MINOS EXPERIMENTAL AREAS

SECTION IV CHAPTER 06 OF THE FERMILAB SAD

Revision 1 March 01, 2024

This Chapter of the Fermilab Safety Assessment Document (SAD) contains a summary of the results of the Safety Analysis for the MINOS Experimental Areas segment 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 IV, Chapter 06 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD), *MINOS Experimental Areas*, was prepared and reviewed by the staff of the Particle Physics Directorate, Neutrino Division, Technical Support Department in conjunction with the Environment, Safety & 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 Safety Assessment Document (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
Angela Aparicio	0	Oct 20, 2020	Initial release of the MINOS Experiment Hall chapter
Z. Pavlovic, C.D. Joe, S. Hahn	1	Dec 21, 2023	• Updates to align with new SAD layout • Updates describing current detector installations

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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 Order, referring 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
CMTF	Cryomodule Test Facility
CMTS1	Cryomodule Test Stand 1
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	kilograms
kW	kilowatt
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
mL	milliliter
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	milliradian
mrem	millirem
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
PE	Professional Engineer
PIN	Personal Identification Number
PIP	Proton Improvement Plan
PIP-II	Proton Improvement Plan – II

PIP-II IT	PIP-II Integrated Test Stand
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-6. MINOS Experimental Areas

IV-6.1. Introduction

This Section IV, Chapter 06 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD) covers the MINOS experimental areas, which is an underground enclosure in the path of neutrinos produced by the NuMI beam hosting various experiment detectors. The current experiment detectors under operation or installation include the ArgonCube 2x2 Demonstrator, MAGIS-100, SENSEI, MOSKITA, the Scintillating Bubble Chamber (SBC), and two smaller cleanroom enclosures known as NEXUS and QUIET which also host experiments. The Near Detector for the NOvA Experiment is also located in this area, but in a separate alcove and is addressed separately in Section IV, Chapter 05. The MINOS experimental area detectors are not accelerators, and the area is separated from the NuMI accelerator segments by interlocked doors.

IV-6.1.1 Purpose/Function

The purpose of the MINOS experimental areas is to provide a space within the NuMI neutrino beam that can be utilized to observe neutrinos at a “near” site and coordinated with a detector at a “far” site (e.g. Ash River, MN), as well as provide a space with lower background from cosmic rays.

IV-6.1.2 Current Status

The MINOS experimental area segment of the Fermilab Main Accelerator is currently: **operational**.

IV-6.1.3 Description

The MINOS experimental area consists of the MINOS service building on the surface and the underground areas accessible from the elevator located in the MINOS service building, which are not a part of the NuMI beamline segment described in Section III Chapter 8. Figure 3 provides a schematic; the MINOS experimental areas are the access shaft, the absorber access tunnel, the MINOS access tunnel, and the MINOS detector hall. The underground areas are approximately 350 ft. below the surface.

The ArgonCube 2x2 Demonstrator is located in the MINOS Detector Hall. It consists of a low-pressure cryostat vessel holding four DUNE Near Detector prototype LAr modules. There are 36 reconfigured scintillator planes from the Main Injector Neutrino ExpeRiment v-A (MINERvA) detector installed in front and behind the LAr vessel. The ArgonCube 2x2 is currently in installation phase.

The 100-meter-long Matter-wave Atomic Gradiometer Interferometric Sensor (MAGIS-100) is a project associated with the quantum science program. The MAGIS-100 Experiment will be installed in the MINOS access shaft and in the MINOS Service Building. The experiment will consist of a cold atom source, atom cloud shuttle, launch system, vacuum pipe, laser system and atom detection system. MAGIS-100 is currently in construction phase.

The Northwestern Experimental Underground Site at Fermilab (NEXUS @ FNAL) is a dark matter detector testing facility primarily in support of the SuperCDMS Experiment. A dilution refrigerator is used for detector characterization and prototyping. A neutron generator, with associated shielding materials, is used for calibration. It is sited in the underground area to reduce exposure from cosmic rays and is located in the MINOS access tunnel. NEXUS@FNAL is currently operating.

The Quantum Underground Instrumentation Experimental Testbed (QUIET) is a cleanroom facility, modeled from and built very similarly to the one for NEXUS, which is used for underground quantum information research. QUIET is part of the quantum science center, one of five DOE national quantum initiative centers. A dilution refrigerator is part of the apparatus. Lead shielding will be used for background reduction. It is sited in the underground area to reduce exposure from cosmic rays and is located in the MINOS Access Tunnel. QUIET was installed in 2023 and is in a commissioning phase.

The Scintillating Bubble Chamber (SBC) is a dark matter detector located just downstream of the NEXUS cleanroom in the MINOS Access Tunnel. The SBC uses pressure and temperature-controlled liquid argon in a self-contained pressure vessel containing a piston-controlled hydraulic system. It is sited in the underground area to reduce exposure from cosmic rays. SBC is in an installation phase and plans to commission in 2024.

The Sub-Electron Noise Skipper Experimental Instrument (SENSEI) is a prototype dark matter detector located in a small clean-room tent in the MINOS Access Tunnel. It is situated in the underground area to reduce exposure from cosmic rays. The SENSEI system uses skipper charge-coupled devices (CCDs) inside a small vacuum vessel. SENSEI is currently operating.

MOSKITA (Mobile Oscura SKIpper Testing Apparatus) is a test setup used to characterize skipper CCDs for an upcoming dark matter experiment called Oscura, which will be located at SNOlab near Sudbury, Ontario in Canada. MOSKITA shares the tent with SENSEI and is similarly located underground to reduce exposure from cosmic rays. MOSKITA is currently operating.

There are no experiment detectors currently located in the absorber access tunnel.

IV-6.1.4 Location

The MINOS experimental areas segment of the Fermilab Main Accelerator is located on the Fermilab site in Batavia, IL. . The MINOS experimental areas are ~ 300 ft. underground. The areas are accessed by an elevator in the MINOS Service Building, which is located on the Neutrino Campus, northwest of the Fermilab Main Accelerator on the Fermilab site, shown in Figure 2.

Figure 1 Regional view showing the location of the Fermilab site in Batavia, IL.

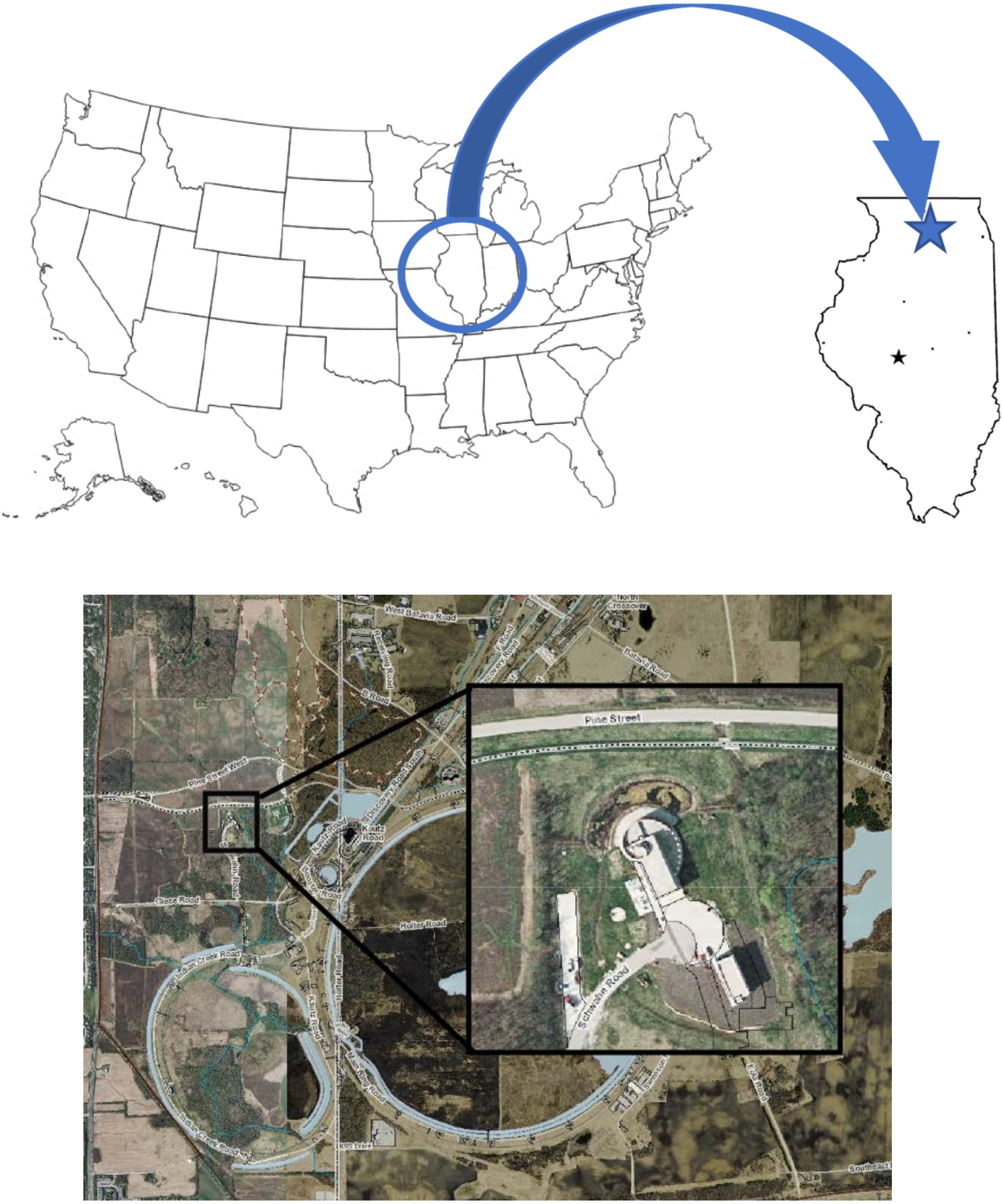

Figure 2 Aerial view of the Fermilab site, indicating the location of the MINOS Service Building.

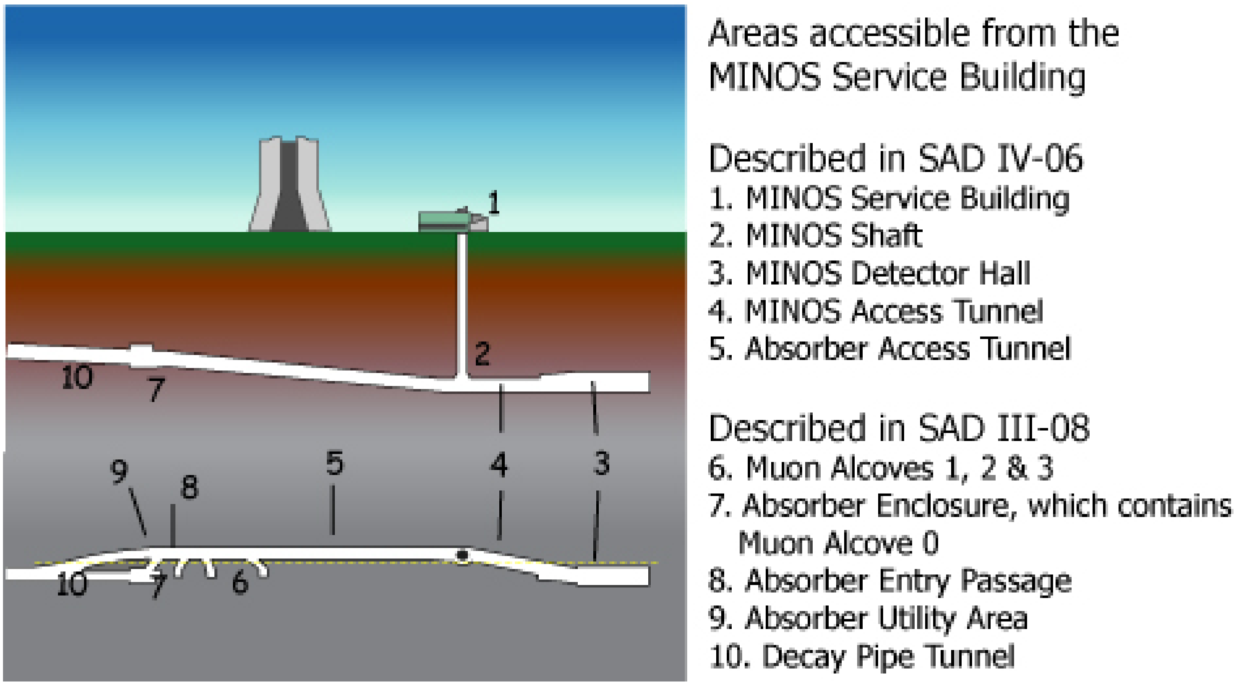

Figure 3 Elevation and plan schematic of the MINOS underground areas. The illustrated buildings (Wilson Hall and MINOS Service Building) are not-to-scale with the underground areas.

