Fermilab Meson and Neutrino Switchyard 120 Experimental Areas

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Revision History

Author	Description of Change	Revision No. & Date
Richard J. Tesarek Maddie Schoell	Updated to include the E1039/SpinQuest Experiment in NM3/NM4 Editorial updates to align with updated FESHM/FRCM Chapters and Organizational structure	Revision 2 October 6, 2022
Eric McHugh	Updated PPD Experimental ORC Procedure to FESHM 2005 ORC	Revision 1 January 15, 2017
Eric McHugh	Initial release of the Fermilab Meson and Neutrino Switchyard 120 Experimental Areas Chapter for the Fermi National Accelerator Safety Assessment Document (SAD)	Revision 0 August 28, 2016

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III - 3.1 Fermilab Meson and Neutrino Switchyard 120 Experimental Areas Area Locations on Fermilab Site

The Fermilab Meson and Neutrino Switchyard 120 Experimental Area consists of four locations that house detectors that are served by three beam lines (Figure 1). These locations house permanent beam characterization equipment, long-term experiments, and are readily configurable and flexible for research and development for new detectors and detector technology.

The Fermilab Test Beam Facility (FTBF), located along the Fermilab meson line, comprises three of the test areas, including Meson Test (MTest), Meson Center 7 (MC7) enclosures and the M03 High Rate Tracking Area. These facilities allow experimenters to expose their experimental equipment to differing beam intensities and energies.

The NM4 enclosure experimental hall, located along the Fermilab neutrino line, currently houses the long-term E1039 SpinQuest experiment. All together, these four locations comprise the Fermilab Meson and Neutrino Switchyard 120 Experimental Areas and allow great flexibility for experimenters to explore new detector technologies and to characterize and improve existing technologies.

