Safety Assessment Document Updates for DOE O 420.2D

SAD Section III Chapter 05 – 8-GeV Line

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8-GeV Line SAD Accelerator Readiness Review

12 March 2024

Outline

- 8-GeV Line Overview
- Hazard Inventory
- Non-Accelerator Specific Hazards
- Accelerator Specific Hazards
- Maximum Credible Incident (MCI) Discussion
- Summary of Credited Controls

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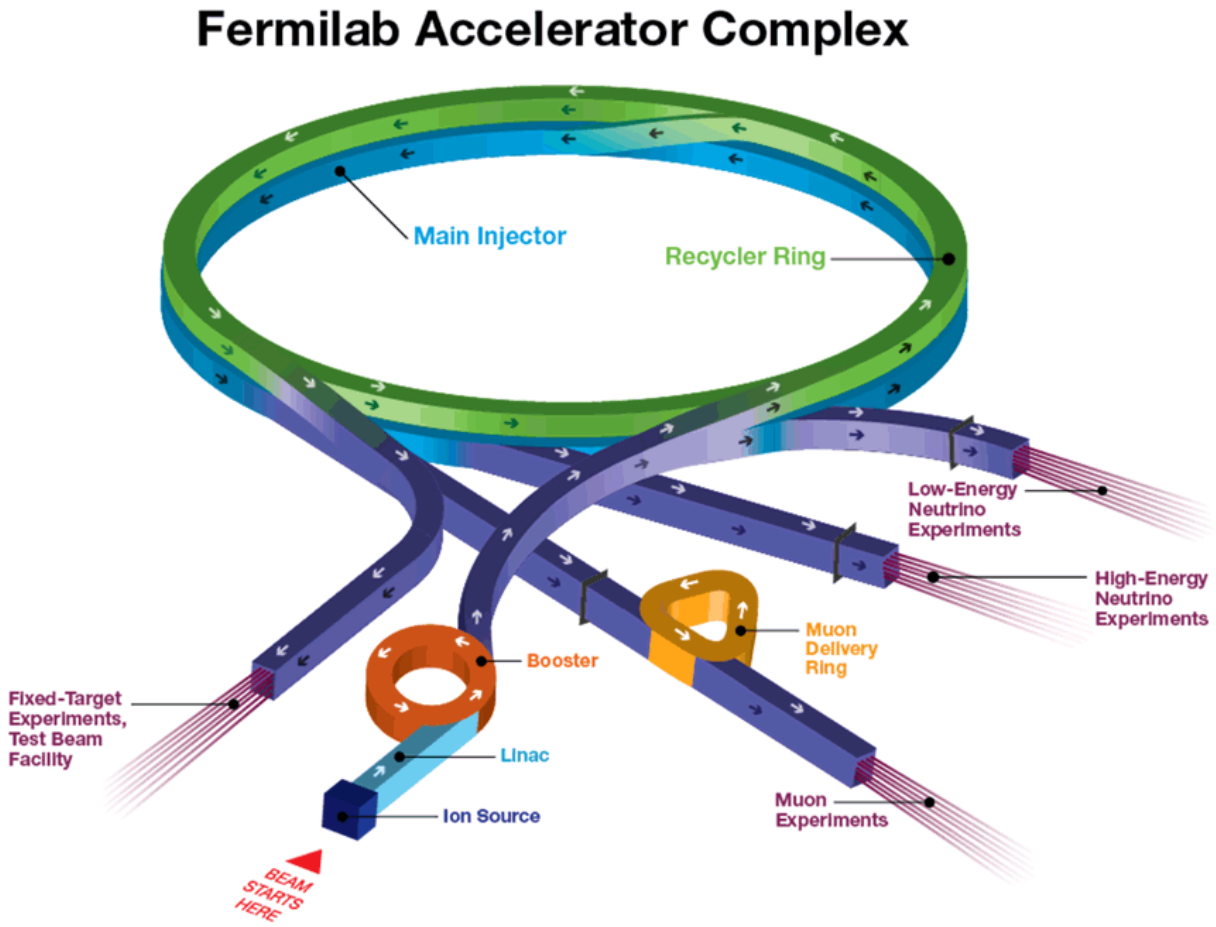
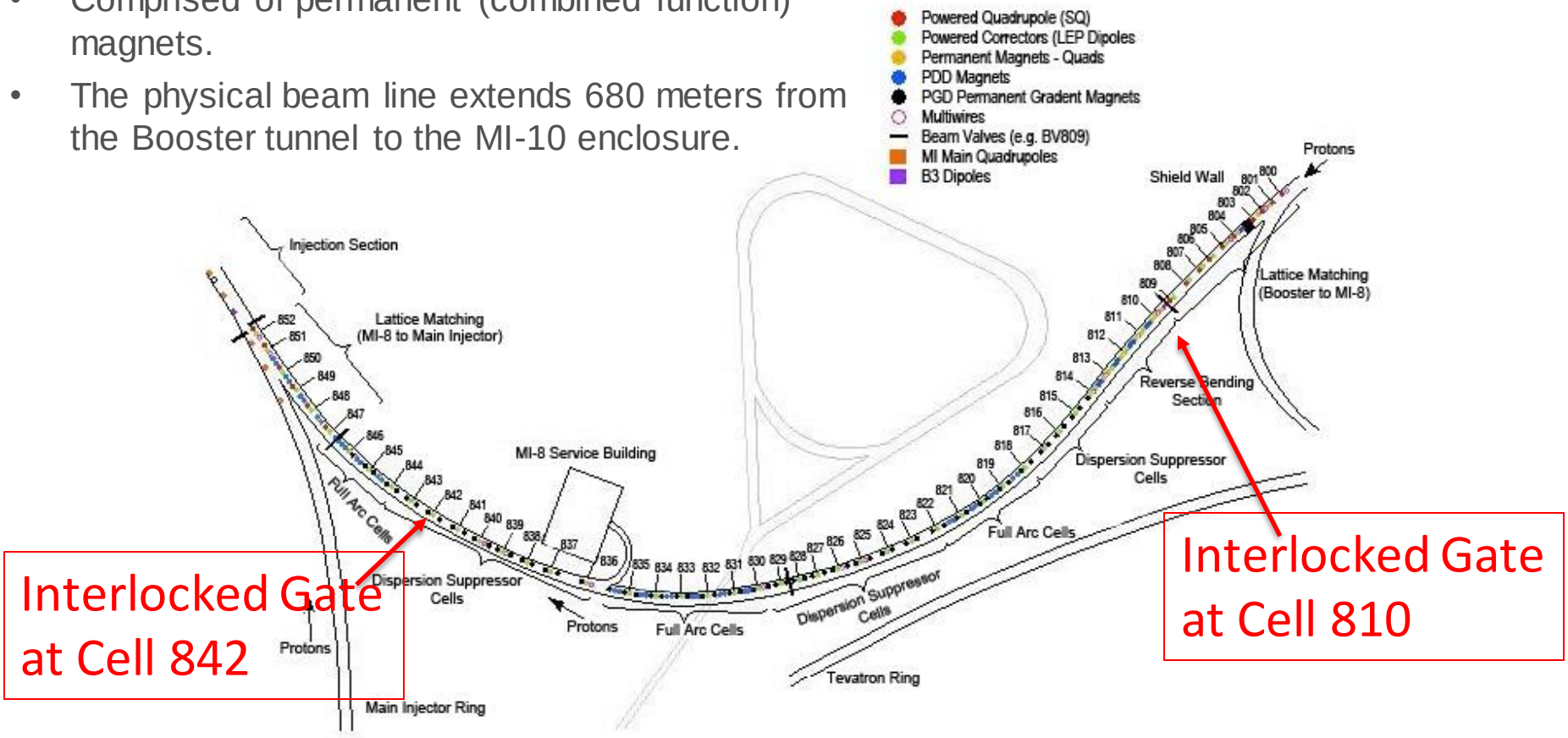
8-GeV Line Overview