IV-6.1.5 Management Organization

The detectors are managed by their respective collaborations and Neutrino Division within the Particle Physics Directorate of Fermilab. The MINOS experimental areas receive area facility management from the Infrastructure Services Division and safety support from the ES&H Division

IV-6.1.6 Operating Modes

The MINOS underground neutrino experiments operate as neutrino detectors utilizing the neutrino beam from the NuMI beam line. The Neutrino Division (ND) is responsible for the operation of the neutrino detectors. The operational neutrino experiments assign shifters to monitor the experiment systems, either in the remote operations center (ROC-West) or remotely. Cryogenic engineers on shift respond to Fermilab Fire Incident Reporting and Utility System (FIRUS) trouble or emergency alarms related to the cryogenic system(s). The dark matter detectors operate independently of the NuMI beam line. The Particle Physics Directorate (PPD) is responsible for the oversight and operations of these detectors.

IV-6.1.7 Inventory of Hazards

The following table lists all of the identified hazards found in the MINOS experimental areas. Section IV-6.9 *Appendix – Risk Matrices* 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 IV-6.2 *Safety Assessment.*

Accelerator specific hazards are identified as **purple/bold** in Table 1; there are no accelerator-specific hazards in the MINOS experimental areas. All hazards present in the MINOS experimental areas are safely managed by 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), as described in Section I Chapter 4. These hazards are considered to be standard industrial hazards (SIH), and their analysis will be summarized in this SAD Chapter.

Table 1. Hazard Inventory for MINOS Experimental Areas.

	Radiological		Toxic Materials
☐	Prompt Ionizing Radiation	☒	Lead
☐	Residual Activation	☐	Beryllium
☐	Groundwater Activation	☒	Flourinert & Its Byproducts
☐	Surface Water Activation	☐	Liquid Scintillator Oil
☒	Radioactive Water (RAW) Systems	☐	Pseudocumene
☐	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 Gasses		**Other Hazards**
☒	Vacuum/Pressure Vessels/Piping	☒	Confined Spaces
☒	Vacuum Pumps	☒	Noise
☒	Material Handling	☒	Silica
	Access & Egress	☒	Ergonomics
☒	Life Safety Egress	☐	Asbestos
		☒	Working at Heights

IV-6.2. Safety Assessment

All hazards for the MINOS Experimental Area segment of the Fermilab Main Accelerator are summarized in this section. All are non-accelerator specific hazards (NASH); lab-wide common mitigations to these hazards are described in Section 1 Chapter 4.

IV-6.2.1 Radiological Hazards

The MINOS experimental area presents radiological hazards in the form of radioactive water (RAW) system, radioactive sources, radiation generating devices, and non-ionizing radiation from lasers.

IV-6.2.1.1 Prompt Ionizing Radiation

N/A

IV-6.2.1.2 Residual Activation

N/A

IV-6.2.1.3 Groundwater Activation

N/A

IV-6.2.1.4 Surface Water Activation

N/A

IV-6.2.1.5 Radioactive Water (RAW) Systems

The MINOS Sump area has a chance of containing tritiated water due to accelerator operations. Access to the MINOS sump requires the oversight of the RSO/ESH and is posted accordingly. Fire suppression systems currently use water from the MINOS groundwater loop and are likewise posted accordingly. Workers are notified of this in their training and all visitors receive notice of this in their safety briefings.

Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

IV-6.2.1.6 Air Activation

N/A

IV-6.2.1.7 Closed Loop Air Cooling

N/A

IV-6.2.1.8 Soil Interactions

N/A

IV-6.2.1.9 Radioactive Waste

N/A

IV-6.2.1.10 Contamination

N/A

IV-6.2.1.11 Beryllium-7

N/A

IV-6.2.1.12 Radioactive Sources

Calibrating the response of the detectors with sealed radioactive sources may be necessary during the course of commissioning and operating. SENSEI, NEXUS, and QUIET use radioactive sources to test detectors. The hazards from radioactive sources are evaluated within the common Risk Matrix table included in SAD Section I Chapter 4 *Safety Analysis*. Usage of radioactive sources implement the controls specified in the common Risk Matrix table, which reduce an unmitigated risk of I to a residual risk of IV. No additional or unique controls are applied.

Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

IV-6.2.1.13 Nuclear Material

N/A

IV-6.2.1.14 Radiation Generating Devices (RGDs)

The NEXUS site will be utilizing a D-D neutron generator for calibration of the detectors tested in the underground facility. Neutron generators require registration at Fermilab, and their use must be approved in accordance with the Fermilab Radiological Control Manual (FRCM) Article 362, *Radiation Generating Devices and Radiography Sources*. Final operational approval is made through an Operational Readiness Clearance (ORC) review. The Environment, Safety and Health (ES&H) Section Radiation Physics Departments will ensure adequate shielding and interlocks are provided, if necessary, to protect workers and visitors. Operating procedures must be developed and approved. The hazard is assessed in the Risk Matrix table in IV-6.10, which reduce an unmitigated risk of I to a residual risk of IV.

Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

IV-6.2.1.15 Non-Ionizing Radiation Hazards

Lasers may be utilized for experiments located in the shaft or underground, including MAGIS-100 and QUIET.

The MAGIS laser room, located inside the MINOS Service Building electronics room, will contain multiple low-power lasers with an interlock on the room entrance to automatically cut power to all laser generators upon unauthorized entry. On the MAGIS tower, three “atom sources” will use high-power 1000 W lasers to cool rubidium atom clouds to near absolute zero. The tower lasers operate within a closed box about the size of a refrigerator with interlocks to turn off laser power if the box is opened.

Any individual who operates/services the laser will have undergone laser safety training and a laser eye exam. All laser installations have been reviewed and approved by the Fermilab Laser Safety Officer (LSO) prior to operation, and meet all requirements found in Fermilab Environment, Safety and Health Manual (FESHM) Chapter Lasers, as stated in Section I Chapter 4.

Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV

IV-6.2.2 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). The Fermilab facilities areas have numerous industrial hygiene issues including lasers, hazardous atmospheres, confined spaces, and hazardous materials.

The laboratory 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, ES&H staff develops additional procedures to mitigate the hazards.

IV-6.2.2.1 Lead Shielding

Lead bricks are used in SENSEI, NEXUS, and in future in QUIET enclosure. These present potential exposure to lead dust during manual handling of un-encased lead bricks. The hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 4 *Safety Analysis*. No further or unique controls are utilized in the MINOS areas.

Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

IV-6.2.2.2 Beryllium

N/A

IV-6.2.2.3 Fluorinert & Its Byproducts

Fluorinert is used as a coolant in the neutron generator at NEXUS. The chiller circulates it through the system in a closed loop during operation. The chiller has a total volume of about 7 liters, and the additional quantity in the tubing is 0.2 liters. The hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 4 *Safety Analysis*. No further or unique controls are utilized in the MINOS areas.

Baseline risk for this hazard was R II and, after control measures were evaluated, the residual risk level was R IV.

IV-6.2.2.4 Liquid Scintillator Oil

N/A

IV-6.2.2.5 Pseudocumene

N/A

IV-6.2.2.6 Ammonia

N/A

IV-6.2.2.7 Nanoparticle Exposures

N/A

IV-6.2.3 Flammables and Combustibles

The instances of this hazard in the MINOS experimental areas have been evaluated within the common Risk Matrix table included in SAD Section I Chapter 4 Safety Analysis. An unmitigated risk of I is reduced to a residual risk of IV with use of the listed controls. No further or unique controls are utilized in the MINOS areas.

IV-6.2.3.1 Combustible Materials

During the construction phase various combustible materials like boxes, paper, wood, cribbing may be present in the area. The MINOS experimental areas utilize the controls described in the tables in Section I Chapter 4.

Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

IV-6.2.3.2 Flammable Materials

The NEXUS facility will use deuterium gas in their neutron generator. The quantity will be limited to the amount necessary to operate the generator. All use of flammable materials in the underground is in conformance with the controls described in the tables in Section I Chapter 4.

Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV

IV-6.2.4 Electrical Energy

The MINOS experimental areas contain standard electrical power distribution systems. There are no exposed conductors. The components installed for the experiment detectors utilize both commercial and custom-made electrical equipment for data-taking including DC power supplies. All experiment equipment is reviewed prior to use following the operational readiness clearance process to ensure compliance with electrical safety standards as listed in Section 1 Chapter 4.

Training, work planning and controls, and the ORC review process provide additional protection for workers and other personnel in the area. Work in the MINOS experimental areas involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

IV-6.2.4.1 Stored Energy Exposure

N/A

IV-6.2.4.2 High Voltage Exposure

High voltage is used by several experiments, as well as for pumps and motors. All custom electronics and power distribution devices were cleared for use via Fermilab's ORC program. Any work involving high voltage exposure is conducted following hazard analysis and work planning and controls guidelines. High voltage electrical installations implement the controls specified in the common Risk Matrix table, which reduce an unmitigated risk of I to a residual risk of IV. No additional or unique controls are applied.

IV-6.2.4.3 Low Voltage, High Current Exposure

ArgonCube, NEXUS, SENSEI, and QUIET all employ low voltage, high current electrical power sources. All custom electronics and power distribution devices are cleared for use via Fermilab's ORC program. Any work involving low voltage high current sources is conducted following hazard analysis and work planning and controls guidelines. The installations implement the controls specified in the common Risk Matrix table, which reduce an unmitigated risk of I to a residual risk of IV. No additional or unique controls are applied.

IV-6.2.5 Thermal Energy

Thermal energy hazards which are applicable to the MINOS experimental area are discussed in this section.

IV-6.2.5.1 Bakeouts

MAGIS-100 requires very high vacuum and will perform a bakeout of their tower vacuum pipe in the MINOS shaft as part of the installation and commissioning process. The hazards are evaluated within the common Risk Matrix table included in SAD Section I Chapter 4 *Safety Analysis*. The bakeout process will implement the controls specified in the common Risk Matrix table, which reduce an unmitigated risk of I to a residual risk of IV. No additional or unique controls are applied. The bakeout work will be conducted using work planning and controls guidelines.

IV-6.2.5.2 Hot Work

Welding is occasionally utilized during the installation phase of the experiments located in the MINOS areas. The risks from welding work are evaluated within the common Risk Matrix table included in SAD Section I Chapter 4 *Safety Analysis.* Work plans implement the controls specified in the common Risk Matrix table, which reduce an unmitigated risk of I to a residual risk of IV. No additional or unique controls are applied.

IV-6.2.5.3 Cryogenic Liquids

Cryogenic liquids - liquid argon and liquid nitrogen – will be present in the underground areas once ArgonCube 2x2 is installed in the MINOS Experimental Hall and has ORC for operation of the cryogenics system. Hazards from these cryogens include the potential for ODH atmospheres which could result from cryogenic system failure/rupture of the vessel or piping, insulation failure, mechanical damage/failure, deficient maintenance, or improper procedures. The cavern will be classified as Engineered ODH0 upon the installation of the additional ventilation system and duct. These hazards are evaluated within the common Risk Matrix table included in SAD Section I Chapter 4 *Safety Analysis*. The cryogenics installations planned for the MINOS areas implement the controls specified in the common Risk Matrix table.

The cryogenic system for ArgonCube 2x2 is designed and installed to comply with applicable standards per FESHM Chapters *Pressure Vessels*, *Piping Systems*, *Inert Gas Trailer Connections and Onsite Filling Guidelines*, *Gas Regulators*, *Inspection and Testing of Relief Systems*, *Cryogenic System Review, Liquid Nitrogen Dewar Installation and Operation Rules*, and *Liquid Cryogenic Targets*, as stated in Section 1 Chapter 4.1.5.3.

The number of dewars and cryogens in the hall used by SENSEI, NEXUS and QUIET is limited to maintain the area ODH0 classification.

The NuMI/MINOS Underground Safety Training course will be updated to include aspects associated with the cryogenics operations, updating the protective measures in place, and any emergency actions that would need to be taken.

The underground emergency passageway is supplied with a ventilation system that operates independently of the experimental hall ventilation. This ventilation system is on the emergency back-up generator so ventilation will still be supplied during power outages.

Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

IV-6.2.6 Kinetic Energy

The MINOS service building contains a large ventilation system in its mechanical rooms, as well as other mechanical systems for domestic and industrial water. An air compressor skid provides air to equipment in the NuMI beamline segment. Underground, the sump system utilizes municipal-scale pumps which removes the ~ 80 GPM rate of water flowing into the sump at the base of the MINOS Shaft. The moving parts in all this large machinery are protected to prevent contact by personnel.