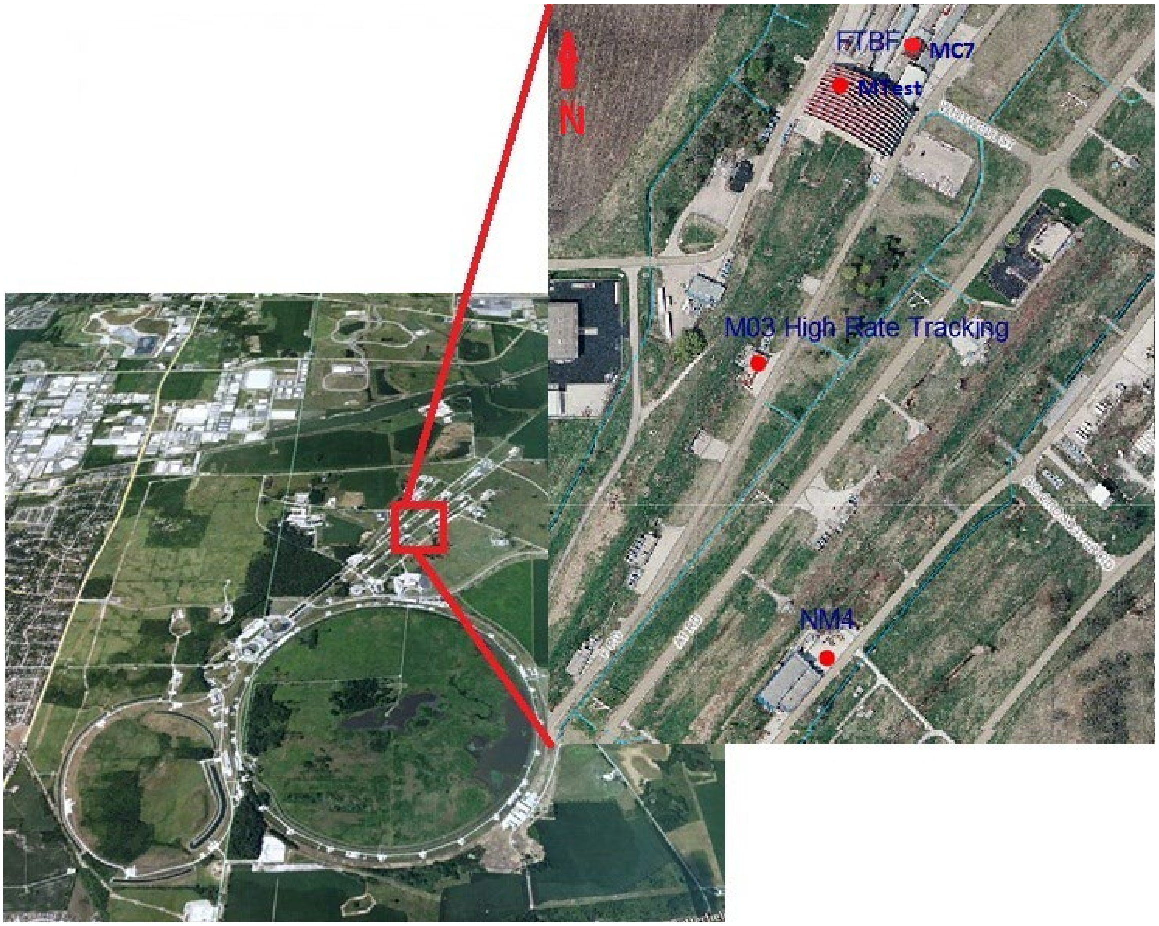

Figure 1 – Aerial view of the Fermilab Meson and Neutrino Switchyard 120 Experimental Areas

III - 3.2 Inventory of Hazards

The following table lists the identified hazards found in the Fermilab Meson and Neutrino Switchyard 120 Experimental Areas. All hazards with an * have been adequately discussed in Chapters 1-10 of the Fermilab Safety Assessment Document and are not covered further in this section.

Radiation Particle beams and prompt radiation Residual component activation Radioactive waste Radioactive sources Lasers	**Kinetic Energy** Power tools * Pumps and motors * Motion tables*
Toxic Materials Lead shielding* Beryllium* Ammonia (solid) Glycol* Other gases*	**Potential Energy** Crane operations * Compressed gases * Vacuum / pressure vessels * Vacuum pumps *
Flammable & Combustible Materials Cables * Flammable gases Combustible and flammable liquids *	**Magnetic Fields** Fringe fields
Electrical Energy Stored energy exposure * High voltage exposure * Low voltage, high current exposure *	**Gaseous Hazards** Confined spaces * ODH hazards
Thermal Energy Cryogens	**Access / Egress** Life Safety Egress *

III - 3.3 Introduction

This Section III, Chapter 3 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD) covers the Fermilab Meson and Neutrino Switchyard 120 Experimental Areas.

III - 3.3.1 Purpose of the Fermilab Meson and Neutrino Switchyard 120 Experimental Areas

The purpose of the Fermilab Meson and Neutrino Switchyard 120 Experimental Areas is to provide experimenters with flexible, equal, and open access to test beams for detector technology research and development and facilities for dedicated physics experiments.

III - 3.3.2 Description of the Fermilab Meson and Neutrino Switchyard 120 Experimental Areas

The FTBF is served by the meson fixed-target beamline and enables experimenters to test their detectors in an active beamline and also permits detectors for other types of research (cosmic rays, etc.) to be calibrated. Typically experiments installed at FTBF are operated for short durations (< 1 month). The NM4 enclosure experimental hall is served by the neutrino fixed-target beamline and is located approximately ¼ mile to the east of the FTBF. The enclosure houses long-term fixed-target experiments. The Neutrino line currently hosts the long-term E1039 SpinQuest experiment at the NM4 enclosure experimental hall. These experiments and tests utilize target materials, charged particle tracking detectors, particle identification detectors and calorimetric detectors. Some experiments use evacuated vessels or helium filled bags to minimize the amount of material in the beam (to reduce scattering of the beam) or experiment detectors.

The character of the hazards associated with these planned experiments is 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 are screened for hazards through the Operational Readiness Clearance (ORC)[1] 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.

III - 3.3.3 Operating Modes

The Accelerator Safety Envelope (ASE)[2] limits operating modes of the Fermilab Meson and Neutrino Switchyard 120 Experimental Areas and describes the beam character and beam limitations delivered to these areas.