- Cartoon showing 8-GeV in the overall Fermilab accelerator complex.



8-GeV Line Overview

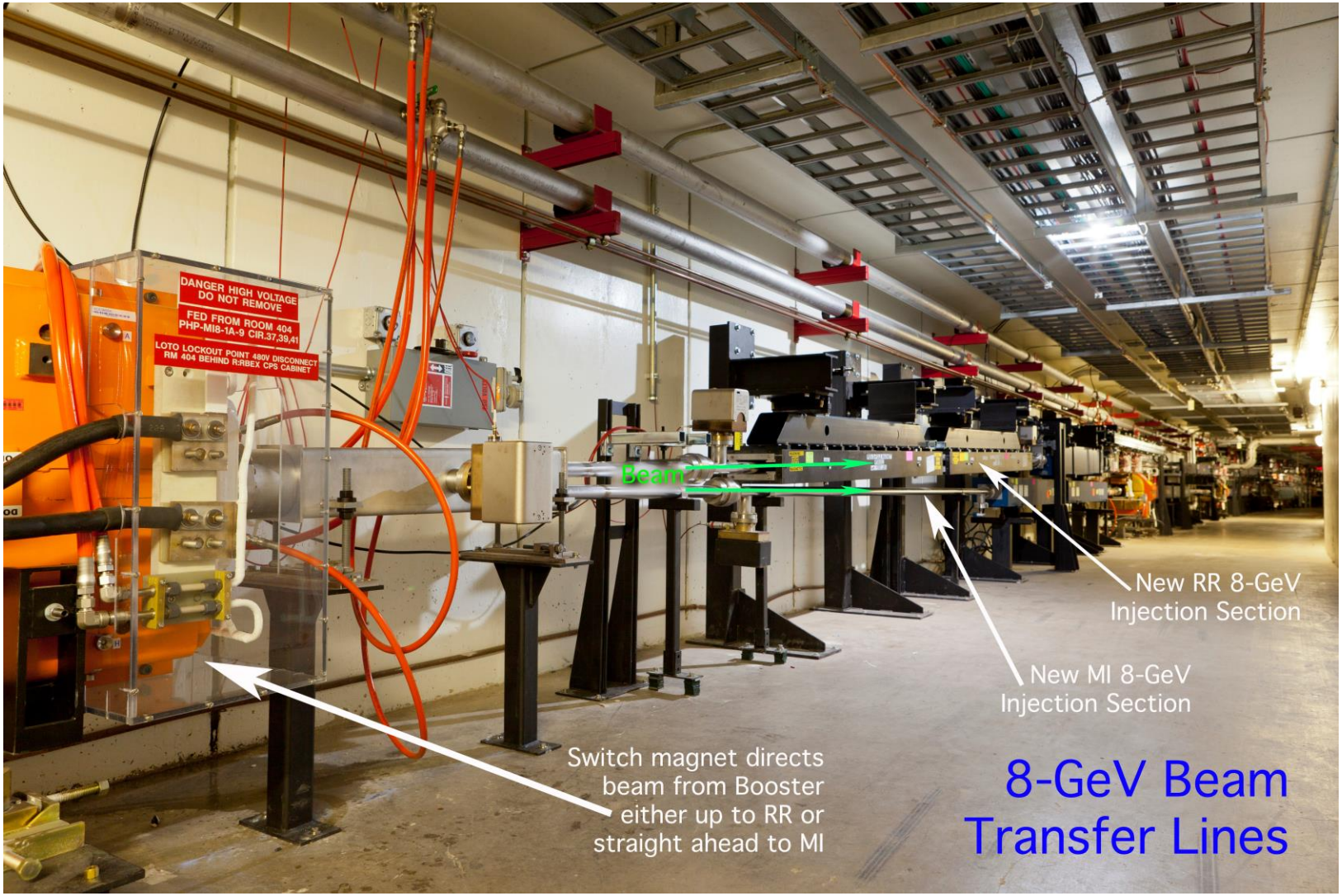
- The 8-GeV Line is designed to transmit protons from the Booster accelerator to the Main Injector, Recycler or Booster Neutrino Beamline (BNB).
- The beam energy is fixed at 8-GeV.
- Comprised of permanent (combined function) magnets.
- The physical beam line extends 680 meters from the Booster tunnel to the MI-10 enclosure.



8-GeV Line Overview

- The 8-GeV Line segment starts at the interlocked gate at Cell 810 and ends in the MI10 enclosure:
  - Cell 852 for Main Injector injection,
  - Cell 853 for Recycler injection,
  - Cell 860 for BNB operation.
- There are two bifurcation points where beam is sent to one path or another (RR/BNB/MI).
- Portions of the physical 8-GeV Line upstream of cell 810 are in the Booster radiation enclosure and as such are included in the Booster SAD chapter.