The experiments in the MINOS areas utilize air compressors and pumps which serve their cryogenic systems. Powered hand tools are occasionally used during experiment maintenance periods.

IV-6.2.6.1 Power Tools

The hazards from powered hand tools are evaluated within the common Risk Matrix table included in SAD Section I Chapter 4 *Safety Analysis*. Usage of powered hand tools implement the controls specified in the common Risk Matrix table, which reduce an unmitigated risk of I to a residual risk of IV. No additional or unique controls are applied.

IV-6.2.6.2 Pumps and Motors

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the MINOS experimental area involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R III.

IV-6.2.6.3 Motion Tables

N/A

IV-6.2.6.4 Mobile Shielding

NEXUS shields its neutron source with polypropylene, which is set on rails to allow adjustment of the distance within he shielded area between the source and detector in the cryocooler. The adjustment motion is controlled by a crank system. The hazards presented by the motion of the shielding are evaluated within the common Risk Matrix table included in SAD Section I Chapter 4 *Safety Analysis*.Controls are utilized as specified in the common Risk Matrix table, which reduce an unmitigated risk of I to a residual risk of IV. No additional or unique controls are applied.

IV-6.2.7 Potential Energy

Multiple overhead cranes are located in the MINOS Service Building and in the underground MINOS Detector Hall. A small hoist crane in located in the NEXUS enclosure. Compressed gases can be present in the MINOS areas, as needed to support experiment installation and operation. Vacuum pumps can likewise be present. The cryostats and cryogenics systems installed for the experiments utilize vacuum and pressure vessels, and vacuum/pressure piping; all are designed, installed, reviewed, and approved following FESHM.

Materials handling occurs as needed at all the MINOS experimental areas.

IV-6.2.7.1 Crane Operations

All of the large items are transported underground using the crane in the MINOS surface building which serves the MINOS access shaft. Operation of this crane is aided by a dedicated CCTV camera located at the bottom of the shaft and live display located in the MINOS service building. Site-specific training is required for all operators of the shaft crane due to its unusually long wire rope and swing potential. Standard bridge cranes are located in the MINOS Service Building and Detector Hall.

The hazards in crane operations are evaluated within the common Risk Matrix table included in SAD Section I Chapter 4 *Safety Analysis*. Work involving crane operations implements the controls specified in the common Risk Matrix table, which reduce an unmitigated risk of I to a residual risk of IV. No additional or unique controls are applied.

IV-6.2.7.2 Compressed Gasses

Standard compressed gas bottles are used throughout the MINOS underground, for both detector operations and for incidental work; gas bottle racks are available for storage. The hazards in the use of compressed gas in bottles are evaluated within the common Risk Matrix table included in SAD Section I Chapter 4 *Safety Analysis*. Work involving compressed gas bottles implements the controls specified in the common Risk Matrix table, which reduce an unmitigated risk of I to a residual risk of IV. No additional or unique controls are applied.

IV-6.2.7.3 Vacuum/Pressure Vessels

The two large pressure vessels in the MINOS underground are the ArgonCube cryostat and the SBC bubble chamber/cryostat. The hazards due to the presence of vacuum/pressure vessels/piping operations are evaluated within the common Risk Matrix table included in SAD Section I Chapter 4 *Safety Analysis*. Work involving vacuum/pressure vessels/piping implements the controls specified in the common Risk Matrix table, which reduce an unmitigated risk of I to a residual risk of IV. No additional or unique controls are applied.

IV-6.2.7.4 Vacuum Pumps

Vacuum pumps are present throughout the MINOS Underground. The hazards due to the presence of vacuum pumps are evaluated within the common Risk Matrix table included in SAD Section I Chapter 4 *Safety Analysis*. Work involving vacuum pumps implements the controls specified in the common Risk Matrix table, which reduce an unmitigated risk of I to a residual risk of III. No additional or unique controls are applied.

IV-6.2.7.5 Material Handling

Material handling may be conducted in this facility. This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the MINOS experimental area involving this hazard implements the controls specified in the common Risk Matrix table. No additional or unique controls are applied.

Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

IV-6.2.8 Magnetic Fields

N/A

IV-6.2.8.1 Fringe Fields

N/A

IV-6.2.9 Other Hazards

Other hazards applicable to the MINOS experimental area are discussed in this section.

IV-6.2.9.1 Confined Spaces

Confined spaces exist in the MINOS experimental areas. The sump areas at the base of the MINOS shaft, both under the main section and under the elevator section, are confined spaces. The ArgonCube cryostat is a confined space during the construction phase, before being filled with liquid argon.

These confined spaces are included on the laboratory's confined space inventory, and require permits for entry, following FESHM Chapter *Confined Spaces*. The hazards in entering these confined spaces are evaluated within the common risk matrix table included in SAD Section I Chapter 4 *Safety Analysis*. Entry into the confined spaces implements the controls specified in the common risk matrix table, which reduce an unmitigated risk of I to a residual risk of III. No additional or unique controls are applied.

IV-6.2.9.2 Noise

Typical levels of noise in this facility do not present a safety hazard. In the event of maintenance or work which produces high levels of noise, applicable training and work planning and controls are utilized, along with applicable PPE, to protect workers and others.

This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 4 *Safety Analysis*. Work in the MINOS experimental area involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use.

Baseline risk for this hazard was R III and, after control measures were evaluated, the residual risk level was R IV.

IV-6.2.9.3 Silica

Silica exposure hazards may result from drilling of concrete or similar material, performed on an as-needed basis. Applicable training and work planning and controls are utilized, along with applicable PPE, to protect workers and others.

This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the MINOS experimental area involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

IV-6.2.9.4 Ergonomics

All work in the MINOS experimental area is conducted following good ergonomics practices and training.

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the MINOS experimental area involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

IV-6.2.9.5 Asbestos

N/A

IV-6.2.9.6 Working at Heights

Occasionally work is performed at heights. This requires fall protection training and hazard protection in accordance with Fermilab's training and work planning and controls program. This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 *Safety Analysis.* Work in the MINOS experimental area involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R III.

IV-6.2.10 Access & Egress

The MINOS experimental area access/egress is governed by NuMI/MINOS underground training and coordination with the MINOS Area Coordinator. Access to the MINOS Service Building requires a valid ID card. Access to the MINOS elevator and underground areas requires a key to the elevator enclosure. The keys are checked out from the main control room. In order to obtain a key, personnel must have current General Employee Radiation Training (GERT) and NuMI/MINOS Underground Safety Training. Underground access training specifies two-person rule, a hard hat, closed toe shoes, and a flashlight. Depending upon work in the underground area, additional PPE may be required. The MINOS Area Coordinator and the MINOS Work Permit/Tour system coordinate all underground work.

The MINOS access tunnel is the main pathway between the elevator and the MINOS detector hall. A smaller parallel passageway is used only for emergency exit. Experiments located in the MINOS access tunnel are required to maintain a small footprint along the walls, so the open width of the tunnel allows the transport of large objects between the shaft and the detector hall.

The absorber access tunnel provides the main pathway to the absorber and muon enclosures, which are part of the NuMI beamline segment of the accelerator and described in Section III Chapter 08. The 11.5-degree slope of the Absorber Access Tunnel makes it difficult to install experiments in that location and there are no experiments located there. The maintenance is shared between Neutrino Division/PPD and the Accelerator Directorate.

IV-6.2.10.1 Life Safety Egress

Primary and secondary egress routes are explained in the NuMI/MINOS Underground Safety Training and in the safety briefing for tourists.

Primary egress for workers (general access and emergency evacuation) is the personnel elevator located in the MINOS Shaft. In the case of fire or ODH emergency, the emergency escape passage to the base of the elevator is used in place of the MINOS Access Tunnel. The escape passage is supplied with over-pressured air by the underground ventilation system. If the MINOS elevator is not functional, the secondary emergency egress path is used. The secondary path goes from the absorber access tunnel to the absorber enclosure, along the decay pipeline to MI-65, to the stairwell that leads to the surface; there is also an elevator at MI-65. Use of the secondary egress path requires breaking the NuMI beam interlock at the entrance to the Absorber Enclosure.

The MINOS Service Building has an emergency generator which engages automatically in a power outage, to ensure that a safe exit is maintained during a power outage. The generator provides power for critical life-safety systems such as fire protection systems, sump system, ventilation of egress paths, elevator power, and also supports any ODH systems currently in operation.

Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

IV-6.2.11 Environmental

No area-specific hazards. Work in MINOS experimental area involving this hazard implements the controls specified in the common Risk Matrix table.

IV-6.2.11.1 Hazard to Air

Locations where there is a potential for the release of airborne radionuclides in measurable concentrations are identified and appropriately monitored to ensure compliance with applicable standards. There is no hazard to air resulting from the MINOS experimental area.

IV-6.2.11.2 Hazard to Water

Groundwater and surface water are monitored on an as needed basis by the assigned RSO or the ESH directorate to ensure compliance with the FRCM and applicable standards. There is no hazard to water resulting from the MINOS experimental area.

IV-6.2.11.3 Hazard to Soil

N/A

IV-6.3. Summary of Hazards to Members of the Public

The MINOS experimental area presents no specific hazards to members of the public.

IV-6.4. Summary of Credited Controls

There are no area-specific Credited Controls.

IV-6.5. Defense-in-Depth Controls

IV-6.5.1 Administrative Controls

Administrative controls and procedures have been put in place to ensure safe operations in the MINOS experimental area.

IV-6.5.1.1 Operation Authorization Document

Operational readiness of the 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. Division head(s) of the area(s) in which that experimental components reside grant approval for operations.

Commissioning, normal operations, and emergency management of the MINOS experimental area are all conducted under the auspices of the Neutrino Division, Particle Physics Directorate headquarters, and the ES&H Division. Areas and equipment under management by the Accelerator Directorate also share access/egress with the MINOS experimental areas and cooperation and communication are maintained with respect to these operations.

IV-6.6. Decommissioning

Decommissioning of any of the experiments in the MINOS Experimental Hall will follow the requirements of FESHM Chapter 8070 *Decontamination and Decommissioning*. DOE field element manager approval shall be obtained prior to the start of any decommissioning activities for the experiments in MINOS Experimental Area.

IV-6.7. Summary and Conclusion

This chapter of the Fermilab SAD identifies and assesses specific hazards associated with experiments that may be present in the MINOS Experimental Hall. The chapter identifies and describes designs, controls, and procedures to mitigate those hazards. In addition to the specific safety considerations presented in this chapter, the MINOS Experimental Hall experiments are subject to the global and more general safety requirements, controls, and procedures outlined in Section 1 of this Fermilab SAD.

All experiments installed and operated in the hall will be constructed, commissioned, and operated within the specific and general considerations of this safety assessment. The preceding discussion of the hazards presented by the experiments and the 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, members of the public, as well as to the environment.

IV-6.8. References

[1] Fermilab Radiological Control Manual
[2] ODH analysis - EN08215

IV-6.9. 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, co-located workers, and Maximally-Exposed Offsite Individuals (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 further summarized in Section IV-6.4.