III - 3.4 Safety Assessment

Hazards of the Fermilab Meson and Neutrino Switchyard 120 Experimental Areas can vary for each scheduled experiment. Radiological hazards such as ionizing radiation, residual activation, radioactive waste and sources can be present depending upon the experiment. Lasers may also be used to align experimental equipment with the particle beam. All other conventional/general industrial hazards are addressed by Fermilab ES&H and quality guidance documents. The unique hazards of the Fermilab Meson and Neutrino Switchyard 120 Experimental Areas are analyzed in this section.

III - 3.4.1 Radiological Hazards

Radiation safety has been carefully considered in the design of the Fermilab Meson and Neutrino Switchyard 120 Experimental Areas. All radiation hazards relating to beam operations safety are the responsibility of the Accelerator Division. The Accelerator Division, whose facilities includes all beamlines, their shielding, radiation, interlocks, beam surveys, monitors and impact of radiation on the environment, is addressed in the Fermilab Switchyard Fixed-Target Beamlines Safety Assessment Document[3], the Meson Area Safety Assessment Document[4], and the Fermilab Neutrino Area Safety Assessment Document[5].

Fermilab protocols require that all personnel and experimenters who work in experimental halls must be trained according to Fermilab Radiological Control Manual (FRCM) Chapter 6 – Training and Qualification[6]. 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.

III - 3.4.1.1 Ionizing Radiation

Prompt ionizing radiation is generated from the particle beam interaction with the materials, such as the beam pipes, beamline elements, and beamline instrumentation. The enclosures of the Meson and Neutrino 120 Experimental Areas are constructed of shielding (concrete, steel, earth, etc.). The enclosure shielding for these areas have been specifically and quantitatively analyzed through the Fermilab Shielding Assessment Process for both normal and accidental loss conditions as referenced in the 2003 Shielding Assessment for the Switchyard 120 Project[7], the 2013 Addendum to the SY 120 Shielding Assessment for Continued Operation of the Meson Center Beam Line[8], and the 2018 Neutrino Muon Beamline Shielding Assessment[9] and Addendum[10].

Locations around the NM4 Experimental Hall with potential for individuals to receive 100 mrem in a year are currently within Restricted Access Areas, beyond "Authorized Personnel Only" signage, and are not Public Access Areas. Additional controls for outdoor areas where members of the public could receive 100 mrem in a year may be implemented in accordance with the plans, currently under development, in response to the 2022 DOE Review of the Environmental Radiological Protection Program. Additional controls for areas where members of the public could potentially be exposed to radiation levels above background may also be implemented in accordance with the plans under development in response to the August 25, 2022 letter, EXPOSURE OF THE PUBLIC AND VISITORS TO RADIATION.

The shielding assessment documents referenced in the Fermilab Switchyard Fixed-Target Beamlines, Fermilab Meson Area, and the Fermilab Neutrino Area Safety Assessment Documents have already addressed the ionizing radiation issues associated with groundwater and surface water activation; air activation; particle interactions in soil; radiation shielding requirements; labyrinth and penetrations; residual dose rates; and active and passive shielding controls and monitoring according to the FRCM Chapter 8 – ALARA Management of Accelerator Radiation Shielding.

III - 3.4.1.2 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 by the beam in the target/beam dump are found in the Neutrino Muon shielding assessment addendum.[10]

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.

III - 3.4.1.3 Radioactive Waste

Radioactive waste hazards and disposal will be managed within the program established throughout the Fermilab accelerator complex and as prescribed in the FRCM. Waste minimization is an objective of both the Fermilab Meson and Neutrino Switchyard 120 Experimental Areas design and operational procedures. Typically, material in the Fermilab Meson and Neutrino Switchyard 120 Experimental Areas does not become activated, but any activated items that cannot be reused will be disposed of as radioactive waste in accordance with the FRCM Chapter 4 – Radioactive Materials.

III - 3.4.1.4 Radioactive Sources

Radioactive sources are used extensively by experiments for 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 Fermilab Radiological Control Manual include requirements for 1) source accountability records to be maintained by the Environment, Safety and Health Section (ES&H) Section 2) ES&H Section 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.