8-GeV Line Overview – Beam to Recycler



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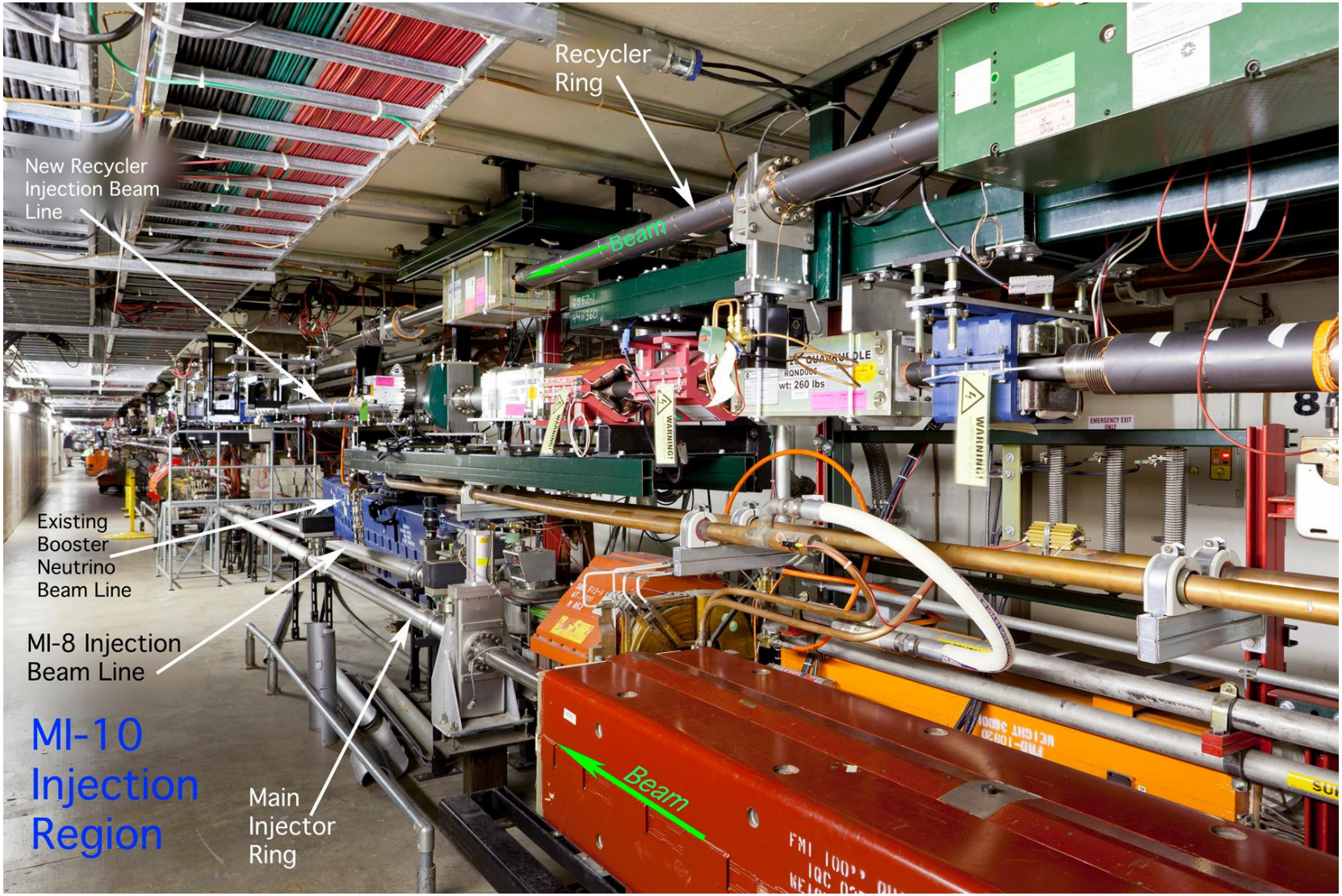
8-GeV Line Overview – Beam to BNB

8-GeV Line Overview – Beam to Main Injector



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Hazard Inventory for 8-GeV

	Radiological		Toxic Materials
☒	**Prompt Ionizing Radiation**	☒	Lead Shielding
☒	Residual Activation	☐	Beryllium
☒	Groundwater Activation	☐	Fluorinert & 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
☐	Magnet 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	☒	Confined Spaces
☒	Vacuum Pumps	☐	Noise
☒	Material Handling	☒	Silica
	Access & Egress	☒	Ergonomics
☒	Life Safety Egress	☐	Asbestos

- Accelerator specific hazards are purple
- Hazards not discussed today are evaluated via the common Risk Matrix tables
  - Covered in SAD Section I, Chapter 4
- Hazards evaluated via risk assessment methodology per DOE-HDBK-1163-2020
  - Likelihood (L):
    - Anticipated (A), Unlikely (U), Extremely Unlikely (EU), Beyond Extremely Unlikely (BEU)
  - Consequence (C):
    - High (H), Moderate (M), Low (L), Negligible (N)
  - Risk (R):
    - I , II, III, IV (descending order of concern)

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8-GeV Risk Table Summary

Summary of Baseline and Residual Risks-8 GeV Line.