Table 2. Summary of Baseline and Residual Risks - Main Injector Neutron Oscillation Search (MINOS) Hall Detectors

Risk Tables Description		Baseline Risk	Residual Risk
2,1	Radiological – Onsite-1 Facility Worker	R: I	R: III, IV
2.2	Radiological – Onsite-2 Co-located Worker	R: I	R: III, IV
2.3	Radiological – MOI Offsite	R: IV	R: IV
2.4	Toxic Materials – Onsite 1 Facility Worker	R: *	R: *
2.5	Toxic Materials – Onsite 2 Co-located Worker	R: *	R: *
2.6	Toxic Materials – MOI Offsite	R: *	R: *
2.7	Flammable & Combustible Materials – Onsite-1 Facility Worker	R: *	R: *
2.8	Flammable & Combustible Materials – Onsite-2 Co-located worker	R: *	R: *
2.9	Flammable & Combustible Materials – MOI Offsite	R: *	R: *
2.10	Electrical Energy – Onsite-1 Facility Worker	R: *	R: *
2.11	Electrical Energy – Onsite-2 Co-located Worker	R: *	R: *
2.12	Electrical Energy – MOI Offsite	R: *	R: *
2.13	Thermal Energy – Onsite-1 Facility Worker	R: *	R: *
2.14	Thermal Energy – Onsite-2 Co-located Worker	R: *	R: *
2.15	Thermal Energy – MOI Offsite	R: *	R: *
2.16	Kinetic Energy – Onsite-1 Facility Worker	R: *	R: *
2.17	Kinetic Energy – Onsite-2 Co-located Worker	R: *	R: *
2.18	Kinetic Energy – MOI Offsite	R: *	R: *
2.19	Potential Energy- Onsite-1 Facility Worker	R: *	R: *
2.20	Potential Energy – Onsite-2 Co-located Worker	R: *	R: *
2.21	Potential Energy – MOI Offsite	R: *	R: *
2.25	Access & Egress – Onsite-1 Facility Worker	R: *	R: *
2.26	Access & Egress – Onsite-2 Co-located Worker	R: *	R: *
2.27	Access & Egress – MOI Offsite	R: *	R: *
2.28	Environmental Hazards	R: *	R: *

*

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the specified areas involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

NOTE:

Per DOE-HDBK-1163-2020, Appendix C, “Risk Assessment Methodology”:

“Events with unmitigated risk values of III or IV would not require additional control assignments to provide reasonable assurance of adequate protection. Whereas, for events with an unmitigated risk value of I or II, controls would need to be assigned to either reduce the likelihood or the consequence, and therefore the overall mitigated risk. 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. Each control is credited for a single “bin drop” either in likelihood or consequence; not both. Following a standard hierarchy of controls, controls are applied until the residual risk is acceptable ‐ reflecting a mitigated risk value of III or IV. After controls are credited, events with a remaining unacceptable residual risk (i.e., I or II) are candidates for additional

analyses and additional controls, often quantitative in nature." For Fermilab, these controls for accelerator-specific hazards are identified as Credited Controls and further summarized in the Accelerator Safety Envelope (ASE).

Table 2.1 Radiological – Onsite-1 Facility Worker

Hazard	**Hazard Description**	Baseline Qualitative Risk (without controls)	**Preventative (P)/ Mitigative (M)**	**Residual Qualitative Risk (with controls)**
Radioactive Water (RAW) Systems	Hazard: Personnel exposed to radioactive water exceeding regulatory levels	L: A C: H R: I	P: Postings intended to caution workers of area hazard. P: Radiological Work Permit prevents unauthorized personnel form areas where excessive residual radiation exists. P: Training for workers to identify and respond to the hazard M: Run Conditions to ensure total radiation levels are within expected parameters	L: BEU C: M R: IV
Radioactive Sources	*Hazard: SENSEI and NEXUS (and QUIET in the near future) use radioactive sources to test detectors*	L: A C: H R: I	P: MINOS Service Building and Underground are posted as “Controlled Area” and “Radioactive Materials.” P: Workers must be on access list or have an MCR key to enter the MINOS Surface Building P: Workers must have a permanent key or an MCR key to enter the elevator room to go down to the MINOS Underground P: Workers must have GERT or Rad Worker training AND have Radioactive Source training to be qualified as Source Monitors M: Sources are either used in place with one of more qualified workers or are placed and signed in or out of Source Monitor box located in MINOS electronics room	L: BEU C: M R: IV
Radiation Generating Devices (RGDs)	*Hazard: NEXUS has a d-d neutron generator in their enclosure, which will be tested soon*	L: A C: H R: I	P: currently, Rad Safety has the key which allows operation of the neutron generator. P: the neutron generator is surrounded by layers of polypropylene, with the intention that nowhere outside the enclosure is considered a radioactive area. The collimated neutron beam hits a target surrounded by lead shielding with the same intention.	L: BEU C: M R: IV

			P: when the neutron generator is first turned on, tests will be made by Rad Safety RCTs and RSOs to ensure that no radioactive area is present that presents a danger. M: Scheduled tests of the radiation field will be made after the neutron generator is brought into operation.	
Non-ionizing Radiation Hazards	*Hazard: MAGIS - Class 3B and 4 lasers.* *Exposure to Class 3R lasers* *Exposure to Class 1 and 2 lasers*	L: A C: H R: I L: A C: L R: III L: A C: N R: IV	P: Class 1 (light tight) enclosures P: ORC and work planning processes P: Locked/Interlocked system P: LOTO procedure or other procedure approved by the LSO P: Affected areas are posted M: Use of PPE No further analysis needed. No further analysis needed.	L: BEU C: M R: IV L: A C: L R: III L: A C: N R: IV

Radiological Hazard Consequences, derived from Figure C-1, "Example Qualitative Consequence Matrix", DOE-HDBK-1163-2020.

Likelihood (L, of event)/year	**Consequence (C, of event)/year**	**Risk (R, Qualitative Ranking)**
A = Anticipated (L > 1.0E-02)	**H** = High	**I** = situation (event) of major concern
U = Unlikely (1.0E-02> L >1.0E-04)	**M** = Moderate	**II** = situation (event) of concern
EU = Extremely Unlikely (1.0E-04 > L >1.0E-06)	**L** = Low	**III** = situation (event) of minor concern
BEU = Beyond Extremely Unlikely (1.0E-06> L)	**N** = Negligible	**IV** = situation (event) of minimal concern

Control(s) Type
- **P** = Preventive (reduce event occurrence likelihood)
- **M** = Mitigative (reduces event consequences)

Acronyms
- **MOI =** Maximally-exposed Offsite Individual
- **rem =** Roentgen equivalent man

C	**Offsite (MOI)**	**Onsite-2 (co-located worker)**	**Onsite-1 (facility worker)**
H	**C** ^{3} 25.0 rem	**C** ^{3} 100 rem	**C** ^{3} 100 rem
M	25.0 rem > **C** ^{3} 5 rem	100 rem **> C** ^{3} 25 rem	100 rem **> C** ^{3} 25 rem
L	5 rem > **C**	25 rem **> C**	25 rem **> C**
N	0.5 rem > **C**	5 rem **> C**	5 rem **> C**

Risk Matrix

Consequences	Likelihood: A	U	EU	BEU
H	I	I	II	III
M	II	II	III	IV
L	III	III	IV	IV
N	IV	IV	IV	IV

Table 2.2 Radiological – Onsite-2 Co-located Worker

Hazard	Hazard Description	Baseline Qualitative Risk (without controls)	Preventative (P)/ Mitigative (M)	Residual Qualitative Risk (with controls)
Radioactive Water (RAW) Systems	Hazard: Personnel exposed to radioactive water exceeding regulatory levels	L: A C: H R: I	P: Postings intended to caution workers of area hazard. P: Radiological Work Permit prevents unauthorized personnel form areas where excessive residual radiation exists. P: Training for workers to identify and respond to the hazard M: Run Conditions to ensure total radiation levels are within expected parameters	L: BEU C: M R: IV
Radioactive Sources	*Hazard: SENSEI and NEXUS (and QUIET soon) use radioactive sources to test detectors*	L: A C: H R: I	P: MINOS Service Building and Underground are posted as "Controlled Area" and "Radioactive Materials." P: Workers must be on access list or have an MCR key to enter the MINOS Surface Building P: Workers must have a permanent key or an MCR key to enter the elevator room to go down to the MINOS Underground P: Workers must have GERT or Rad Worker training AND have Radioactive Source training to be qualified as Source Monitors M: Sources are either used in place with one of more qualified workers or are placed and signed in or out of Source Monitor box located in MINOS electronics room	L: BEU C: M R: IV
Radiation Generating Devices (RGDs)	*Hazard: NEXUS has a d-d neutron generator in their enclosure, which will be tested soon*	L: A C: H R: I	P: currently, Rad Safety has the key which allows operation of the neutron generator. P: the neutron generator is surrounded by layers of polypropylene, with the intention that nowhere outside the enclosure is considered a radioactive area. The collimated neutron beam hits a target surrounded by lead shielding with the same intention.	L: BEU C: M R: IV

			P: when the neutron generator is first turned on, tests will be made by Rad Safety RCTs and RSOs to ensure that no radioactive area is present that presents a danger. M: Scheduled tests of the radiation field will be made after the neutron generator is brought into operation.	
Non-ionizing Radiation Hazards	*Hazard: MAGIS Class 3B and 4 lasers*	L: A C: H R: I	P: Class 1 (light tight) enclosures P: Locked/Interlocked system or administrative control approved by the LSO P: LOTO procedure or other procedure approved by the LSO P: Affected areas are posted	L: BEU C: H R: IV
	Exposure to Class 3R lasers	L: A C: L R: III	No analysis needed.	L: A C: L R: III
	Exposure to Class 1 and 2 lasers	L: A C: N R: IV	No analysis needed.	L: A C: N R: IV

Radiological Hazard Consequences, derived from Figure C-1, “Example Qualitative Consequence Matrix”, DOE-HDBK-1163-2020.

Likelihood (L, of event)/year	Consequence (C, of event)/year	Risk (R, Qualitative Ranking)
A = Anticipated (L > 1.0E-02) **U** = Unlikely (1.0E-02> L >1.0E-04) **EU** = Extremely Unlikely (1.0E-04 > L >1.0E-06) **BEU** = Beyond Extremely Unlikely (1.0E-06> L)	**H** = High **M** = Moderate **L** = Low **N** = Negligible	**I** = situation (event) of major concern **II** = situation (event) of concern **III** = situation (event) of minor concern **IV** = situation (event) of minimal concern

Control(s) Type
- **P** = Preventive (reduce event occurrence likelihood)
- **M** = Mitigative (reduces event consequences)

Acronyms
- **MOI =** Maximally-exposed Offsite Individual
- **rem =** Roentgen equivalent man

C	Offsite (MOI)	Onsite-2 (co-located worker)	Onsite-1 (facility worker)
H	**C** ^{3} 25.0 rem	**C** ^{3} 100 rem	**C** ^{3} 100 rem
M	25.0 rem > **C** ^{3} 5 rem	100 rem **> C** ^{3} 25 rem	100 rem **> C** ^{3} 25 rem
L	5 rem > **C**	25 rem **> C**	25 rem **> C**
N	0.5 rem > **C**	5 rem **> C**	5 rem **> C**

Risk Matrix

Consequences	Likelihood A	Likelihood U	Likelihood EU	Likelihood BEU
H	I	I	II	III
M	II	II	III	IV
L	III	III	IV	IV
N	IV	IV	IV	IV

Table 2.3 Radiological – MOI Offsite

Hazard	Hazard Description	Baseline Qualitative Risk (without controls)	Preventative (P)/ Mitigative (M)	Residual Qualitative Risk (with controls)
Radioactive Water (RAW) Systems	Hazard: Personnel exposed to radioactive water exceeding regulatory levels	L: A C: H R: I	P: Postings intended to caution workers of area hazard. P: Radiological Work Permit prevents unauthorized personnel form areas where excessive residual radiation exists. P: Training for workers to identify and respond to the hazard M: Run Conditions to ensure total radiation levels are within expected parameters	L: BEU C: M R: IV
Radioactive Sources	*Hazard: There are no radioactive sources outside the MINOS Surface Building*	L: BEU C: N R: IV	No further analysis required.	L: BEU C: N R: IV
Radiation Generating Devices (RGDs)	*Hazard: There are no RGDs outside the MINOS Surface Building*	L: BEU C: N R: IV	No further analysis required.	L: BEU C: N R: IV
Non-ionizing Radiation Hazards	*Hazard: There are no non-ionizing radiation hazards outside the MINOS Surface Building*	L: BEU C: N R: IV	No further analysis required.	L: BEU C: N R: IV

Radiological Hazard Consequences, derived from Figure C-1, "Example Qualitative Consequence Matrix", DOE-HDBK-1163-2020.			
Likelihood (L, of event)/year **A** = Anticipated (L > 1.0E-02) **U** = Unlikely (1.0E-02> L >1.0E-04) **EU** = Extremely Unlikely (1.0E-04 > L >1.0E-06)	**Consequence (C, of event)/year** **H** = High **M** = Moderate **L** = Low	**Risk (R, Qualitative Ranking)** **I** = situation (event) of major concern **II** = situation (event) of concern **III** = situation (event) of minor concern	**Risk Matrix**

		Likelihood			
		A	U	EU	BEU
C	H	I	I	II	III

BEU = Beyond Extremely Unlikely (1.0E-06> L)	**N** = Negligible	**IV** = situation (event) of minimal concern	

	M	II	II	III	IV
	L	III	III	IV	IV
	N	IV	IV	IV	IV

Control(s) Type	**C**	**Offsite (MOI)**	**Onsite-2 (co-located worker)**	**Onsite-1 (facility worker)**
P = Preventive (reduce event occurrence likelihood)	**H**	**C** ³ 25.0 rem	**C** ³ 100 rem	**C** ³ 100 rem
M = Mitigative (reduces event consequences)	**M**	25.0 rem > **C** ³ 5 rem	100 rem **> C** ³ 25 rem	100 rem **> C** ³ 25 rem
Acronyms	**L**	5 rem > **C**	25 rem **> C**	25 rem **> C**
MOI = Maximally-exposed Offsite Individual	**N**	0.5 rem > **C**	5 rem **> C**	5 rem **> C**
rem = Roentgen equivalent man				

Table 2.4 Toxic Materials – Onsite 1 Facility Worker

Hazard	Hazard Description	Baseline Qualitative Risk (without controls)	Preventative (P)/ Mitigative (M)	Residual Qualitative Risk (with controls)
Lead		L: C: R:	See Section I Chapter 4	L: C: R:
Fluorinert & Its byproducts		L: C: R:	See Section I Chapter 4	L: C: R:

Chemical Hazard Consequences, derived from Figure C-1, "Example Qualitative Consequence Matrix", DOE-HDBK-1163-2020.

