Safety Assessment Document Updates for DOE O 420.2D

SAD Section III Chapter 07 – Main Injector & Recycler Ring

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Main Injector Accelerator Readiness Review

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Outline

- Main Injector Overview
- Hazard Inventory
- Non-Accelerator Specific Hazards
- Accelerator Specific Hazards
- Maximum Credible Incident (MCI) Discussion
- Summary of Credited Controls

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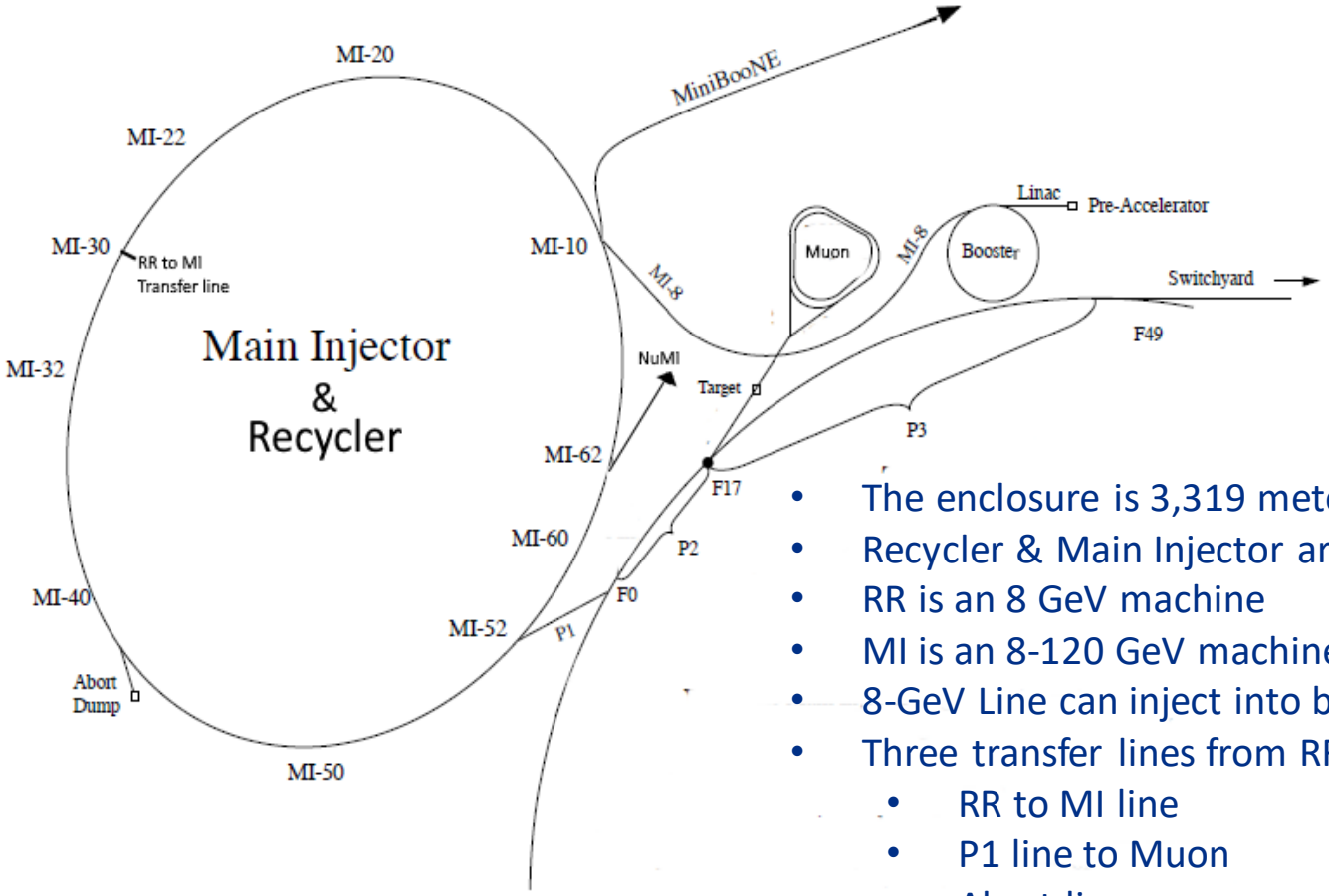
Main Injector Overview