	Risk Tables Description	Baseline Risk	Residual Risk
9.1	Radiological – Onsite-1 Facility Worker	R: I	R: IV
9.2	Radiological – Onsite-2 Co-located Worker	R: I	R: IV
9.3	Radiological – MOI Offsite	R:NA	R:NA
9.4	Toxic Materials – Onsite 1 Facility Worker	R: *	R: *
9.5	Toxic Materials – Onsite 2 Co-located Worker	R: *	R: *
9.6	Toxic Materials – MOI Offsite	R: *	R: *
9.7	Flammable & Combustible Materials – Onsite-1 Facility Worker	R: NA*	R: NA*
9.8	Flammable & Combustible Materials – Onsite-2 Co-located worker	R: *	R: *
9.9	Flammable & Combustible Materials – MOI Offsite	R: *	R: *
9.10	Electrical Energy – Onsite-1 Facility Worker	R: *	R: *
9.11	Electrical Energy – Onsite-2 Co-located Worker	R: *	R: *
9.12	Electrical Energy – MOI Offsite	R: NA*	R: NA*
9.13	Thermal Energy – Onsite-1 Facility Worker	R: *	R: *
9.14	Thermal Energy – Onsite-2 Co-located Worker	R: *	R: *
9.15	Thermal Energy – MOI Offsite	R: NA*	R: NA*
9.16	Kinetic Energy – Onsite-1 Facility Worker	R: *	R: *
9.17	Kinetic Energy – Onsite-2 Co-located Worker	R: *	R: *
9.18	Kinetic Energy – MOI Offsite	R: NA*	R: NA*
9.19	Potential Energy- Onsite-1 Facility Worker	R: *	R: *
9.20	Potential Energy – Onsite-2 Co-located Worker	R: *	R: *
9.21	Potential Energy – MOI Offsite	R: NA*	R: NA*
9.22	Magnetic Fields – Onsite-1 Facility Worker	R: *	R: *
9.23	Magnetic Fields – Onsite-2 Co-located Worker	R: *	R: *
9.24	Magnetic Fields – MOI Offsite	R: NA*	R: NA*
9.25	Other Hazards – Onsite-1 Facility Worker	R: *	R: *
9.26	Other Hazards – Onsite-2 Co-located Worker	R: *	R: *
9.27	Other Hazards – MOI Offsite	R: NA*	R: NA*
9.28	Access & Egress – Onsite-1 Facility Worker	R: *	R: *
9.29	Access & Egress – Onsite-2 Co-located Worker	R: *	R: *
9.30	Access & Egress – MOI Offsite	R: NA*	R: NA*
9.31	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.			

Non-Accelerator Specific Hazards - Radiological

- Residual Activation
  - High intensity beam delivery can produce activated materials inside the 8-GeV Line enclosure due to beam loss.
  - The residual dose rate found in the 8-GeV Line from initial entry surveys is historically less than 5 mrem/hr, exceptions include:
    - Beam collimators at cells 836 and 838, respectively. Dose rates at those locations are usually in excess of 200 mrem/hour.
  - Hazard applies to onsite facility workers and onsite co-located workers

Baseline Qualitative Risk (without controls)	Controls Preventive (P)/Mitigative (M)	Residual Qualitative Risk (with controls)
L: A C: H R: I	P – Locked Gates: P – Key Control Program: P – Radiological Work Permit P – Postings P – Training P – Beam Loss Monitoring M – Machine Protection System M – Local Component Shielding M – Run Conditions	L: BEU C: N R: IV

Non-Accelerator Specific Hazards - Radiological

- Ground Water
  - Radionuclides are produced which may contaminate ground water, surface water. Can occur in areas of high chronic losses
  - Hazard applies to onsite facility workers and onsite co-located workers

