope and requirements of a new experiment, the shielding assessments, SAD, and ASE are updated through the USI process as necessary.

IV-9.1.4 Location

The Neutrino Switchyard 120 Experimental Areas are located on the Fermilab site in Batavia, IL. The Neutrino Switchyard 120 Experimental Areas are located beyond Obvious Indicators, as shown in Figure 2 below.

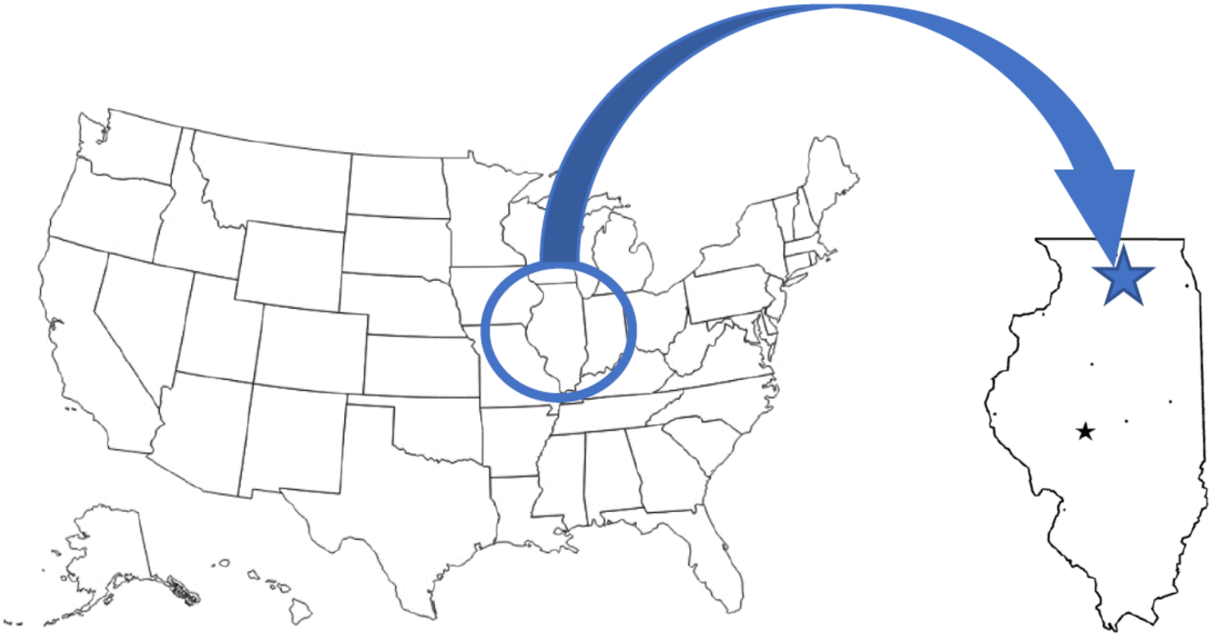

Figure 4. Regional view showing the location of the Fermilab site in Batavia, IL.

Figure 2: Obvious Indicators

The Neutrino Switchyard 120 Experimental Areas are located northeast of Wilson Hall along Discovery Road in the fixed-target area on the Fermilab site as shown in Figure 5.

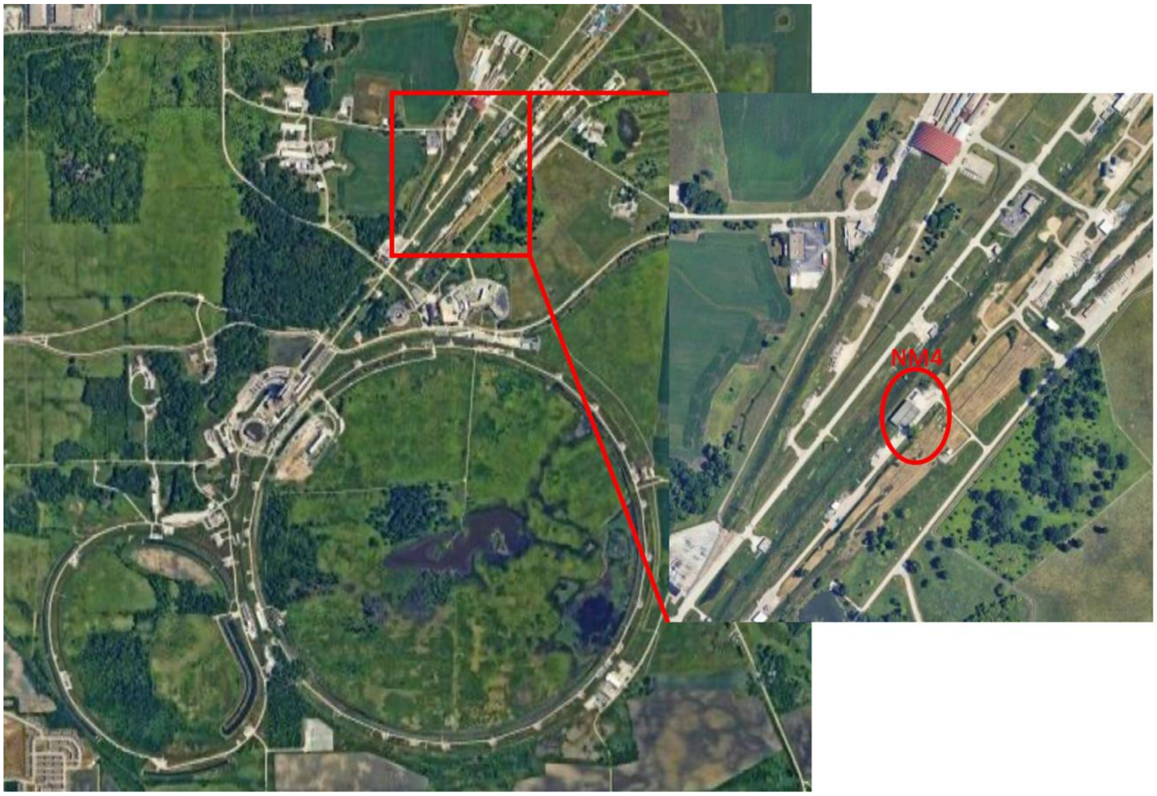

Figure 3: Aerial view of the Fermilab site, indicating the location of the Neutrino Switchyard 120 Experimental Area, which is the NM4 building.