Likelihood (L, of event)/year	Consequence (C, of event)/year	Risk (R, Qualitative Ranking)
A = Anticipated (L > 1.0E-02) **U** = Unlikely (1.0E-02> L >1.0E-04) **EU** = Extremely Unlikely (1.0E-04 > L >1.0E-06) **BEU** = Beyond Extremely Unlikely (1.0E-06> L)	**H** = High **M** = Moderate **L** = Low **N** = Negligible	**I** = situation (event) of major concern **II** = situation (event) of concern **III** = situation (event) of minor concern **IV** = situation (event) of minimal concern

Control(s) Type

P = Preventive (reduce event occurrence likelihood)

M = Mitigative (reduces event consequences)

Acronyms

IDLH = Immediately Dangerous to Life and Health

MOI = Maximally-exposed Offsite Individual

PAC = Protective Action Criteria

PEL = Permissible Exposure Limit

TLV$_c$ = Threshold Limit Value (ceiling)

C	Offsite (MOI)	Onsite-2 (co-located worker)	Onsite-1 (facility worker)
H	**C** ^{3} PAC-2	**C** ^{3} PAC-3	**C** ^{3} IDLH
M	PAC-2 > **C** ^{3} PAC-1	PAC-3 **> C** ^{3} PAC-2	IDLH **> C** ^{3} PEL or TLV$_c$
L	PAC-1 > **C**	PAC-2 **> C**	PEL or TLV$_c$ **> C**
N	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level

Risk Matrix

Consequences	Likelihood A	Likelihood U	Likelihood EU	Likelihood BEU
H	I	I	II	III
M	II	II	III	IV
L	III	III	IV	IV
N	IV	IV	IV	IV

Table 2.5 Toxic Materials – Onsite 2 Co-located Worker

Hazard	Hazard Description	Baseline Qualitative Risk (without controls)	Preventative (P)/ Mitigative (M)	Residual Qualitative Risk (with controls)
Lead		L: C: R:	See Section I Chapter 4	L: C: R:
Fluorinert & Its byproducts		L: C: R:	See Section I Chapter 4	L: C: R:

Chemical Hazard Consequences, derived from Figure C-1, "Example Qualitative Consequence Matrix", DOE-HDBK-1163-2020.

Likelihood (L, of event)/year	Consequence (C, of event)/year	Risk (R, Qualitative Ranking)
A = Anticipated (L > 1.0E-02) **U** = Unlikely (1.0E-02> L >1.0E-04) **EU** = Extremely Unlikely (1.0E-04 > L >1.0E-06) **BEU** = Beyond Extremely Unlikely (1.0E-06> L)	**H** = High **M** = Moderate **L** = Low **N** = Negligible	**I** = situation (event) of major concern **II** = situation (event) of concern **III** = situation (event) of minor concern **IV** = situation (event) of minimal concern

Control(s) Type
- **P** = Preventive (reduce event occurrence likelihood)
- **M** = Mitigative (reduces event consequences)

Acronyms
- **IDLH** = Immediately Dangerous to Life and Health
- **MOI =** Maximally-exposed Offsite Individual
- **PAC** = Protective Action Criteria
- **PEL** = Permissible Exposure Limit
- **TLV_c =** Threshold Limit Value (ceiling)

C	Offsite (MOI)	Onsite-2 (co-located worker)	Onsite-1 (facility worker)
H	**C** ^{3} PAC-2	**C** ^{3} PAC-3	**C** ^{3} IDLH
M	PAC-2 > **C** ^{3} PAC-1	PAC-3 **> C** ^{3} PAC-2	IDLH **> C** ^{3} PEL or TLV_c
L	PAC-1 > **C**	PAC-2 **> C**	PEL or TLV_c **> C**
N	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level

Risk Matrix

Consequences	Likelihood: A	U	EU	BEU
H	I	I	II	III
M	II	II	III	IV
L	III	III	IV	IV
N	IV	IV	IV	IV

Table 2.6 Toxic Materials – MOI Offsite

Hazard	Hazard Description	Baseline Qualitative Risk (without controls)	Preventative (P)/ Mitigative (M)	Residual Qualitative Risk (with controls)
Lead	*Hazard: There are no lead hazards outside the MINOS Areas*	L: C: R:	See Section I Chapter 4	L: C: R:
Fluorinert & Its byproducts		L: C: R:	See Section I Chapter 4	L: C: R:

Chemical Hazard Consequences, derived from Figure C-1, "Example Qualitative Consequence Matrix", DOE-HDBK-1163-2020.

Likelihood (L, of event)/year
- **A** = Anticipated (L > 1.0E-02)
- **U** = Unlikely (1.0E-02> L >1.0E-04)
- **EU** = Extremely Unlikely (1.0E-04 > L >1.0E-06)
- **BEU** = Beyond Extremely Unlikely (1.0E-06> L)

Consequence (C, of event)/year
- **H** = High
- **M** = Moderate
- **L** = Low
- **N** = Negligible

Risk (R, Qualitative Ranking)
- **I** = situation (event) of major concern
- **II** = situation (event) of concern
- **III** = situation (event) of minor concern
- **IV** = situation (event) of minimal concern

Control(s) Type
- **P** = Preventive (reduce event occurrence likelihood)
- **M** = Mitigative (reduces event consequences)

Acronyms
- **IDLH** = Immediately Dangerous to Life and Health
- **MOI =** Maximally-exposed Offsite Individual
- **PAC** = Protective Action Criteria
- **PEL** = Permissible Exposure Limit
- **TLV$_c$ =** Threshold Limit Value (ceiling)

C	**Offsite (MOI)**	**Onsite-2 (co-located worker)**	**Onsite-1 (facility worker)**
H	**C** ^{3} PAC-2	**C** ^{3} PAC-3	**C** ^{3} IDLH
M	PAC-2 > **C** ^{3} PAC-1	PAC-3 **> C** ^{3} PAC-2	IDLH **> C** ^{3} PEL or TLV$_c$
L	PAC-1 > **C**	PAC-2 **> C**	PEL or TLV$_c$ **> C**
N	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level

Risk Matrix

Consequences	Likelihood: A	U	EU	BEU
H	I	I	II	III
M	II	II	III	IV
L	III	III	IV	IV
N	IV	IV	IV	IV

Table 2.7 Flammable and Combustible Materials – Onsite -1 Facility Worker

Hazard	Hazard Description	Baseline Qualitative Risk (without controls)	Preventative (P)/ Mitigative (M)	Residual Qualitative Risk (with controls)
Combustible materials (cables, Boxes, Paper, wood cribbing, etc.)	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:
Flammable Materials (Flammable gas, cleaning materials, etc.)	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:

Other Hazard Consequences, derived from Figure C-1, "Example Qualitative Consequence Matrix", DOE-HDBK-1163-2020.

Likelihood (L, of event)/year
- **A** = Anticipated (L > 1.0E-02)
- **U** = Unlikely (1.0E-02> L >1.0E-04)
- **EU** = Extremely Unlikely (1.0E-04 > L >1.0E-06)
- **BEU** = Beyond Extremely Unlikely (1.0E-06> L)

Consequence (C, of event)/year
- **H** = High
- **M** = Moderate
- **L** = Low
- **N** = Negligible

Risk (R, Qualitative Ranking)
- **I** = situation (event) of major concern
- **II** = situation (event) of concern
- **III** = situation (event) of minor concern
- **IV** = situation (event) of minimal concern

Control(s) Type
- **P** = Preventive (reduce event occurrence likelihood)
- **M** = Mitigative (reduces event consequences)

Acronyms
- **MOI** = Maximally-exposed Offsite Individual

C	Offsite (MOI)	Onsite-2 (co-located worker)	Onsite-1 (facility worker)
H	C [3] Irreversible, other serious effects, or symptoms which could impair an individual's ability to	C [3] Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.	C [3] Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.

Risk Matrix

Consequences \ Likelihood	A	U	EU	BEU
H	I	I	II	III
M	II	II	III	IV
L	III	III	IV	IV
N	IV	IV	IV	IV

		take protective action.			
	M	**C** ³ Mild, transient adverse effects.	**C** ³ Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	**C** ³ Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	
	L	Mild, transient adverse effects > **C**	Minor injuries; no hospitalization **> C**	Minor injuries; no hospitalization **> C**	
	N	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	

Table 2.8 Flammable and Combustible Materials – Onsite -2 Co-located Worker

Hazard	Hazard Description	Baseline Qualitative Risk (without controls)	Preventative (P)/ Mitigative (M)	Residual Qualitative Risk (with controls)
Combustible materials (cables, Boxes, Paper, wood cribbing, etc.)	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:
Flammable Materials (Flammable gas, cleaning materials, etc.)	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:

Other Hazard Consequences, derived from Figure C-1, "Example Qualitative Consequence Matrix", DOE-HDBK-1163-2020.

Likelihood (L, of event)/year
- **A** = Anticipated (L > 1.0E-02)
- **U** = Unlikely (1.0E-02> L >1.0E-04)
- **EU** = Extremely Unlikely (1.0E-04 > L >1.0E-06)
- **BEU** = Beyond Extremely Unlikely (1.0E-06> L)

Consequence (C, of event)/year
- **H** = High
- **M** = Moderate
- **L** = Low
- **N** = Negligible

Risk (R, Qualitative Ranking)
- **I** = situation (event) of major concern
- **II** = situation (event) of concern
- **III** = situation (event) of minor concern
- **IV** = situation (event) of minimal concern

Control(s) Type
- **P** = Preventive (reduce event occurrence likelihood)
- **M** = Mitigative (reduces event consequences)

Acronyms
- **MOI =** Maximally-exposed Offsite Individual

C	Offsite (MOI)	Onsite-2 (co-located worker)	Onsite-1 (facility worker)
H	C [3] Irreversible, other serious effects, or symptoms which could impair an individual's ability to	C [3] Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.	C [3] Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.

Risk Matrix

Consequences	Likelihood: A	U	EU	BEU
H	I	I	II	III
M	II	II	III	IV
L	III	III	IV	IV
N	IV	IV	IV	IV

		take protective action.			
	M	**C** ³ Mild, transient adverse effects.	**C** ³ Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	**C** ³ Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	
	L	Mild, transient adverse effects > **C**	Minor injuries; no hospitalization **> C**	Minor injuries; no hospitalization **> C**	
	N	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	

Table 2.9 Flammable and Combustible Materials – MOI Offsite

Hazard	Hazard Description	Baseline Qualitative Risk (without controls)	Preventative (P)/ Mitigative (M)	Residual Qualitative Risk (with controls)
Combustible materials (cables, Boxes, Paper, wood cribbing, etc.)	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:
Flammable Materials (Flammable gas, cleaning materials, etc.)	*Hazard:*	L: C: R:	See Section I Chapter 4 .	L: C: R:

Other Hazard Consequences, derived from Figure C-1, "Example Qualitative Consequence Matrix", DOE-HDBK-1163-2020.				
Likelihood (L, of event)/year **A** = Anticipated (L > 1.0E-02) **U** = Unlikely (1.0E-02> L >1.0E-04) **EU** = Extremely Unlikely (1.0E-04 > L >1.0E-06) **BEU** = Beyond Extremely Unlikely (1.0E-06> L)	**Consequence (C, of event)/year** **H** = High **M** = Moderate **L** = Low **N** = Negligible	**Risk (R, Qualitative Ranking)** **I** = situation (event) of major concern **II** = situation (event) of concern **III** = situation (event) of minor concern **IV** = situation (event) of minimal concern		
Control(s) Type **P** = Preventive (reduce event occurrence likelihood) **M** = Mitigative (reduces event consequences) **Acronyms** **MOI =** Maximally-exposed Offsite Individual	**C**	**Offsite (MOI)**	**Onsite-2 (co-located worker)**	**Onsite-1 (facility worker)**
	H	**C** [3] Irreversible, other serious effects, or symptoms which could impair an individual's ability to	**C** [3] Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.	**C** [3] Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.