Baseline Qualitative Risk (without controls)	Controls Preventive (P)/Mitigative (M)	Residual Qualitative Risk (with controls)
L: A C: H R: I	P – Beam loss monitoring P– ES&H periodic monitoring M – Machine Protection System M – Beamline Design M – Run Conditions M – Sump pumps to surface	L: U C: N R: IV

Non-Accelerator Specific Hazards - Radiological

- Surface Water Contamination
  - Hazard applies to onsite facility workers, onsite co-located workers and a maximally exposed offsite individual (MOI)

Baseline Qualitative Risk (without controls)	Controls Preventive (P)/Mitigative (M)	Residual Qualitative Risk (with controls)
L: A C: M R: II	P – ES&H periodic monitoring P – Affected area postings	L: BEU C: M R: IV

Non-Accelerator Specific Hazards - Radiological

- Soil Interactions
  - Radionuclides are produced during beam loss events, which may contaminate soil. Can occur in areas of high chronic losses.
  - Hazard applies to onsite facility workers and onsite co-located workers

Baseline Qualitative Risk (without controls)	Controls Preventive (P)/Mitigative (M)	Residual Qualitative Risk (with controls)
L: A C: H R: I	P – Beam loss monitoring P– ES&H testing of soil samples M – Machine Protection System M – Beamline Design M – Run Conditions	L: U C: N R: IV

Non-Accelerator Specific Hazards - Radiological

- Air Activation
  - Air activation can occur at any area in the 8-GeV Line where high beam losses are present.
  - This is limited to the collimation area of Cells 836 & 838.
  - Hazard applies to onsite facility workers and onsite co-located workers

Baseline Qualitative Risk (without controls)	Controls Preventive (P)/Mitigative (M)	Residual Qualitative Risk (with controls)
L: A C: H R: I	P – Air Monitoring P– Beam loss Monitoring M – Run Conditions M – Machine Protection System M – Engineered Air Flow	L: EU C: N R: IV

Non-Accelerator Specific Hazards - Radiological

- Radioactive Waste
  - Radioactive waste produced during 8-GeV Line operations will be managed within the established Radiological Protection Program (RPP) as prescribed in the Fermilab Radiological Control Manual (FRCM)
  - Hazard applies to onsite facility workers and onsite co-located workers

Baseline Qualitative Risk (without controls)	Controls Preventive (P)/Mitigative (M)	Residual Qualitative Risk (with controls)
L: A C: H R: I	P – Postings P – Beam tuned to minimize beam loss M – Shielding to reduce generation of waste M – Material survey and release process	L: EU C: L R: IV

Non-Accelerator Specific Hazards - Radiological

- Contamination/^{7}Be Contamination
  - The area in the immediate vicinity of the beam collimators at 836 and 838 are areas of residual contamination typically in the form of activated dust.
  - Hazard applies to onsite facility workers and onsite co-located workers

Baseline Qualitative Risk (without controls)	Controls Preventive (P)/Mitigative (M)	Residual Qualitative Risk (with controls)
L: A C: H R: I	P – Radiological controls personnel survey and decontamination P – Postings place in the event contamination is identified P – Beam tuned to minimize beam loss P – Locked Gates P – Key Control Program M – Shielding to reduce generation of waste M – Material survey and release process	L: EU C: L R: IV

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Accelerator Specific Hazards - Radiological

- Prompt Ionizing Radiation – Beam Loss
  - Ionizing radiation due to beam loss in the 8-GeV Line enclosure
  - Analyzed maximum credible incident (MCI) to determine credited controls
  - Hazard applies to onsite facility workers, onsite co-located workers

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Maximum Credible Incident (MCI) – Radiological

- The MCI is defined as an event that is expected to occur over the lifetime of the accelerator
- The MCI focuses on exposure to an onsite worker, an onsite coworker and the maximally exposed off-site individual (MOI)
- Incident bounds all postulated accident scenarios for the Fermilab Main Injector
- The 8-GeV Line is located beyond the public access gate and contains no areas where the public is invited.
- Fermilab uses Credited Controls that flow down to the Accelerator Safety Envelope (ASE) to mitigate the consequences of an MCI to the following conditions:

Table 2. Acceptable Dose Levels Used in MCI Analysis.