III - 3.4.1.5 Lasers

Lasers may be used for alignment or calibration of detectors. It is unlikely that a hazard class 1, 2, or 3A laser used for alignment of equipment would cause an inadvertent injury. On the other hand, hazard class 3B and 4 lasers have a significant potential for causing accidental injuries due to their inherently higher beam power. All laser installations (class 3B or greater) must be reviewed by the Fermilab Laser Safety Officer (LSO) prior to commencement of operations according to FESHM[11] Chapter 4260 - Lasers.

III - 3.4.2 Toxic Materials

III - 3.4.2.1 Ammonia

The E1039 target system includes two cells containing a total 28.9g of solid ammonia located in the experiment's target cave. This ammonia presents a toxicity hazard should its temperature rise above its melting point of -77°C. An active ventilation system comprising a 1,800 CFM curtain fan blowing air into the target cave and a 5,000 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, warning lights and sounding of an audio alarm, occurs should either of two sensors located in the target cave detect ammonia concentrations above 25 ppm[12]. Additionally, an alarm is sent through the Fermilab FIRUS system to the Fire Department. Should all the target material be spilled or otherwise vaporized in the target cave, engineering analysis[13] 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[14]. These exposure limits are at or lower than those referenced by FESHM 4170[15]. 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 will be allowed into the target cave area. 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.

III - 3.4.3 Gaseous Materials

III - 3.4.3.1 Flammable gases

The E1039 target system includes two 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 vaporize. An active ventilation system comprising a 1,800 CFM curtain fan blowing air into the target cave and a 5,000 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, warning lights and sounding of an audio alarm, occurs should either of two sensors located in the target cave detect ammonia concentrations above 25 ppm[12]. Additionally, under an ammonia alarm a alert is sent through the Fermilab FIRUS system to the Fire Department. Should all the target material be spilled or otherwise vaporized in the target cave, engineering analysis[13] concludes that the ventilation system ensures gaseous ammonia concentrations below 30 ppm[14]. Review and approval of the ventilation system for ammonia hazard is conducted by Fermilab industrial hygiene personnel and the fire hazard subcommittee.

III - 3.4.3.2 Cryogenic Liquids

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

III - 3.4.3.3 Oxygen Deficiency Hazards

Oxygen deficiency hazards (ODH) in E1039 arise from the venting of cryogens into either the NM3/target cave area or from the cryo-platform area in NM4. An active ventilation system[12,13] comprising a 1,800 CFM curtain fan and blowing air into the target cave and a 5,000 SCFM, explosion proof, ducted fan mixes the atmosphere in the target cave with that of the NM3 enclosure. Automatic activation of the ventilation system, warning lights and 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 Fire Department for oxygen concentrations below 19.5% and 18% in accordance with FESHM chapter 4240. Engineering analysis of the NM3/target cave enclosure[16] characterize the area as Engineered ODH-0.

Engineering analysis of the NM4 enclosure[17] conclude that the NM4 enclosure is classified Engineered ODH-0. 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%[18]. The additional ventilation and active controls are reviewed and approved by the cryo-safety committee.

III - 3.4.4 Magnetic Field Hazards

III - 3.4.4.1 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. 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.

III - 3.5 Credited Controls

III - 3.5.1 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 Meson and Neutrino 120 Experimental Areas 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

III - 3.5.1.1 Permanent Shielding Including Labyrinths

Permanent shielding surrounds the detector halls and enclosures. Concrete shielding blocks are used to shield surrounding work areas and create labyrinths for personnel access to enclosures. The enclosures of the Meson and Neutrino 120 Experimental Areas are constructed of shielding (concrete, steel, earth, etc.). The enclosure shielding for these areas have been specifically and quantitatively analyzed through the Fermilab Shielding Assessment Process for both normal and accidental loss conditions as referenced in the 2003 Shielding Assessment for the Switchyard 120 Project, the 2013 Addendum to the SY 120 Shielding Assessment for Continued Operation of the Meson Center Beam Line, and the 2012 Neutrino Muon Beamline Shielding Assessment.

III - 3.5.1.2 Penetration Shielding

The beamline has several utility penetrations routing between the exclusion areas and occupied areas which were analyzed for required shielding and designed to eliminate the need for additional penetration shielding. Consequently, the prompt dose rates at the exits of the penetrations are within the limits established in the FRCM Chapter 2.