IV-9.1.5 Management Organization

The Neutrino Switchyard 120 Experimental Area is managed by the Particle Physics Directorate (PPD). Facility staff coordinate with the beamline physicist assigned from the External Beams Delivery Department in the Accelerator Directorate (AD), who maintains any AD-owned systems, instrumentation, beamlines, and controls that are present in the experimental space.

IV-9.1.6 Operating Modes

The Accelerator Safety Envelope (ASE) [3] limits operating modes of the Fermilab Neutrino Switchyard 120 Experimental Areas and describes the beam character and beam limitations delivered to these areas.

The NM4 facility receives 120-GeV primary proton beam to its experiment target station.

IV-9.1.7 Inventory of Hazards

The following table lists all the identified hazards found in the Neutrino Switchyard 120 Experiment Area enclosures and support buildings. *Appendix C – Non-Accelerator Specific Hazard (NASH) Risk Matrix Tables* describes the baseline risk (i.e., unmitigated risk), any preventative controls and/or mitigative controls in place to reduce the risk, and residual risk (i.e., mitigated risk) for facility worker, co-located worker, and Maximally Exposed Offsite Individual (MOI) (i.e., members of the public). A summary of these controls is described within Section I-4.1 *Non-Accelerator Specific Hazards.*

Prompt ionizing radiation and oxygen deficiency hazards due to cryogenic systems within accelerator enclosures have been identified as accelerator specific hazards, and as such, their controls are identified as Credited Controls. The analysis of these hazards and their Credited Controls will be discussed within this SAD Chapter, and their Credited Controls summarized in the Accelerator Safety Envelope for the Main Accelerator. Accelerator specific controls are identified as **purple/bold** throughout this Chapter.

All other hazards present in the Neutrino Switchyard 120 Experimental Areas are safely managed by other DOE approved applicable safety and health programs and/or processes, and their analyses have been performed according to applicable DOE requirements as flowed down through the Fermilab Environment, Safety and Health Manual (FESHM). These hazards are considered to be Non-Accelerator Specific Hazards (NASH), and their analysis will be summarized in this SAD Chapter.

Table 1. Hazard Inventory for Neutrino Switchyard 120 Experiment Area

	Radiological		**Toxic Materials**
☒	Prompt Ionizing Radiation	☒	Lead
☒	Residual Activation	☐	Beryllium
☒	Groundwater Activation	☐	Fluorinert and Its Byproducts
☒	Surface Water Activation	☐	Liquid Scintillator
☒	Radioactive Water (RAW) Systems	☐	
☒	Air Activation	☒	Ammonia
☐	Closed-Loop Air Cooling	☐	Nanoparticle Exposures
☒	Soil Interactions		**Flammables and Combustibles**
☒	Radioactive Waste	☒	Combustible Materials (e.g., cables, wood cribbing, etc.)
☒	Contamination	☒	Flammable Materials (e.g., flammable gas, cleaning materials, etc.)
☒	Beryllium-7		**Electrical Energy**
☒	Radioactive Sources	☒	Stored-Energy Exposure
☒	Nuclear Material	☒	High-Voltage Exposure
☐	Radiation Generating Devices (RGDs)	☒	Low-Voltage, High-Current Exposure
☐	Non-Ionizing Radiation Hazards		**Kinetic Energy**
	Thermal Energy	☒	Power Tools
☐	Bakeouts	☒	Pumps and Motors
☒	Hot Work	☒	Motion Tables
☒	Cryogenics	☐	Mobile Shielding
	Potential Energy		**Magnetic Fields**
☒	Crane Operations	☒	Fringe Fields
☒	Compressed Gases		**Other Hazards**
☒	Vacuum/Pressure Vessels/Pipes	☒	Confined Spaces
☒	Vacuum Pumps	☒	Noise
☒	Material Handling	☒	Silica
	Access and Egress	☒	Ergonomics
☒	Life Safety Egress	☐	Asbestos
		☒	Working at Heights

IV-9.2. Safety Assessment

All hazards for the Neutrino Switchyard 120 Experimental Areas segment of the Main Accelerator are summarized in this section, with additional details of the analyses for accelerator-specific hazards.

IV-9.2.1 Radiological Hazards

Radiation safety has been carefully considered in the design of the Fermilab Neutrino Switchyard 120 Experimental Areas. All radiation hazards relating to beam operations safety are the responsibility of the

AD. The AD, whose facilities include all beamlines, their shielding, radiation, interlocks, beam surveys, monitors, and impact of radiation on the environment, is addressed in SAD Section III Chapter 14 on the Neutrino Area.

The Neutrino Switchyard 120 Experimental Areas present radiological hazards in the form of prompt ionizing radiation, residual activation, groundwater activation, surface water activation, RAW systems, air activation, soil interactions, radioactive waste, contamination, Beryllium-7, radioactive sources, and non-ionizing radiation. Detailed shielding assessments **Error! Reference source not found.Error! Reference source not found.** address these hazards and provide a detailed analysis of the facility demonstrating the required shielding, controls, and interlocks to comply with the Fermilab Radiological Control Manual (FRCM) [1].

Fermilab protocols require that all personnel and experimenters who work in experimental halls must be trained according to FRCM Chapter 6 – *Training and Qualification*. All radiological work, posting, labeling, and monitoring in experimental halls must be conducted in accordance with requirements described in FRCM Chapter 2 – *Radiological Standards*. All experiments at Fermilab will participate in Fermilab's ALARA (As Low As Reasonably Achievable) program as described in FRCM Chapter 3 – *Conduct of Radiological Work*.

IV-9.2.1.1 Prompt Ionizing Radiation

Ionizing radiation due to beam loss is a primary concern for beam transported through the Neutrino Switchyard 120 enclosures. To protect workers and the general public, the enclosures and beam pipes are surrounded either by sufficient amounts of shielding (earth, concrete, or iron), and/or networks of interlocked radiation detectors to keep any prompt radiation within acceptable levels. Operation of the area conforms to the FRCM to maintain exposures for operating personnel in the ALARA program.

This hazard has been evaluated via a Maximum Credible Incident (MCI) analysis that is described in Section III-14.3.1 for the Neutrino Area beamlines which includes the experimental areas the beam passes through. This analysis specifies that Fermilab uses Credited Controls that flow down to the Accelerator Safety Envelope (ASE) to mitigate the consequences of the MCI to at or below the acceptable dose levels described in SAD Section I Chapter 4. A detailed description of each of the Credited Controls and their function is provided in Section III-14.4. The conclusion of these analyses is that the mitigated dose level associated with prompt ionizing radiation due to beam loss is acceptable.