Risk Matrix

Consequences	Likelihood: A	U	EU	BEU
H	I	I	II	III
M	II	II	III	IV
L	III	III	IV	IV
N	IV	IV	IV	IV

		take protective action.			
	M	**C** ^{3} Mild, transient adverse effects.	**C** ^{3} Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	**C** ^{3} Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	
	L	Mild, transient adverse effects > **C**	Minor injuries; no hospitalization **> C**	Minor injuries; no hospitalization **> C**	
	N	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	

Table 2.10 Electrical Energy – Onsite-1 Facility Worker

Hazard	Hazard Description	Baseline Qualitative Risk (without controls)	Preventative (P)/ Mitigative (M)	Residual Qualitative Risk (with controls)
High Voltage Exposure	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:
Low Voltage, High Current Exposure.		L: C: R:	See Section I Chapter 4	L: C: R:

Other Hazard Consequences, derived from Figure C-1, "Example Qualitative Consequence Matrix", DOE-HDBK-1163-2020.

Likelihood (L, of event)/year
- **A** = Anticipated (L > 1.0E-02)
- **U** = Unlikely (1.0E-02> L >1.0E-04)
- **EU** = Extremely Unlikely (1.0E-04 > L >1.0E-06)
- **BEU** = Beyond Extremely Unlikely (1.0E-06> L)

Consequence (C, of event)/year
- **H** = High
- **M** = Moderate
- **L** = Low
- **N** = Negligible

Risk (R, Qualitative Ranking)
- **I** = situation (event) of major concern
- **II** = situation (event) of concern
- **III** = situation (event) of minor concern
- **IV** = situation (event) of minimal concern

Control(s) Type
- **P** = Preventive (reduce event occurrence likelihood)
- **M** = Mitigative (reduces event consequences)

Acronyms
- **MOI =** Maximally-exposed Offsite Individual

C	Offsite (MOI)	Onsite-2 (co-located worker)	Onsite-1 (facility worker)
H	C [3] Irreversible, other serious effects, or symptoms which could impair an individual's ability to take protective action.	C [3] Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.	C [3] Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.
M	C [3] Mild, transient adverse effects.	C [3] Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	C [3] Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.

Risk Matrix

Consequences	Likelihood: A	U	EU	BEU
H	I	I	II	III
M	II	II	III	IV
L	III	III	IV	IV
N	IV	IV	IV	IV

	L	Mild, transient adverse effects > **C**	Minor injuries; no hospitalization **> C**	Minor injuries; no hospitalization **> C**	
	N	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	

Table 2.11 Electrical Energy Onsite-2 Co-located Worker

Hazard	Hazard Description	Baseline Qualitative Risk (without controls)	Preventative (P)/ Mitigative (M)	Residual Qualitative Risk (with controls)
High Voltage Exposure	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:
Low Voltage, High Current Exposure.	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:

Other Hazard Consequences, derived from Figure C-1, "Example Qualitative Consequence Matrix", DOE-HDBK-1163-2020.

Likelihood (L, of event)/year
- **A** = Anticipated (L > 1.0E-02)
- **U** = Unlikely (1.0E-02> L >1.0E-04)
- **EU** = Extremely Unlikely (1.0E-04 > L >1.0E-06)
- **BEU** = Beyond Extremely Unlikely (1.0E-06> L)

Consequence (C, of event)/year
- **H** = High
- **M** = Moderate
- **L** = Low
- **N** = Negligible

Risk (R, Qualitative Ranking)
- **I** = situation (event) of major concern
- **II** = situation (event) of concern
- **III** = situation (event) of minor concern
- **IV** = situation (event) of minimal concern

Control(s) Type
- **P** = Preventive (reduce event occurrence likelihood)
- **M** = Mitigative (reduces event consequences)

Acronyms
- **MOI =** Maximally-exposed Offsite Individual

C	Offsite (MOI)	Onsite-2 (co-located worker)	Onsite-1 (facility worker)
H	C [3] Irreversible, other serious effects, or symptoms which could impair an individual's ability to take protective action.	C [3] Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.	C [3] Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.
M	C [3] Mild, transient adverse effects.	C [3] Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	C [3] Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.

Risk Matrix

Consequences	Likelihood: A	U	EU	BEU
H	I	I	II	III
M	II	II	III	IV
L	III	III	IV	IV
N	IV	IV	IV	IV

	L	Mild, transient adverse effects > **C**	Minor injuries; no hospitalization **> C**	Minor injuries; no hospitalization **> C**	
	N	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	

Table 2.12 Electrical Energy – MOI Offsite

Hazard	Hazard Description	Baseline Qualitative Risk (without controls)	Preventative (P)/ Mitigative (M)	Residual Qualitative Risk (with controls)
High Voltage Exposure	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:
Low Voltage, High Current Exposure.	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:

Other Hazard Consequences, derived from Figure C-1, "Example Qualitative Consequence Matrix", DOE-HDBK-1163-2020.

Likelihood (L, of event)/year
- **A** = Anticipated (L > 1.0E-02)
- **U** = Unlikely (1.0E-02> L >1.0E-04)
- **EU** = Extremely Unlikely (1.0E-04 > L >1.0E-06)
- **BEU** = Beyond Extremely Unlikely (1.0E-06> L)

Consequence (C, of event)/year
- **H** = High
- **M** = Moderate
- **L** = Low
- **N** = Negligible

Risk (R, Qualitative Ranking)
- **I** = situation (event) of major concern
- **II** = situation (event) of concern
- **III** = situation (event) of minor concern
- **IV** = situation (event) of minimal concern

Risk Matrix

Consequences	Likelihood A	U	EU	BEU
H	I	I	II	III
M	II	II	III	IV
L	III	III	IV	IV
N	IV	IV	IV	IV

Control(s) Type
- **P** = Preventive (reduce event occurrence likelihood)
- **M** = Mitigative (reduces event consequences)

Acronyms
- **MOI =** Maximally-exposed Offsite Individual

C	Offsite (MOI)	Onsite-2 (co-located worker)	Onsite-1 (facility worker)
H	**C** ³ Irreversible, other serious effects, or symptoms which could impair an individual's ability to take protective action.	**C** ³ Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.	**C** ³ Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.
M	**C** ³ Mild, transient adverse effects.	**C** ³ Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	**C** ³ Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.

	L	Mild, transient adverse effects > **C**	Minor injuries; no hospitalization **> C**	Minor injuries; no hospitalization **> C**	
	N	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	

Table 2.13 Thermal Energy – Onsite-1 Facility Worker

Hazard	Hazard Description	Baseline Qualitative Risk (without controls)	Preventative (P)/ Mitigative (M)	Residual Qualitative Risk (with controls)
Bakeout	*Hazard: MAGIS-100 will do a bakeout of their tower vacuum pipe in the MINOS shaft*	L: C: R:	See Section I Chapter 4	L: C: R:
Cryogenics	*Hazard: Liquid nitrogen, liquid helium, in cryogenic vessels and piping systems in the SENSEI, NEXUS, and QUIET enclosures* *Liquid argon (Lar) used by ArgonCube*	L: C: R:	See Section I Chapter 4	L: C: R:

Other Hazard Consequences, derived from Figure C-1, "Example Qualitative Consequence Matrix", DOE-HDBK-1163-2020.

Likelihood (L, of event)/year
- **A** = Anticipated (L > 1.0E-02)
- **U** = Unlikely (1.0E-02> L >1.0E-04)
- **EU** = Extremely Unlikely (1.0E-04 > L >1.0E-06)
- **BEU** = Beyond Extremely Unlikely (1.0E-06> L)

Consequence (C, of event)/year
- **H** = High
- **M** = Moderate
- **L** = Low
- **N** = Negligible

Risk (R, Qualitative Ranking)
- **I** = situation (event) of major concern
- **II** = situation (event) of concern
- **III** = situation (event) of minor concern
- **IV** = situation (event) of minimal concern

Control(s) Type
- **P** = Preventive (reduce event occurrence likelihood)
- **M** = Mitigative (reduces event consequences)

Acronyms
- **MOI =** Maximally-exposed Offsite Individual

C	Offsite (MOI)	Onsite-2 (co-located worker)	Onsite-1 (facility worker)
H	C [3] Irreversible, other serious effects, or symptoms which could impair an	C [3] Prompt worker fatality or acute injury that is immediately life-	C [3] Prompt worker fatality or acute injury that is immediately life-

Risk Matrix

Consequences		Likelihood A	U	EU	BEU
	H	I	I	II	III
	M	II	II	III	IV
	L	III	III	IV	IV
	N	IV	IV	IV	IV

		individual's ability to take protective action.	threatening or permanently disabling.	threatening or permanently disabling.	
	M	**C** ^{3} Mild, transient adverse effects.	**C** ^{3} Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	**C** ^{3} Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	
	L	Mild, transient adverse effects > **C**	Minor injuries; no hospitalization **> C**	Minor injuries; no hospitalization **> C**	
	N	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	

Table 2.14 Thermal Energy – Onsite-2 Co-located Worker

Hazard	Hazard Description	Baseline Qualitative Risk (without controls)	Preventative (P)/ Mitigative (M)	Residual Qualitative Risk (with controls)
Bakeout	*Hazard: MAGIS-100 will do a bakeout of their tower vacuum pipe in the MINOS shaft*	L: C: R:	See Section I Chapter 4	L: C: R:
Cryogenics	*Hazard: Liquid nitrogen, liquid helium, in cryogenic vessels and piping systems in the SENSEI, NEXUS, and QUIET enclosures* *Liquid argon (Lar) used by ArgonCube*	L: C: R:	See Section I Chapter 4	L: C: R:

Other Hazard Consequences, derived from Figure C-1, "Example Qualitative Consequence Matrix", DOE-HDBK-1163-2020.

Likelihood (L, of event)/year	Consequence (C, of event)/year	Risk (R, Qualitative Ranking)
A = Anticipated (L > 1.0E-02) **U** = Unlikely (1.0E-02> L >1.0E-04) **EU** = Extremely Unlikely (1.0E-04 > L >1.0E-06) **BEU** = Beyond Extremely Unlikely (1.0E-06> L)	**H** = High **M** = Moderate **L** = Low **N** = Negligible	**I** = situation (event) of major concern **II** = situation (event) of concern **III** = situation (event) of minor concern **IV** = situation (event) of minimal concern

Control(s) Type
P = Preventive (reduce event occurrence likelihood)
M = Mitigative (reduces event consequences)
Acronyms
MOI = Maximally-exposed Offsite Individual

C	Offsite (MOI)	Onsite-2 (co-located worker)	Onsite-1 (facility worker)
H	C [3] Irreversible, other serious effects, or symptoms which could impair an individual's ability to	C [3] Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.	C [3] Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.

Risk Matrix

Consequences \ Likelihood	A	U	EU	BEU
H	I	I	II	III
M	II	II	III	IV
L	III	III	IV	IV
N	IV	IV	IV	IV

		take protective action.			
	M	**C** ³ Mild, transient adverse effects.	**C** ³ Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	**C** ³ Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	
	L	Mild, transient adverse effects > **C**	Minor injuries; no hospitalization **> C**	Minor injuries; no hospitalization **> C**	
	N	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	

Table 2.15 Thermal Energy – MOI Offsite

Hazard	Hazard Description	Baseline Qualitative Risk (without controls)	Preventative (P)/ Mitigative (M)	Residual Qualitative Risk (with controls)
Bakeout	*Hazard: MAGIS-100 will do a bakeout of their tower vacuum pipe in the MINOS shaft*	L: C: R:	See Section I Chapter 4	L: C: R:
Cryogenics	*Hazard: Liquid nitrogen, liquid helium, in cryogenic vessels and piping systems in the SENSEI, NEXUS, and QUIET enclosures* *Liquid argon (Lar) used by ArgonCube*	L: C: R:	See Section I Chapter 4	L: C: R:

Other Hazard Consequences, derived from Figure C-1, "Example Qualitative Consequence Matrix", DOE-HDBK-1163-2020.