III - 3.5.2 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 Meson and 120 Neutrino Experimental Areas are discussed below.

III - 3.5.2.1 Radiation Safety Interlock System

The Fermilab Meson and Neutrino Switchyard 120 Experimental Areas, the MT6 Section 1 & 2 enclosures, MC7 enclosure and NM4 enclosure experimental hall, are all protected by a radiation safety interlock system that is described in the Switchyard Fixed-Target Beam Lines, Fermilab Meson Area, and Fermilab Neutrino Area Safety Assessment Documents.

Trained and qualified personnel from the Accelerator Division 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 beamline enclosure, controlled access procedures, personnel training requirements, and procedures for maintenance of interlock systems, are in conformance with the requirements stated in the FRCM Chapter 10 – Radiation Safety Interlock Systems.

Fermilab Radiological Worker training and Fermilab Controlled Access training are required to enter beamline areas when the particle beam has been disabled and the interlocks remain active. The Main Control Room controls access to beamline enclosures when the interlocks are active.

III - 3.5.3 Administrative Controls

All Fermilab Meson and Neutrino Switchyard 120 Experimental Areas' 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 operations. The administrative procedures and programs considered necessary to ensure safe accelerator operations are discussed below in the Switchyard Fixed Target Beam Lines, Fermilab Meson Area and Fermilab Neutrino Area Safety Assessment Document.

III - 3.6 Summary & Conclusion

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

The Fermilab Meson and Neutrino Switchyard 120 Experimental Areas have been constructed, 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 Meson and Neutrino Switchyard 120 Experimental Areas' operations and the credited controls established to mitigate those hazards demonstrate that the experiment can be operated in a manner that will produce minimal hazards to the health and safety of Fermilab workers, researchers, members of the public, as well as to the environment.

III - 3.7 Glossary, Acronyms

AD	Accelerator Division
ALARA	As Low As Reasonably Achievable
ASE	Accelerator Safety Envelope
ES&H	Environment, Safety and Health (ESH)
FESHM	Fermilab Environmental, Safety and Health Manual
FTBF	Fermilab Test Beam Facility
FRCM	Fermilab Radiological Control Manual
LSO	Laser Safety Officer
M03	Meson enclosure number 3
MC7	Meson Center enclosure number 7
NM4	New Muon enclosure number 4
PPD	Particle Physics Division
RSO	Radiation Safety Officer
RWP	Radiation Work Permit
SAD	Safety Assessment Document

III - 3.8 References

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

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

[3] Fermilab Switchyard Fixed-Target Beam Lines Safety Assessment Document, John Anderson Jr., Craig Moore, October 2013.

[4] Fermilab Meson Area Safety Assessment Document, John Anderson Jr., Craig Moore, April 2014.

[5] Fermilab Neutrino Area Safety Assessment Document, Thomas Kobilarcik, February 2012.

[6] Fermilab Radiological Control Manual – All references to FRCM can be found here at the current web link: http://esh.fnal.gov/xms/ESHQ-Manuals/FRCM

[7] 2003 Shielding Assessment for the Switchyard 120 Project, C. Brown, T. Kobilarcik, G. Koizumi, E. Ramberg, W. Higgins, April 8, 2003

[8] Addendum to the SY 120 Shielding Assessment for Continued Operation of the Meson Center Beam Line, T. Kobilarcik, W. Schmitt, November 25, 2013

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

[10] C. Johnstone and I. Rakhno, Neutrino Muon Beamline Shielding Assessment Addendum for E1039, December 18, 2019. https://fermipoint.fnal.gov/org/eshq/sa/Shared%20Documents/Neutrino%20Muon%20Beamline%20Shielding%20Assessment/Addendum%20for%20E1039%20('SpinQuest')/Neutrino%20Muon%20Beamline%20Shielding%20Assessment%20Addendum%20for%20E-1039%20v2.7.pdf

[11] 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

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

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

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

[15] 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/.

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

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

[18] K.Overhage “E1039 NM4 ODH Controls” Fermilab Engineering Note, TeamCenter reference EN07072, 2022.