IV-9.2.1.2 Residual Activation

Positioning detector components in the path of the beam may result in activation of the components. This type of radio-activation is called residual activation. The activation level and quantity of activated material will not be unique relative to other accelerator enclosures at Fermilab. Details of the expected tritium (^{3}H) and sodium 22 (^{22}Na) produced in soil by beam to the target/beam dump are found in the Neutrino Muon shielding assessment addendum [4][5].

Activation in the E1039 experiment target cave is also anticipated, including the solid ammonia target material. Changing out the irradiated target will be supervised by the Radiological Control Organization to monitor dose rate and handling while preparing for offsite shipment. In a typical beam exposure, one 28.9 gram ammonia target is expected to activate to approximately 0.74 mrem/hr at one foot at the time it is changed out, which is roughly weekly. Isotopes present in the ammonia target are tritium (^{3}H) and Beryllium 7 (^{7}Be).

Residual activation hazards will be managed within the ALARA program established throughout the Fermilab accelerator complex and as prescribed in the FRCM Chapter 3. All potential residual activation hazards are handled operationally as in all other primary beam enclosures. These controls include verification of training, centralized authorization, and key entry. The level of control depends on the level of residual radiation. In most cases, the typical Radiological Work Permit (RWP) as described in FRCM Chapter 3 for accesses will suffice. A job-specific RWP and an ALARA plan will be required for work on any highly activated equipment. Experimental equipment intended for shipment offsite will be surveyed and handled by trained workers in accordance with FRCM Chapter 4. Risk matrix tables 28.1-28.3 show there is an unmitigated risk of I for this hazard and a risk of IV after the listed prevention and mitigation strategies.

IV-9.2.1.3 Groundwater Activation

Groundwater activation is estimated in the beamline SAD chapter III-14 for the Neutrino Area. Additionally, the Neutrino Muon shielding assessment addendum [4][5] covers conditions specific to the E1039 experiment presently occupying the space. In all cases, the contribution from targets and materials in the beamlines are insignificant. Risk matrix tables 28.1-28.3 show there is an unmitigated risk of III for this hazard and a risk of IV after the listed prevention and mitigation strategies.

IV-9.2.1.4 Surface Water Activation

Surface water activation is estimated in the beamline SAD chapter III-14 for the Neutrino Area. Additionally, the Neutrino Muon shielding assessment addendum [4][5] covers conditions specific to the E1039 experiment presently occupying the space. In all cases, the contribution from targets and materials in the beamlines are insignificant. Risk matrix tables 28.1-28.3 show there is an unmitigated risk of III for this hazard and a risk of IV after the listed prevention and mitigation strategies.

IV-9.2.1.5 Radioactive Water (RAW) Systems

FMag has a RAW system with the skid located in NM3. In NM4, there is a water system in service of the microwave system in the SpinQuest experiment that is expected to activate. All RAW systems are monitored and treated in accordance with FRCM requirements. Risk matrix tables 28.1-28.3 show there is an unmitigated risk of III for this hazard and a risk of IV after the listed prevention and mitigation strategies.

IV-9.2.1.6 Air Activation

Air activation is estimated in the beamline SAD chapter III-14 for the Neutrino Area. Additionally, the Neutrino Muon shielding assessment addendum [4][5] covers conditions specific to the E1039 experiment presently occupying the space. In NM4, the cool-off period is imposed at the discretion of the RSO and specified in the beam permit and run conditions as further discussed in the beamline-specific SAD chapter. Risk matrix tables 28.1-28.3 show there is an unmitigated risk of I for this hazard and a risk of IV after the listed prevention and mitigation strategies.

IV-9.2.1.7 Closed-Loop Air Cooling

N/A

IV-9.2.1.8 Soil Interactions

Soil interactions are estimated in the beamline SAD chapter III-14 for the Neutrino Area. Additionally, the Neutrino Muon shielding assessment addendum [4][5] covers conditions specific to the E1039 experiment presently occupying the space. In all cases, the contribution from targets and materials in the beamlines are insignificant. Risk matrix tables 28.1-28.3 show there is an unmitigated risk of III for this hazard and a risk of IV after the listed prevention and mitigation strategies.

IV-9.2.1.9 Radioactive Waste

Radioactive waste produced in the course of Neutrino Switchyard 120 Experimental Area operations will be managed within the established Radiological Protection Program (RPP) and as prescribed in the FRCM.

Radioactive waste is a standard radiological hazard that is managed within the established RPP 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 Neutrino Switchyard 120 Experimental Area, beam loss, and, in the case of some beam diagnostics devices, intentional interception of the beam, will result in activation of beamline 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 FRCM requirements.

Risk matrix tables 28.1-28.3 show there is an unmitigated risk of III for this hazard and a risk of IV after the listed prevention and mitigation strategies.

IV-9.2.1.10 Contamination

NM4 has beam traveling through an air gap around the target station (NM4), where contamination in the form of Be7 in the air is possible. Both areas are monitored for contamination in accordance with the FRCM. Risk matrix tables 28.1-28.3 show there is an unmitigated risk of I for this hazard and a risk of IV after the listed prevention and mitigation strategies.

IV-9.2.1.11 Beryllium-7

Beryllium-7 is not hazardous in the pattern of use at this accelerator segment and prevention and mitigation are not required. The risk summarized in tables 28.1-28.3 is IV.

IV-9.2.1.12 Radioactive Sources

Radioactive sources are used extensively by experiments for the calibration and testing of detectors. Radioactive sources present minimal potential hazards for onsite personnel and negligible hazards off site and are monitored according to FRCM Chapter 11 *Environmental Radiation Monitoring and Control*.

Commonly used sources are Co-60, Sr-90, Cs-137, Fe-55, and Ru-106. Radioactive source controls described in the FRCM include requirements for 1) source accountability records to be maintained by the Environment, Safety, and Health (ES&H) Division; 2) ES&H Division notification and supervision for changes in use, storage, transfer, disposal, or loss; 3) labeling; 4) source cabinets and source monitors responsible for issuing sources to users; and 5) source procurement. Radioactive source monitors and source users must be trained in accordance with requirements set forth in FRCM Chapter 4. Radioactive sources pose a contamination hazard if they are not handled properly. Following policies set forth in FRCM Chapter 4 mitigates the contamination hazard. Risk matrix tables 28.1-28.3 show there is an unmitigated risk of IV for this hazard and a risk of IV after the listed prevention and mitigation strategies.