Likelihood (L, of event)/year	Consequence (C, of event)/year	Risk (R, Qualitative Ranking)
A = Anticipated (L > 1.0E-02) **U** = Unlikely (1.0E-02> L >1.0E-04) **EU** = Extremely Unlikely (1.0E-04 > L >1.0E-06) **BEU** = Beyond Extremely Unlikely (1.0E-06> L)	**H** = High **M** = Moderate **L** = Low **N** = Negligible	**I** = situation (event) of major concern **II** = situation (event) of concern **III** = situation (event) of minor concern **IV** = situation (event) of minimal concern

Risk Matrix

Consequences	Likelihood: A	U	EU	BEU
H	I	I	II	III
M	II	II	III	IV
L	III	III	IV	IV
N	IV	IV	IV	IV

Control(s) Type	C	Offsite (MOI)	Onsite-2 (co-located worker)	Onsite-1 (facility worker)
P = Preventive (reduce event occurrence likelihood)	**H**	**C** ³ Irreversible, other serious effects, or	**C** ³ Prompt worker fatality or acute injury that is	**C** ³ Prompt worker fatality or acute injury that is

M = Mitigative (reduces event consequences) **Acronyms** **MOI =** Maximally-exposed Offsite Individual		symptoms which could impair an individual's ability to take protective action.	immediately life-threatening or permanently disabling.	immediately life-threatening or permanently disabling.	
	M	**C** ^{3} Mild, transient adverse effects.	**C** ^{3} Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	**C** ^{3} Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	
	L	Mild, transient adverse effects > **C**	Minor injuries; no hospitalization **> C**	Minor injuries; no hospitalization **> C**	
	N	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	

Table 2.16 Kinetic Energy – Onsite-1 Facility Worker

Hazard	Hazard Description	Baseline Qualitative Risk (without controls)	Preventative (P)/ Mitigative (M)	Residual Qualitative Risk (with controls)
Power Tools	*Hazard*	L: C: R:	See Section I Chapter 4	L: C: R:
Pumps and Motors	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:
Mobile Shielding	*Hazard: NEXUS Polypropylene shield runs on rails*	L: C: R:	See Section I Chapter 4	L: C: R:

Other Hazard Consequences, derived from Figure C-1, "Example Qualitative Consequence Matrix", DOE-HDBK-1163-2020.

Likelihood (L, of event)/year	Consequence (C, of event)/year	Risk (R, Qualitative Ranking)
A = Anticipated (L > 1.0E-02) **U** = Unlikely (1.0E-02> L >1.0E-04) **EU** = Extremely Unlikely (1.0E-04 > L >1.0E-06) **BEU** = Beyond Extremely Unlikely (1.0E-06> L)	**H** = High **M** = Moderate **L** = Low **N** = Negligible	**I** = situation (event) of major concern **II** = situation (event) of concern **III** = situation (event) of minor concern **IV** = situation (event) of minimal concern

Risk Matrix

Consequences		Likelihood			
		A	U	EU	BEU
	H	I	I	II	III
	M	II	II	III	IV
	L	III	III	IV	IV
	N	IV	IV	IV	IV

Control(s) Type	C	Offsite (MOI)	Onsite-2 (co-located worker)	Onsite-1 (facility worker)
P = Preventive (reduce event occurrence likelihood) **M** = Mitigative (reduces event consequences) **Acronyms** **MOI** = Maximally-exposed Offsite Individual	H	C^3 Irreversible, other serious effects, or symptoms which could impair an individual's ability to take protective action.	C^3 Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.	C^3 Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.

	M	**C** ³ Mild, transient adverse effects.	**C** ³ Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	**C** ³ Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	
	L	Mild, transient adverse effects > **C**	Minor injuries; no hospitalization **> C**	Minor injuries; no hospitalization **> C**	
	N	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	

Table 2.17 Kinetic Energy – Onsite-2 Co-located Worker

Hazard	Hazard Description	Baseline Qualitative Risk (without controls)	Preventative (P)/ Mitigative (M)	Residual Qualitative Risk (with controls)
Power Tools	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:
Pumps and Motors	*Hazard:*	L: C: R:	See Section I Chapter 4	L: E C: R:
Mobile Shielding	*Hazard: NEXUS Polypropylene shield runs on rails*	L: C: R:	See Section I Chapter 4	L: C: R:

Other Hazard Consequences, derived from Figure C-1, "Example Qualitative Consequence Matrix", DOE-HDBK-1163-2020.

Likelihood (L, of event)/year
- **A** = Anticipated (L > 1.0E-02)
- **U** = Unlikely (1.0E-02> L >1.0E-04)
- **EU** = Extremely Unlikely (1.0E-04 > L >1.0E-06)
- **BEU** = Beyond Extremely Unlikely (1.0E-06> L)

Consequence (C, of event)/year
- **H** = High
- **M** = Moderate
- **L** = Low
- **N** = Negligible

Risk (R, Qualitative Ranking)
- **I** = situation (event) of major concern
- **II** = situation (event) of concern
- **III** = situation (event) of minor concern
- **IV** = situation (event) of minimal concern

Control(s) Type
- **P** = Preventive (reduce event occurrence likelihood)
- **M** = Mitigative (reduces event consequences)

Acronyms
- **MOI =** Maximally-exposed Offsite Individual

C	Offsite (MOI)	Onsite-2 (co-located worker)	Onsite-1 (facility worker)
H	C ³ Irreversible, other serious effects, or symptoms which could impair an individual's ability to take protective action.	C ³ Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.	C ³ Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.

Risk Matrix

Consequences	Likelihood: A	U	EU	BEU
H	I	I	II	III
M	II	II	III	IV
L	III	III	IV	IV
N	IV	IV	IV	IV

	M	**C** ^{3} Mild, transient adverse effects.	**C** ^{3} Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	**C** ^{3} Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	
	L	Mild, transient adverse effects > **C**	Minor injuries; no hospitalization **> C**	Minor injuries; no hospitalization **> C**	

Table 2.18 Kinetic Energy – MOI Offsite

Hazard	Hazard Description	Baseline Qualitative Risk (without controls)	Preventative (P)/ Mitigative (M)	Residual Qualitative Risk (with controls)
Power Tools	*Hazard:.*	L: C: R:	See Section I Chapter 4	L: C: R:
Pumps and Motors	*Hazard:.*	L: C: R:	See Section I Chapter 4	L: C: R:
Mobile Shielding	*Hazard: NEXUS Polypropylene shield runs on rails*	L: C: R:	See Section I Chapter 4	L: C: R:

Other Hazard Consequences, derived from Figure C-1, "Example Qualitative Consequence Matrix", DOE-HDBK-1163-2020.

Likelihood (L, of event)/year
- **A** = Anticipated (L > 1.0E-02)
- **U** = Unlikely (1.0E-02> L >1.0E-04)
- **EU** = Extremely Unlikely (1.0E-04 > L >1.0E-06)
- **BEU** = Beyond Extremely Unlikely (1.0E-06> L)

Consequence (C, of event)/year
- **H** = High
- **M** = Moderate
- **L** = Low
- **N** = Negligible

Risk (R, Qualitative Ranking)
- **I** = situation (event) of major concern
- **II** = situation (event) of concern
- **III** = situation (event) of minor concern
- **IV** = situation (event) of minimal concern

Control(s) Type
- **P** = Preventive (reduce event occurrence likelihood)
- **M** = Mitigative (reduces event consequences)

Acronyms
- **MOI =** Maximally-exposed Offsite Individual

C	Offsite (MOI)	Onsite-2 (co-located worker)	Onsite-1 (facility worker)
H	C [3] Irreversible, other serious effects, or symptoms which could impair an individual's ability to	C [3] Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.	C [3] Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.

Risk Matrix

Consequences \ Likelihood	A	U	EU	BEU
H	I	I	II	III
M	II	II	III	IV
L	III	III	IV	IV
N	IV	IV	IV	IV

		take protective action.			
	M	**C** ³ Mild, transient adverse effects.	**C** ³ Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	**C** ³ Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	
	L	Mild, transient adverse effects > **C**	Minor injuries; no hospitalization **> C**	Minor injuries; no hospitalization **> C**	

Table 2.19 Potential Energy – Onsite-1 Facility Worker

Hazard	Hazard Description	Baseline Qualitative Risk (without controls)	Preventative (P)/ Mitigative (M)	Residual Qualitative Risk (with controls)
Crane Operations	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:
Compressed Gasses	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:
Vacuum/ Pressure Vessels	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:
Vacuum Pumps	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:
Material Handling	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:

Other Hazard Consequences, derived from Figure C-1, "Example Qualitative Consequence Matrix", DOE-HDBK-1163-2020.

Likelihood (L, of event)/year	Consequence (C, of event)/year	Risk (R, Qualitative Ranking)
A = Anticipated (L > 1.0E-02) **U** = Unlikely (1.0E-02> L >1.0E-04) **EU** = Extremely Unlikely (1.0E-04 > L >1.0E-06) **BEU** = Beyond Extremely Unlikely (1.0E-06> L)	**H** = High **M** = Moderate **L** = Low **N** = Negligible	**I** = situation (event) of major concern **II** = situation (event) of concern **III** = situation (event) of minor concern **IV** = situation (event) of minimal concern

Control(s) Type	C	Offsite (MOI)	Onsite-2 (co-located worker)	Onsite-1 (facility worker)
P = Preventive (reduce event occurrence likelihood) **M** = Mitigative (reduces event consequences)	H	C^{3} Irreversible, other serious effects, or	C^{3} Prompt worker fatality or acute injury that is	C^{3} Prompt worker fatality or acute injury that is

Risk Matrix

Consequences	Likelihood: A	U	EU	BEU
H	I	I	II	III
M	II	II	III	IV
L	III	III	IV	IV
N	IV	IV	IV	IV

Acronyms **MOI =** Maximally-exposed Offsite Individual		symptoms which could impair an individual's ability to take protective action.	immediately life-threatening or permanently disabling.	immediately life-threatening or permanently disabling.	
	M	**C** ^{3} Mild, transient adverse effects.	**C** ^{3} Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	**C** ^{3} Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	
	L	Mild, transient adverse effects > **C**	Minor injuries; no hospitalization **> C**	Minor injuries; no hospitalization **> C**	
	N	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	

Table 2.20 Potential Energy – Onsite-2 Co-located Worker

Hazard	Hazard Description	Baseline Qualitative Risk (without controls)	Preventative (P)/ Mitigative (M)	Residual Qualitative Risk (with controls)
Crane Operations	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R: I
Compressed Gasses	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:
Vacuum/ Pressure Vessels	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:
Vacuum Pumps	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:

Other Hazard Consequences, derived from Figure C-1, "Example Qualitative Consequence Matrix", DOE-HDBK-1163-2020.

Likelihood (L, of event)/year
- **A** = Anticipated (L > 1.0E-02)
- **U** = Unlikely (1.0E-02> L >1.0E-04)
- **EU** = Extremely Unlikely (1.0E-04 > L >1.0E-06)
- **BEU** = Beyond Extremely Unlikely (1.0E-06> L)

Consequence (C, of event)/year
- **H** = High
- **M** = Moderate
- **L** = Low
- **N** = Negligible

Risk (R, Qualitative Ranking)
- **I** = situation (event) of major concern
- **II** = situation (event) of concern
- **III** = situation (event) of minor concern
- **IV** = situation (event) of minimal concern

Control(s) Type
- **P** = Preventive (reduce event occurrence likelihood)
- **M** = Mitigative (reduces event consequences)

Acronyms
- **MOI =** Maximally-exposed Offsite Individual

C	Offsite (MOI)	Onsite-2 (co-located worker)	Onsite-1 (facility worker)
H	C ³ Irreversible, other serious effects, or symptoms which could impair an individual's ability to	C ³ Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.	C ³ Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.

Risk Matrix

Consequences	Likelihood: A	U	EU	BEU
H	I	I	II	III
M	II	II	III	IV
L	III	III	IV	IV
N	IV	IV	IV	IV

		take protective action.			
	M	**C** ³ Mild, transient adverse effects.	**C** ³ Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	**C** ³ Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	
	L	Mild, transient adverse effects > **C**	Minor injuries; no hospitalization **> C**	Minor injuries; no hospitalization **> C**	
	N	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	

Table 2.21 Potential Energy – MOI Offsite

Hazard	Hazard Description	Baseline Qualitative Risk (without controls)	Preventative (P)/ Mitigative (M)	Residual Qualitative Risk (with controls)
Crane Operations	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:
Compressed Gasses	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:
Vacuum/ Pressure Vessels	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:
Vacuum Pumps	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:

Other Hazard Consequences, derived from Figure C-1, "Example Qualitative Consequence Matrix", DOE-HDBK-1163-2020.