Dose Level	Location	Potentially Exposed Individual
Worker Basis: Mitigated consequence of any credible postulated accident scenario at maximum operating intensity that could potentially result in **5 rem** in one hour in any area accessible by facility workers or co-located workers	Inside service buildings, where public cannot access	Facility Worker and/or Co-Located Worker
General Site Basis: Mitigated consequence of any credible postulated accident scenario at maximum operating intensity that could potentially result in **500 mrem** in one hour in areas to which the public is assumed to be excluded	Outside of enclosure/facility and surrounding shielding, in non-publicly accessible areas (beyond Obvious and Operating Barriers to Ensure Only Authorized Access)	Members of the public if they access areas where they are not authorized
Public Area Basis: Mitigated consequence of any credible postulated accident scenario at maximum operating intensity that could potentially result in **100 mrem** in one hour at Fermilab's site boundary AND/OR in any areas onsite in which the public is authorized. • Batavia Road, Prairie Path (MBO), parking lots open to the public. • All General Access Areas, including but not limited to the following: ○ Wilson Hall ○ Ramsey Auditorium ○ Lederman Science Center ○ Building 327	Outside of enclosure, in location where the public is authorized	Maximally-exposed Off-Site Individual (a.k.a., a member of the public)

8-GeV Line is behind obvious & operating barriers

Maximum Credible Incident (MCI) – Radiological

- The MCI for the Fermilab 8-GeV enclosure is a beam with an intensity of 3.78 x10^{17} protons per hour at an energy of 8 GeV persistently incident on a beamline component
- Assuming no shielding or other controls are present this incident would result in a dose to any individual of approximately 8 x10^{6} rem
- MCI intensity is the theoretical maximum the machine could produce and is a product of the following parameters:
  - 7 x10^{12} per Booster batch* 15 times per second (15 Hz)**.
    - *Booster intensity limitation
    - **15Hz is the maximum rate Booster can deliver beam.
  - Transmission efficiency of 100% to the location of MCI
  - All beam stability limitations, machine integrity limitations, and machine protection systems are ignored

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Credited Controls – Passive

- Permanent Shielding
  - Efficacy of passive shielding evaluated at MCI intensity at any location in the 8-GeV Line determined that a minimum 17.9 e.f.d. (equivalent feet of dirt) is required to limit the dose received to an individual standing on top of the berm at the maximum dose point to 500 mrem in an hour.
  - **Credited Control: 17.9 e.f.d. shielding between the interior surface of the enclosure walls and the surface of the berm.**
- Penetration Shielding
  - There are four "sight riser" 14-inch diameter penetrations along the length of the tunnel. They used for survey and alignment of the accelerator are filled with 2600 lbs steel plugs and additional poly beads. Sight risers are found near cells 812, 816, 831, 833.5. Local inspection in 2023 shows shielding remains undisturbed at all locations. These locations have been physically tagged as credited controls in the field.
- Obvious and operating access barriers
  - Located West Wilson Hall parking lot, East Wilson Hall parking lot & Site 55.

Credited Controls – Active Engineering

- **Credited Control: Radiation Safety Interlock System (RSIS)**
  - Inhibits beam by controlled redundant critical devices.
  - Enforces the search and secure process.
  - Interlocked doors are present at all access points into the 8-GeV Line enclosure.
  - The ES&H Radiation Physics Engineering Dept. (RPE) ensures that all requirements for hardware and system testing are completed semi-annually with a four-month grace period.
  - RPE also verifies the inventory of interlock keys and updates procedures for maintenance and testing of interlock systems.
  - All RSIS are designed, installed and configuration managed in conformance with the requirements of the Fermilab Radiological Control Manual (FRCM).

Credited Controls - Administrative

- **Credited Control: Operation Authorization Document**
  - Machine Beam Permit
  - Machine Run Condition
  - Beam will not be transported through 8-GeV Line without approval of these documents
- **Credited Control: Staffing**
  - To ensure accelerator operations are disabled and initiate an immediate response in the event of a determined ASE violation.
  - The following staffing shall be in place during applicable beam operation:
    - At least one member of the AD Operations Department who has achieved the rank of Operator II or higher shall be on duty and on site.
    - At least one member of the AD Operations Department shall be present in the Main Control Room (MCR).
    - Note: these requirements could be satisfied by a single person
- **Credited Control: Accelerator Operating Parameters**
  - The MCI intensity of 3.78 x10^{17} protons/hr shall not be exceeded

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