IV-9.2.1.13 Nuclear Material

There is depleted uranium that is stored in NM4, but it is not in use and has no planned use. This material and hazard are fully described, and the risk matrix and prevention and mitigation strategies are detailed in section II chapter 7.

IV-9.2.1.14 Radiation Generating Devices (RGDs)

N/A

IV-9.2.1.15 Non-Ionizing Radiation Hazards

N/A

IV-9.2.2 Toxic Materials

Controlling industrial hygiene hazards is addressed through the application of the relevant OSHA standards and other applicable standards (such as ANSI and ACGIH). Fermilab employs a professional ES&H staff that monitors industrial hygiene hazards for compliance with the national standards and the FESHM 4000 series requirements. When necessary, the ES&H staff develops additional procedures to mitigate the hazards. Specific hazards are detailed below.

IV-9.2.2.1 Lead

Lead presents a potential exposure hazard from manual handling of un-encased materials. At NM4, lead could come in the form of shielding or be brought in by an experiment as a detector component, such as a calorimeter. Proposed materials are reviewed through the TSW and ORC process in addition to handling training and painting/sealing exposed material. When present, work involving this hazard implements the controls specified in the common risk matrix table that reduces the unmitigated risk from II to IV. No unique controls are in use.

IV-9.2.2.2 Beryllium

N/A

IV-9.2.2.3 Fluorinert and Its Byproducts

N/A

IV-9.2.2.4 Liquid Scintillator

N/A

IV-9.2.2.5 Ammonia

The E1039 target system includes cells containing a total 28.9g of solid ammonia located in the experiment's target cave in NM3. This ammonia presents a toxicity hazard should its temperature rise above its melting point of -77°C. Ammonia needed for E1039 is shipped from offsite, stored in an external shed by NM4, prepared for target operations in NM4, loaded into the target cryostat in the NM3 target cave, and then retrieved after beam exposure to package in NM4 and ship offsite. Hazards associated with ammonia have been considered in all aspects of this work and are further described below. All activities described are governed by approved standard operating procedures that include emergency response plans to a variety of scenarios.

Anhydrous ammonia has a lower explosion limit (LEL) of 15%. Engineering analysis of the NM3 target cave and handling areas in NM4 do not approach this lower limit in any spill scenario of 28.9 grams of ammonia. This analysis was also performed for an external storage shed with up to 196 grams of ammonia, which also does not approach the LEL. Additionally, there are no ignition sources in these work areas.

When handling ammonia in the NM3 target cave moving in and out of the cryostat, there is an active ventilation system comprising a 1800 CFM curtain fan blowing air into the target cave and a 5000 SCFM explosion-proof ducted fan draws any ammonia away from the target cave and dilutes the gas in the NM3 enclosure. Automatic activation of the ventilation system and warning lights and the sounding of an audio alarm occurs should either of two sensors, which sample from the downstream wall of the target cave, detect ammonia concentrations above 25 ppm[7]. Additionally, an alarm is sent through the Fermilab FIRUS system to the Fermilab Fire Department. Should all the target material be spilled or otherwise vaporized in the target cave, engineering analysis [8] concludes that the ventilation system ensures a breathable atmosphere in the NM3/target cave enclosure and the NM4 enclosure with ammonia concentrations below the US EPA's Acute Exposure Guide Line (AEGL) Level 1 threshold of 30 ppm[9]. These exposure limits are at or lower than those referenced by FESHM 4170[10]. Review and approval of the ventilation system for ammonia hazard is conducted by Fermilab industrial hygiene personnel and the fire hazard subcommittee.

The experiment will change out the target material (solid ammonia) periodically. Only those trained in target change-out procedures and ammonia hazards will be allowed into the target cave area in NM3. Access will be controlled by issuing keys from the Main Control Room. As an added safety measure during the target change-out, the target cave ventilation system will be engaged and locked on by trained personnel as part of the target change-out procedure.

There is space designated in the northwest corner of NM4 for the handling of ammonia to load material into the target insert before moving to the NM3 target cave and remove material after beam exposure. Work is performed next to the air intake for the building ventilation system. Trained workers handle the ammonia according to approved procedures and with appropriate personal protective equipement (PPE). After beam exposure, the Radiological Control Organization provides additional coverage during handling operations and surveying of the dose rates. The Hazard Control Technology Team (HCTT) oversees the packaging of ammonia for offsite shipping according to applicable regulations.

The ammonia is transported on site and off site in a dry shipping container that contains an absorbent material soaked with liquid nitrogen to maintain ammonia in a solid state without any loose liquid during shipping. The shipping container can hold its temperature under static conditions for 18 days [15]. Transportation of the packaged shipment around the site is handled by trained personnel.

Prior to use in NM3/NM4 and after use while awaiting shipping, the ammonia is stored in liquid nitrogen dewars in an external explosion-proof shed near the NM4 facility. The shed has vents on two sides. PPE and approved standard operating procedures are used for trained individuals when accessing the shed, including sampling of the air prior to entry.

Risk matrix tables 28.4-28.6 show there is an unmitigated risk of II for this hazard and a risk of IV after the listed prevention and mitigation strategies.

IV-9.2.2.6 Nanoparticle Exposure

N/A

IV-9.2.3 Flammables and Combustibles

Flammable and combustible materials are present in this area and their hazards are detailed below.

IV-9.2.3.1 Combustible Materials

Combustible materials may be present in building materials and in liquid forms brought in as part of experiments. Use of combustible material in the Neutrino Switchyard 120 Experimental Area is strongly discouraged in favor of non-combustible alternatives. In cases where combustible building materials, such as wood, must be used, they are required to be coated in approved fire-retardant coatings. Combustible liquid use is identified and reviewed during the TSW and ORC review by members of the Industrial Hygiene Department and the Fermilab Fire Department. All unnecessary combustible materials are removed from beam enclosures and stored in safe areas or disposed of. All combustible material used must adhere to FESHM Chapter 6040.1 *Fire Construction Requirements – Fire Retardant Coatings for Combustible Construction Materials*, FESHM Chapter 6040.2 *Fire Construction Requirements – Interior Finish Materials*, and FESHM 6020.5 *Flammable and Combustible Liquids*.

When present, work involving this hazard implements the controls specified in the common risk matrix table that reduces the unmitigated risk from I to IV. No unique controls are in use.