Likelihood (L, of event)/year
- **A** = Anticipated (L > 1.0E-02)
- **U** = Unlikely (1.0E-02> L >1.0E-04)
- **EU** = Extremely Unlikely (1.0E-04 > L >1.0E-06)
- **BEU** = Beyond Extremely Unlikely (1.0E-06> L)

Consequence (C, of event)/year
- **H** = High
- **M** = Moderate
- **L** = Low
- **N** = Negligible

Risk (R, Qualitative Ranking)
- **I** = situation (event) of major concern
- **II** = situation (event) of concern
- **III** = situation (event) of minor concern
- **IV** = situation (event) of minimal concern

Risk Matrix

Consequences	Likelihood A	Likelihood U	Likelihood EU	Likelihood BEU
H	I	I	II	III
M	II	II	III	IV
L	III	III	IV	IV
N	IV	IV	IV	IV

Control(s) Type
- **P** = Preventive (reduce event occurrence likelihood)
- **M** = Mitigative (reduces event consequences)

Acronyms
- **MOI =** Maximally-exposed Offsite Individual

C	Offsite (MOI)	Onsite-2 (co-located worker)	Onsite-1 (facility worker)
H	C [3] Irreversible, other serious effects, or symptoms which could impair an individual's ability to	C [3] Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.	C [3] Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.

		take protective action.			
	M	**C** ³ Mild, transient adverse effects.	**C** ³ Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	**C** ³ Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	
	L	Mild, transient adverse effects > **C**	Minor injuries; no hospitalization **> C**	Minor injuries; no hospitalization **> C**	
	N	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	

Table 2.22 Other hazards – Onsite-1 Facility Worker

Hazard	Hazard Description	Baseline Qualitative Risk (without controls)	Preventative (P)/ Mitigative (M)	Residual Qualitative Risk (with controls)
Confined Space	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:

Other Hazard Consequences, derived from Figure C-1, "Example Qualitative Consequence Matrix", DOE-HDBK-1163-2020.

Likelihood (L, of event)/year
- **A** = Anticipated (L > 1.0E-02)
- **U** = Unlikely (1.0E-02> L >1.0E-04)
- **EU** = Extremely Unlikely (1.0E-04 > L >1.0E-06)
- **BEU** = Beyond Extremely Unlikely (1.0E-06> L)

Consequence (C, of event)/year
- **H** = High
- **M** = Moderate
- **L** = Low
- **N** = Negligible

Risk (R, Qualitative Ranking)
- **I** = situation (event) of major concern
- **II** = situation (event) of concern
- **III** = situation (event) of minor concern
- **IV** = situation (event) of minimal concern

Control(s) Type
- **P** = Preventive (reduce event occurrence likelihood)
- **M** = Mitigative (reduces event consequences)

Acronyms
- **MOI =** Maximally-exposed Offsite Individual

C	Offsite (MOI)	Onsite-2 (co-located worker)	Onsite-1 (facility worker)
H	**C** ³ Irreversible, other serious effects, or symptoms which could impair an individual's ability to take protective action.	**C** ³ Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.	**C** ³ Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.
M	**C** ³ Mild, transient adverse effects.	**C** ³ Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	**C** ³ Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.
L	Mild, transient adverse effects > **C**	Minor injuries; no hospitalization **> C**	Minor injuries; no hospitalization **> C**

Risk Matrix

Consequences	Likelihood: A	U	EU	BEU
H	I	I	II	III
M	II	II	III	IV
L	III	III	IV	IV
N	IV	IV	IV	IV

	N	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	

Table 2.23 Other hazards – Onsite-2 Co-located Worker

Hazard	Hazard Description	Baseline Qualitative Risk (without controls)	Preventative (P)/ Mitigative (M)	Residual Qualitative Risk (with controls)
Confined Space	*Hazard:*	L: C: R:	See Section I Chapter 4 .	L: C: R:

Other Hazard Consequences, derived from Figure C-1, "Example Qualitative Consequence Matrix", DOE-HDBK-1163-2020.

Likelihood (L, of event)/year
- **A** = Anticipated (L > 1.0E-02)
- **U** = Unlikely (1.0E-02> L >1.0E-04)
- **EU** = Extremely Unlikely (1.0E-04 > L >1.0E-06)
- **BEU** = Beyond Extremely Unlikely (1.0E-06> L)

Consequence (C, of event)/year
- **H** = High
- **M** = Moderate
- **L** = Low
- **N** = Negligible

Risk (R, Qualitative Ranking)
- **I** = situation (event) of major concern
- **II** = situation (event) of concern
- **III** = situation (event) of minor concern
- **IV** = situation (event) of minimal concern

Risk Matrix

Consequences	Likelihood: A	U	EU	BEU
H	I	I	II	III
M	II	II	III	IV
L	III	III	IV	IV
N	IV	IV	IV	IV

Control(s) Type
- **P** = Preventive (reduce event occurrence likelihood)
- **M** = Mitigative (reduces event consequences)

Acronyms
- **MOI =** Maximally-exposed Offsite Individual

C	Offsite (MOI)	Onsite-2 (co-located worker)	Onsite-1 (facility worker)
H	**C** ³ Irreversible, other serious effects, or symptoms which could impair an individual's ability to take protective action.	**C** ³ Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.	**C** ³ Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.
M	**C** ³ Mild, transient adverse effects.	**C** ³ Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	**C** ³ Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.
L	Mild, transient adverse effects > **C**	Minor injuries; no hospitalization **> C**	Minor injuries; no hospitalization **> C**

	N	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	

Table 2.24 Other hazards – MOI Offsite

Hazard	Hazard Description	Baseline Qualitative Risk (without controls)	Preventative (P)/ Mitigative (M)	Residual Qualitative Risk (with controls)
Confined Spaces	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:

Other Hazard Consequences, derived from Figure C-1, "Example Qualitative Consequence Matrix", DOE-HDBK-1163-2020.

Likelihood (L, of event)/year
- **A** = Anticipated (L > 1.0E-02)
- **U** = Unlikely (1.0E-02> L >1.0E-04)
- **EU** = Extremely Unlikely (1.0E-04 > L >1.0E-06)
- **BEU** = Beyond Extremely Unlikely (1.0E-06> L)

Consequence (C, of event)/year
- **H** = High
- **M** = Moderate
- **L** = Low
- **N** = Negligible

Risk (R, Qualitative Ranking)
- **I** = situation (event) of major concern
- **II** = situation (event) of concern
- **III** = situation (event) of minor concern
- **IV** = situation (event) of minimal concern

Risk Matrix

Consequences	Likelihood: A	U	EU	BEU
H	I	I	II	III
M	II	II	III	IV
L	III	III	IV	IV
N	IV	IV	IV	IV

Control(s) Type
- **P** = Preventive (reduce event occurrence likelihood)
- **M** = Mitigative (reduces event consequences)

Acronyms
- **MOI =** Maximally-exposed Offsite Individual

C	Offsite (MOI)	Onsite-2 (co-located worker)	Onsite-1 (facility worker)
H	C [3] Irreversible, other serious effects, or symptoms which could impair an individual's ability to take protective action.	C [3] Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.	C [3] Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.
M	C [3] Mild, transient adverse effects.	C [3] Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	C [3] Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.
L	Mild, transient adverse effects > **C**	Minor injuries; no hospitalization **> C**	Minor injuries; no hospitalization **> C**

	N	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	

Table 2.25 Access & Egress – Onsite-1 Facility Worker

Hazard	Hazard Description	Baseline Qualitative Risk (without controls)	Preventative (P)/ Mitigative (M)	Residual Qualitative Risk (with controls)
Life Safety Egress	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:
Working at Heights	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:

Other Hazard Consequences, derived from Figure C-1, "Example Qualitative Consequence Matrix", DOE-HDBK-1163-2020.

Likelihood (L, of event)/year
- **A** = Anticipated (L > 1.0E-02)
- **U** = Unlikely (1.0E-02> L >1.0E-04)
- **EU** = Extremely Unlikely (1.0E-04 > L >1.0E-06)
- **BEU** = Beyond Extremely Unlikely (1.0E-06> L)

Consequence (C, of event)/year
- **H** = High
- **M** = Moderate
- **L** = Low
- **N** = Negligible

Risk (R, Qualitative Ranking)
- **I** = situation (event) of major concern
- **II** = situation (event) of concern
- **III** = situation (event) of minor concern
- **IV** = situation (event) of minimal concern

Control(s) Type
- **P** = Preventive (reduce event occurrence likelihood)
- **M** = Mitigative (reduces event consequences)

Acronyms
- **MOI =** Maximally-exposed Offsite Individual

C	Offsite (MOI)	Onsite-2 (co-located worker)	Onsite-1 (facility worker)
H	C [3] Irreversible, other serious effects, or symptoms which could impair an individual's ability to take protective action.	C [3] Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.	C [3] Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.
M	C [3] Mild, transient adverse effects.	C [3] Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	C [3] Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.

Risk Matrix

Consequences	Likelihood A	U	EU	BEU
H	I	I	II	III
M	II	II	III	IV
L	III	III	IV	IV
N	IV	IV	IV	IV

	L	Mild, transient adverse effects > **C**	Minor injuries; no hospitalization **> C**	Minor injuries; no hospitalization **> C**	
	N	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	

Table 2.26 Access & Egress – Onsite-2 Co-located Worker

Hazard	Hazard Description	Baseline Qualitative Risk (without controls)	Preventative (P)/ Mitigative (M)	Residual Qualitative Risk (with controls)
Life Safety Egress	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:
Working at Heights	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:

Other Hazard Consequences, derived from Figure C-1, "Example Qualitative Consequence Matrix", DOE-HDBK-1163-2020.

Likelihood (L, of event)/year
- **A** = Anticipated (L > 1.0E-02)
- **U** = Unlikely (1.0E-02> L >1.0E-04)
- **EU** = Extremely Unlikely (1.0E-04 > L >1.0E-06)
- **BEU** = Beyond Extremely Unlikely (1.0E-06> L)

Consequence (C, of event)/year
- **H** = High
- **M** = Moderate
- **L** = Low
- **N** = Negligible

Risk (R, Qualitative Ranking)
- **I** = situation (event) of major concern
- **II** = situation (event) of concern
- **III** = situation (event) of minor concern
- **IV** = situation (event) of minimal concern

Control(s) Type
- **P** = Preventive (reduce event occurrence likelihood)
- **M** = Mitigative (reduces event consequences)

Acronyms
- **MOI =** Maximally-exposed Offsite Individual

C	Offsite (MOI)	Onsite-2 (co-located worker)	Onsite-1 (facility worker)
H	C [3] Irreversible, other serious effects, or symptoms which could impair an individual's ability to take protective action.	C [3] Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.	C [3] Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.
M	C [3] Mild, transient adverse effects.	C [3] Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	C [3] Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.

Risk Matrix

Consequences	Likelihood: A	U	EU	BEU
H	I	I	II	III
M	II	II	III	IV
L	III	III	IV	IV
N	IV	IV	IV	IV

	L	Mild, transient adverse effects > **C**	Minor injuries; no hospitalization **> C**	Minor injuries; no hospitalization **> C**	
	N	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	

Table 2.27 Access & Egress – MOI Offsite

Hazard	Hazard Description	Baseline Qualitative Risk (without controls)	Preventative (P)/ Mitigative (M)	Residual Qualitative Risk (with controls)
Life Safety Egress	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:
Working at Heights	*Hazard:*	L: C: R:	See Section I Chapter 4	L: C: R:

Other Hazard Consequences, derived from Figure C-1, "Example Qualitative Consequence Matrix", DOE-HDBK-1163-2020.

Likelihood (L, of event)/year
- **A** = Anticipated (L > 1.0E-02)
- **U** = Unlikely (1.0E-02> L >1.0E-04)
- **EU** = Extremely Unlikely (1.0E-04 > L >1.0E-06)
- **BEU** = Beyond Extremely Unlikely (1.0E-06> L)

Consequence (C, of event)/year
- **H** = High
- **M** = Moderate
- **L** = Low
- **N** = Negligible

Risk (R, Qualitative Ranking)
- **I** = situation (event) of major concern
- **II** = situation (event) of concern
- **III** = situation (event) of minor concern
- **IV** = situation (event) of minimal concern

Risk Matrix

Consequences \ Likelihood	A	U	EU	BEU
H	I	I	II	III
M	II	II	III	IV
L	III	III	IV	IV
N	IV	IV	IV	IV

Control(s) Type
- **P** = Preventive (reduce event occurrence likelihood)
- **M** = Mitigative (reduces event consequences)

Acronyms
- **MOI =** Maximally-exposed Offsite Individual

C	Offsite (MOI)	Onsite-2 (co-located worker)	Onsite-1 (facility worker)
H	**C** ³ Irreversible, other serious effects, or symptoms which could impair an individual's ability to take protective action.	**C** ³ Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.	**C** ³ Prompt worker fatality or acute injury that is immediately life-threatening or permanently disabling.
M	**C** ³ Mild, transient adverse effects.	**C** ³ Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.	**C** ³ Serious injury, no immediate loss of life no permanent disabilities; hospitalization required.

	L	Mild, transient adverse effects > **C**	Minor injuries; no hospitalization **> C**	Minor injuries; no hospitalization **> C**	
	N	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	Consequences less than those for Low Consequence Level	