IV-9.2.3.2 Flammable Materials

Flammable liquids and gases may be used by facility equipment or may be brought by experiments for use in their apparatus. Flammable gas and liquid use are identified at the TSW and ORC review process. Their use is subject to approval by subject matter experts from the Industrial Hygiene Department and the Fermilab Fire Department. All flammable gas and liquid use must abide by FESHM 6020.3: *Storage and Use of Flammable Gases* and FESHM 6020.5: *Flammable & Combustible Liquids*.

The E1039 target system includes cells containing a total 28.9g of solid ammonia located in the experiment's target cave. This ammonia presents a fire hazard should its temperature rise above its melting point of -77C and the material vaporizes. An active ventilation system comprising a 1800 CFM curtain fan blowing air into the target cave and a 5000 SCFM explosion-proof ducted fan draws any ammonia away from the target cave and dilutes the gas in the NM3 enclosure. The ventilation system is manually activated prior to any personnel entering the target cave. Automatic activation of the ventilation system and warning lights and the sounding of an audio alarm occurs should either of two sensors, which sample from the downstream wall of the target cave, detect ammonia concentrations above 25 ppm [7]. Additionally, under an ammonia alarm, an alert is sent through the Fermilab FIRUS system to the Fermilab Fire Department. Should all the target material be spilled or otherwise vaporized in the target cave, engineering analysis [8] concludes that the ventilation system ensures gaseous ammonia concentrations below 30 ppm [9]. Review and approval of the ventilation system for ammonia hazard is conducted by Fermilab industrial hygiene personnel and the fire hazard subcommittee.

For the quantities of ammonia present at any point on the Fermilab site (transport, storage, NM3 target cave, NM4), the flammability hazard is calculated as risk class 0 per FESHM 6020.3.

When present, work involving this hazard implements the controls specified in the common risk matrix table that reduces the unmitigated risk from I to IV. No unique controls are in use.

IV-9.2.4 Electrical Energy

Electrical equipment that can pose electrical energy hazards can be present in the Neutrino Switchyard 120 Experimental Area. These include power supplies, electrical equipment, and experimental apparatuses that have large internal energy storage or high-voltage sources or can produce large electrical currents. All such equipment is identified, reviewed, and approved in the TSW and ORC process by suitable SMEs before the equipment may be energized. In all cases, such equipment must be NRTL-listed and unmodified from its original state. If no NRTL equipment exists, the non-NRTL equipment must be inspected and approved by the Fermilab electrical authority having jurisdiction (AHJ) or designee. All electrical equipment and work thereon must adhere to FESHM 9100: *Fermilab Electrical Safety Program*.

IV-9.2.4.1 Stored-Energy Exposure

Equipment with large amounts of stored energy can be present in the Neutrino Switchyard 120 Experimental Area. These include power supplies and electrical equipment for facility and experimental apparatuses. Equipment brought by an experiment is assessed through the ORC by an SME to ensure it complies with all laboratory standards. When present, work involving this hazard implements the controls specified in the common risk matrix table that reduces the unmitigated risk from I to IV. No unique controls are in use.

IV-9.2.4.2 High-Voltage Exposure

High-voltage power supplies are common to facility equipment and experiential apparatuses brought into these facilities. Equipment brought in by an experiment is assessed through the ORC by an SME to ensure it complies with all laboratory standards. When present, work involving this hazard implements the controls specified in the common risk matrix table that reduces the unmitigated risk from I to IV. No unique controls are in use.

IV-9.2.4.3 Low-Voltage, High-Current Exposure

NM4 has three magnets present. The target polarization magnet is a superconducting magnet operating at 73 A. The absorber magnet (FMag) has a peak current of 2400 A, and the spectrometer magnet (KMag) operates up to 2000 A. All maintenance and upkeep of these power supplies and their power buses carrying the current are performed only by equipment experts.

When present, work involving this hazard implements the controls specified in the common risk matrix table that reduces the unmitigated risk from I to IV. No unique controls are in use.

IV-9.2.5 Thermal Energy

NM4 has hazards associated with thermal energy. Hot work is performed and cryogenic liquids are used by experiments in these spaces. Details below describe the type of work and hazards associated with them.

IV-9.2.5.1 Bakeouts

N/A

IV-9.2.5.2 Hot Work

Hot work in NM4 may occasionally occur. Examples include welding and grinding. This type of work is not typical at these locations and is performed by trained and authorized personnel. All work will have a hazard analysis (HA) and required permits before being performed. Individuals will also have approved training. When present, work involving this hazard implements the controls specified in the common risk matrix table that reduces the unmitigated risk from I to IV. No unique controls are in use.

IV-9.2.5.3 Cryogenics

Cryogenic materials (liquid helium and nitrogen, gaseous helium and nitrogen, and solid ammonia) are present in the NM3/target cave and NM4 enclosures. Special training in the handling of all cryogenic materials is required for all personnel working with cryogens. Specific procedures and training are required for handling solid ammonia.

Oxygen deficiency hazards (ODH) in E1039 arise from the venting of cryogens (i.e., not ammonia, which is handled separately) into either the NM3/target cave area or from the cryo-platform area in NM4. An active ventilation system [7][8] comprising a 1800 CFM curtain fan and blowing air into the target cave and a 5000 SCFM, explosion-proof ducted fan mixes the atmosphere in the target cave with that of the NM3 enclosure. NM3 also has a 500 CFM exhaust fan. Automatic activation of the ventilation system and warning lights and the sounding of an audio alarm occurs should either of two sensors located in the target cave detect oxygen concentrations below 19.5%. Additionally, cryogen flow to the target cave is inhibited. Alarms are sent through the Fermilab FIRUS system to the Fermilab Fire Department for oxygen concentrations below 18%, and to ODH System Experts for alarms between 19.5% and 18%, in accordance with FESHM Chapter 4240. Engineering analysis of the NM3/target cave enclosure [11] characterize the area as Engineered ODH-0 due to the presence of liquid nitrogen and helium.

The ODH assessment of the NM4 enclosure [12] concludes that the NM4 enclosure is classified Engineered ODH-0, due to the presence of liquid nitrogen and helium. All credible failure scenarios leading to the release of inert gas into the area are analyzed in the ODH assessment. The scenarios include leak and rupture of piping and welds, vessel leak and rupture, relief valve failure, and leak and rupture of valves. Two 20000 CFM fans are installed to mix air in the region of the NM4 cryo-platform with the air in the rest of the enclosure. Oxygen monitors detect and trigger the fans and shut off flow of cryogens to the cryo-platform should the oxygen concentration fall below 19.5% [13]. The additional ventilation and active controls are reviewed and approved by the cryo-safety committee.

The ODH systems for the E1039 experiment each are composed of sensors that measure the oxygen concentration, a control box (relays) that turn on fans and/or blowers, and audio and visual alarms that warn of low oxygen concentrations that conform to the standards outlined in the Fermilab ES&H Manual 4240 [14]. The sensors for the systems are replaced, tested, and calibrated in-situ annually to confirm operation along with both the audio and visual alarms. The fans/blowers are tested every six months. The ODH systems in NM3 and NM4 are independent of each other (e.g., if the NM3 ODH system fails with the NM4 system still functioning, the NM3 area would still need reevaluation prior to entry). Table 2 summarizes the ODH assessment for the NM4 area.

Table 2. ODH Requirements of Analysis for Neutrino Switchyard 120 Experimental Area

Building Space	NM4 Cryo Platform	NM3 Target Cave
Minimum O2 (%)	11.89[1]	0
ODH Class	Engineered 0	Engineered 0
Oxygen sensors	One high and one low both near the cryo-platform	One high and one low continuous sample points within the NM3 Target Cave, sensors outside of the shielding blocks
Ventilation	Two 20000 CFM mixing fans	One 1800 CFM mixing fan, one 5000 CFM mixing fan, and one 500 CFM exhaust fan
Exceptions to FESHM 4240 control measures	No exceptions	No exceptions
Training	ODH awareness for all employees and NM4 building hazard awareness training	ODH awareness for all employees and NM3 building hazard awareness training

[1] Failure of the liquid nitrogen tank isolation valve when ODH event occurs

Risk tables 28.13-28.15 show an unmitigated risk of I for this hazard in all areas and a risk of IV after the listed prevention and mitigation strategies.

IV-9.2.6 Kinetic Energy

Kinetic energy hazards present in this segment are described below.

IV-9.2.6.1 Power Tools

Experiment installation and support at NM4 requires the use of a tech shop and power hand tools. Tech shop power tools are used only by trained personnel authorized by a tech shop point of contact. Such training and other tech shop safety requirements followed can be found in FESHM 7090 *Tech Shop Safety*. Power hand tools — typically, battery-operated drills — can be used by experimenters, although they are encouraged to coordinate with technicians for such activities. When present, work involving this hazard implements the controls specified in the common risk matrix table that reduces the unmitigated risk from I to IV. No unique controls are in use.

IV-9.2.6.2 Pumps and Motors

A variety of pumps or motors may support SY120 experiments. Motors are all of the enclosed type with the only exposed moving parts being whatever is attached to output shafts. When present, work involving this hazard implements the controls specified in the common risk matrix table that reduces the unmitigated risk from I to III. No unique controls are in use.

IV-9.2.6.3 Motion Tables

The NM3 target cave has a remotely controlled lifting station to vertically move the target insert while inside the cryostat. The lifting station has limit switching restricting motion and is not generally accessible to someone working in the target cave. Risk tables 28.16-28.18 show an unmitigated risk of I for this hazard and a residual risk of IV after the listed prevention and mitigation strategies.

IV-9.2.6.4 Mobile Shielding

N/A

IV-9.2.7 Potential Energy

NM4 has hazards associated with potential energy. These hazards are described below.

IV-9.2.7.1 Crane Operations

NM4 has rail-mounted overhead cranes, which have the potential for physical injury from falling/crushing. The cranes are subjected to prescribed inspections and only trained operators are allowed to use the cranes. Barriers and access restrictions will be used as identified in any task specific HA.

Additionally, there is a jib crane present in the NM3 target cave used to raise the target insert containing anhydrous ammonia from the ground level into the target cave and cryostat. The crane is manually operated with a rope and a pulley. Use of these devices requires crane and job-specific training. Additional controls for work with ammonia in the NM3 target cave are discussed in IV-9.2.2.5.

When present, work involving this hazard implements the controls specified in the common risk matrix table that reduces the unmitigated risk from I to IV. No unique controls are in use.

IV-9.2.7.2 Compressed Gases

The E1039 experiment uses nitrogen and helium gas sources in addition to an argon/CO2 mixture, which can release potential energy. The TSW and ORC process identifies gases being brought in by an experiment to assure cylinders are properly secured and use appropriate piping. There is training that anyone working with gas cylinders takes. Compressed gases can pose a flammability or ODH risk. These risks are discussed in other sections of the SAD. NM4 is an engineered ODH 0 space. New experiment gas needs are assessed through the engineering note process to ensure they comply with the current ODH postings. Risk matrix tables 28.19-28.21 show an unmitigated risk of I and a residual risk of IV after the listed prevention and mitigation actions.

IV-9.2.7.3 Vacuum/Pressure Vessels/Pipes

The E1039 experiment in NM4 contains a complex cryogenic system with pipes holding nitrogen and helium in liquid and gaseous form, in addition to vacuum-insulating spaces. All present and future components of this system go through the TSW and ORC process to flag any potential vessels for engineering notes and review prior to operation. When present, work involving this hazard implements the controls specified in the common risk matrix table that reduces the unmitigated risk from I to IV. No unique controls are in use.

IV-9.2.7.4 Vacuum Pumps

NM4 has a large permanent Roots pump in addition to other pumps used in support of the E1039 experiment cryogenic systems. When present, work involving this hazard implements the controls specified in the common risk matrix table that reduces the unmitigated risk from I to III. No unique controls are in use.

IV-9.2.7.5 Material Handling

Experiments may need forklifts, hand trucks, carts, and other rigging for installation purposes that present a falling/crushing hazard. When present, work involving this hazard implements the controls specified in the common risk matrix table that reduces the unmitigated risk from I to IV. No unique controls are in use.

IV-9.2.8 Magnetic Fields

There are permanent magnets and electromagnets present in the Neutrino Switchyard 120 Experimental Areas that can have fringe fields present. These fields can present hazards both from flying objects and to medical implants.

IV-9.2.8.1 Fringe Fields

The E1039 experiment has three magnets, two of which produce fringe fields outside their aperture, the target polarization magnet and the spectrometer analysis magnet NM4AN1 (KMag). Magnetic fields are posted in accordance with FESHM 4270 *Static Magnetic Fields*. During open or supervised access to NM4, the power supplies for NM4AN1 are locked out by the NM4 lab manager or designee. During controlled access conditions, the current from the power supplies for NM4AN1 are set to zero prior to the access by Main Control Room personnel.

All electromagnets discussed above have warning lights that flash when the magnet power supply is on and the magnet has the potential to be energized There is facility-specific hazard awareness training connected to keyed entry to these spaces that further describes the hazard. All fields have been measured by the industrial hygiene group and posted accordingly. Magnets used for experiments go through the ORC process to ensure the standard operating procedure (SOP) and intended pattern of use of the magnet conform with FESHM. Risk matrix tables 28.22-28.24 show an unmitigated risk of I and a risk of IV after the listed prevention and mitigation actions.

IV-9.2.9 Other Hazards

Other categories of hazard are discussed and assessed below.

IV-9.2.9.1 Confined Spaces

There is a sump pump in NM4 with a confined space. Sump sampling and maintenance is done by trained workers and is not a part of normal experiment operations. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. When present, work involving this hazard implements the controls specified in the common risk matrix table that reduces the unmitigated risk from I to III. No unique controls are in use.

IV-9.2.9.2 Noise

There are localized spots in the NM3 target cave and NM4 cryo platform with noise above 85 dB when some pieces of equipment such as fans and compressors are operational. Noise levels are monitored by IH and awareness and mitigation are incorporated as necessary into the work planning and standard operating procedures in those areas. Risk matrix tables 28.25-28.27 show an unmitigated risk of III and a risk of IV after the listed prevention and mitigation actions.

IV-9.2.9.3 Silica

Work with silica in this segment typically comes in the form of drilling into concrete to anchor equipment. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. When present, work involving this hazard implements the controls specified in the common risk matrix table that reduces the unmitigated risk from I to IV. No unique controls are in use.

IV-9.2.9.4 Ergonomics

Work in this segment takes place in both office and industrial settings where repetitive motion and lifting injuries are possible. Work in the Neutrino Switchyard 120 Experimental Areas involving this hazard implements the controls specified in the common risk matrix table that bring the unmitigated risk level of I to IV. No unique controls are in use.

IV-9.2.9.5 Asbestos

N/A

IV-9.2.9.6 Working at Heights

Work at heights in this segment typically involves the use of ladders for installing cables and detector equipment. There is a fixed permanent ladder to access the target cave for the experiment via NM3. NM4 does have a mobile scissor lift and areas where fall protection may be used to access some parts of the E1039 experiment. Work in the Neutrino Switchyard 120 Experimental Areas involving this hazard implements the controls specified in the common risk matrix table that bring the unmitigated risk level of I to IV. No unique controls are in use.

IV-9.2.10 Access and Egress

In the event of hazardous events such as fire, ODH alarms, tornados, flooding, etc., access and egress paths are maintained to get personnel to safety.

IV-9.2.10.1 Life Safety Egress

The upper level of the NM4 hall has egress through a door at the north end to the external parking lot, in addition to a roll-up door. From the lower level, there are egress points on both the east and west sides to stairwells leading to ground level. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the Neutrino Switchyard 120 Experimental Areas involving this hazard implements the controls specified in the common risk matrix table that bring the unmitigated risk level of I to IV. No unique controls are in use.

IV-9.2.11 Environmental

Environmental hazards are addressed through compliance with legal and regulatory requirements imposed by DOE Orders, Federal/State/local regulations, and FESHM 8000 series. Numerous activities at Fermilab have the potential to produce environmental impacts. These include air emission sources such as fuel combustion, greenhouse gases, component cleaning, paint spray booths, soil erosion from construction activities, oil spills from transformers and generators utilized within the electrical distribution system, and glycol spills from various cooling systems. The laboratory has an IEPA-approved air emissions permit and a Spill Prevention, Control, and Countermeasures Plan (SPCC) that has been certified by a registered Professional Engineer. New activities are reviewed for potential environmental and regulatory issues as part of the NEPA process. The Neutrino Switchyard 120 Experimental Areas adhere to the laboratory regulatory standards and programs.

IV-9.2.11.1 Hazard to Air

Experimental groups may bring materials, chemicals, or equipment that present a hazard to the air if released. One example is anhydrous ammonia. These hazards are identified through the TSW and ORC process and evaluated by SMEs prior to use, with appropriate mitigations put in place. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the Neutrino Switchyard 120 Experimental Areas involving this hazard implements the controls specified in the common risk matrix table. Both the unmitigated and mitigated risk levels are IV. No unique controls are in use.

IV-9.2.11.2 Hazard to Water

Experimental groups may bring materials, chemicals, or equipment that present a hazard to the water if released. One example is anhydrous ammonia. These hazards are identified through the TSW and ORC process and evaluated by SMEs prior to use with appropriate mitigations put in place. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the Neutrino Switchyard 120 Experimental Areas involving this hazard implements the controls specified in the common risk matrix table that bring the unmitigated risk level of I to IV. No unique controls are in use.

IV-9.2.11.3 Hazard to Soil

Experimental groups may bring materials, chemical, or equipment that present a hazard to the soil if released. One example is anhydrous ammonia. These hazards are identified through the TSW and ORC process and evaluated by SMEs prior to use with appropriate mitigations put in place. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the Neutrino Switchyard 120 Experimental Areas involving this hazard implements the controls specified in the common risk matrix table that bring the unmitigated risk level of I to IV. No unique controls are in use.

IV-9.3. Summary of Hazards to Members of the Public

The Neutrino Switchyard 120 experiments in the Neutrino beamline enclosures present no specific hazards to members of the public.

IV-9.4. Summary of Credited Controls

As described in chapters 1-10 of the Fermilab SAD, credited controls are designed to reduce the risk of accelerator operations hazards to an acceptable level. Although the experiments are installed in the neutrino beamline areas, the experiments themselves do not affect the MCI as presented in Section III Chapter 14 for the Neutrino Area beamlines. The MCI for the experimental area is covered by the MCI analysis for the beamlines that pass through the experimental enclosures. The Neutrino Area experiments do not require any additional radiological credited controls for the MCI. The E1039 SpinQuest experiment does introduce an ODH condition with credited controls listed below.

New experiments for the Neutrino Switchyard 120 Experimental Areas are proposed through a Technical Scope of Work (TSW). If an experiment introduces new hazards or requires changes to beamline configuration or operations, the USI screening process would evaluate any necessary changes to shielding assessments, the SAD chapter, or ASE for III-13 or IV-03.

IV-9.4.1 Credited Engineering Controls

The purpose of this section is to provide the information necessary to understand the engineering controls that are used to prevent or mitigate the consequences of the maximum credible incident. Engineering controls can be classified as passive or active. This section presents a separate discussion of the engineering controls that fall under each classification.

IV-9.4.1.1 Passive Credited Engineering Controls

No passive credited engineering controls are specific to the experiments in this area. Radiological controls are covered in III-14 for the Neutrino Area beamline.

IV-9.4.1.2 Active Engineered Credited 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 Neutrino Switchyard 120 Experimental Areas are discussed below.

IV-9.4.1.2.1 Radiation Safety Interlock System

The RSIS is covered in III-14 for the Neutrino Area beamline. The experiments present in the enclosure require no additions.

IV-9.4.1.2.2 ODH Safety System

During personnel access into NM4, the following components of the Oxygen Deficiency Hazard (ODH) Safety System shall be in place, with no known loss of safety function, during personnel access into applicable areas:

- Two (2) area/fixed oxygen monitors (one high, one low), within NM4
- One (1) horn and one (1) strobe within NM4

During personnel access into the NM3 target cave, the following components of the ODH Safety System shall be in place, with no known loss of safety function, during personnel access into applicable areas:

- Two (2) area/fixed oxygen monitors (one high, one low), within NM3
- One (1) horn and one (1) strobe within NM3

IV-9.5. Defense-in-Depth Controls

IV-9.5.1 Administrative Controls

Administrative controls and procedures have been put in place to ensure safe operations at the Neutrino Switchyard 120 Experimental Areas. Operational readiness of each experiment is governed by PPD ESH 006 ES&H Review of Experiments. Subject matter experts review each aspect of the experiment prior to operations to ensure safe operations. The review includes procedure, hazard analysis and document reviews, and walk-throughs of the experiment components. The division head(s) of the area(s) in which experimental components reside grant approval for operations.

IV-9.5.1.1 Operation Authorization Document

Commissioning, normal operations, and emergency management of the Neutrino Switchyard 120 Experimental Areas are all conducted under the auspices of the Particle Physics Directorate Headquarters and the Environment, Safety, and Health Division.

IV-9.6. Decommissioning

DOE Field Element Manager approval shall be obtained prior to the start of any decommissioning activities for the Neutrino Switchyard 120 Experimental Areas.

IV-9.7. Summary and Conclusion

This chapter of the Fermilab SAD identifies and assesses specific radiological and other hazards associated with the commissioning and operation of the Fermilab Neutrino Switchyard 120 Experimental Areas. The chapter identifies and describes designs, controls, and procedures to mitigate Fermilab Neutrino Switchyard 120 Experimental Areas hazards. In addition to the specific safety considerations presented in this chapter, Fermilab Neutrino Switchyard 120 Experimental Areas are subject to the global and more general safety requirements, controls, and procedures outlined in Section 1 of the Fermilab SAD.

The Fermilab Neutrino Switchyard 120 Experimental Areas have been constructed and commissioned and will be operated within the specific and general considerations of this safety assessment. The preceding discussion of the hazards presented by the Fermilab Neutrino Switchyard 120 Experimental Areas operations and the credited controls established to mitigate those hazards demonstrate that the experiments can be operated in a manner that will produce minimal hazards to the health and safety of Fermilab workers, researchers, and members of the public, as well as to the environment.

IV-9.8. References

[1] Fermilab Radiological Control Manual

[2] Fermilab Environment, Safety and Health Manual Chapter 2005 (FESHM 2005), *Operational Readiness Clearance*

[3] Fermilab Environment, Safety and Health Manual Chapter 2010 (FESHM 2010), *Planning and Review of Accelerator Facilities and Their Operations*

[4] Neutrino Muon Beamline Shielding Assessment, T. Kobilarcik, M. Geelhoed, February 24, 2012

[5] C. Johnstone and I. Rakhno, Neutrino Muon Beamline Shielding Assessment Addendum for E1039, December 18, 2019

[6] Fermilab Environmental Safety and Health Manual – All references to FESHM can be found here at the current web link: http://esh.fnal.gov/xms/ESHQ-Manuals/FESHM

[7] K. Overhage, "Fermilab E1039 ODH and Hazardous Gas System Design Documentation," Fermilab Engineering Note, TeamCenter Reference, EN05275, 25 October 2021

[8] E. Voirin, "Ammonia Spill Hazards in the NM4 Experimental Hall," Fermilab Engineering Note, TeamCenter Reference: ED0016616, 19 January 2022

[9] https://www.epa.gov/aegl/ammonia-results-aegl-program

[10] FESHM 4170 references the Code of Federal Regulations (CFR) Part 851, "Worker Safety and Health Program." CFR 851 defers to the American Conference of Governmental Industrial Hygienists (ACGIH) for many chemical exposure limits. Exposure limits for ammonia may be found at the URL: https://www.acgih.org/ammonia/.

[11]J. Kintner, "Oxygen Deficiency Hazards – E1039 NM3/Target cave," Fermilab Engineering Note, TeamCenter Reference: EN04847, 4 October 2021

[12] J. Kintner, "E1039 NM4 ODH Calculations," Fermilab Engineering Note, TeamCenter reference: EN07073, 30 March 2022

[13] K. Overhage "E1039 NM4 ODH Controls," Fermilab Engineering Note, TeamCenter reference EN07072, 2022

[14] Fermilab ES&H Manual (FESHM-4240), "Oxygen Deficiency Hazards (ODH)," June 2018

[15]https://www.mitegen.com/product/cryo-express-dry-shipper-cx100/

IV-9.9. Appendix – Risk Matrices

Risk assessment methodology was developed based on the methodology described in DOE-HDBK-1163-2020. Hazards and their potential events are evaluated for likelihood and potential consequence assuming no controls in place, which results in a baseline risk. A baseline risk (i.e., an unmitigated risk) value of III and IV does not require further controls based on the handbook. Events with a baseline risk value of I or II do require prevention and/or mitigation measures to be established in order to reduce the risk value to an acceptable level of III or IV. Generally, preventive controls are applied prior to a loss event, reflecting a likelihood reduction, and mitigative controls are applied after a loss event, reflecting a consequence reduction. For each control put in place, likelihood or consequence can have a single “bin drop,” resulting in a new residual risk (i.e., a mitigated risk). This risk assessment process is repeated for each hazard for Facility Workers (FW), Co-Located Workers (CLW), and Maximally-Exposed Offsite Individual (MOI). At the conclusion of the risk assessments, controls that are in place for the identified accelerator specific hazards are identified as Credited Controls and are further summarized in Section IV-9.4 of this Chapter as well as in SAD Chapter VII-A.1 *Accelerator Safety Envelope – Fermi Main Accelerator.*