- The enclosure is 3,319 meters in circumference
- Recycler & Main Injector are in the same enclosure
- RR is an 8 GeV machine
- MI is an 8-120 GeV machine
- 8-GeV Line can inject into both MI & RR
- Three transfer lines from RR
  - RR to MI line
  - P1 line to Muon
  - Abort line
- Three extraction lines from MI
  - P1 line to Switchyard
  - NuMI extraction line
  - Abort line

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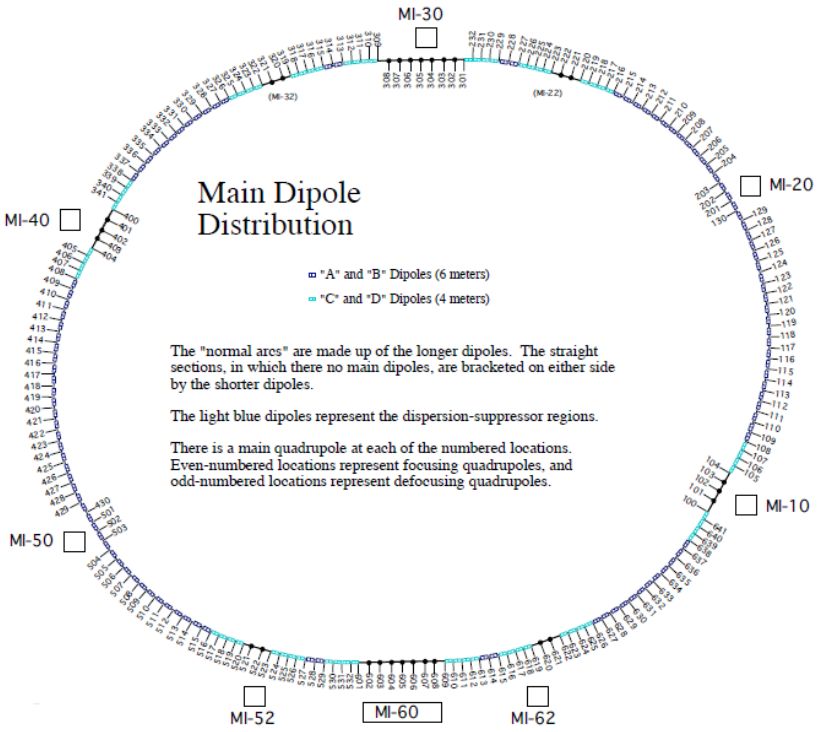

- MI is the bottom machine and utilizes electromagnets.
- RR is the top machine and utilizes magnets made from magnetized ferrite.
- Vacuum is around 5 x 10^{-8} torr to prevent scattering of the beam.
- Beam Loss Monitors are located at every quadrupole location (red magnet).

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Hazard Inventory for Main Injector

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

- 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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MI/RR Risk Table Summary

Summary of Baseline and Residual Risks for the Main Injector and Recycler.

Risk Tables Description		Baseline Risk	Residual Risk
11.1	Radiological – Onsite-1 Facility Worker	R: I	R: IV
11.2	Radiological – Onsite-2 Co-located Worker	R: I	R: IV
11.3	Radiological – MOI Offsite	R: NA	R: NA
11.4	Toxic Materials – Onsite 1 Facility Worker	R: *	R: *
11.5	Toxic Materials – Onsite 2 Co-located Worker	R: *	R: *
11.6	Toxic Materials – MOI Offsite	R:NA	R: NA
11.7	Flammable & Combustible Materials – Onsite-1 Facility Worker	R: *	R: *
11.8	Flammable & Combustible Materials – Onsite-2 Co-located worker	R: *	R: *
11.9	Flammable & Combustible Materials – MOI Offsite	R: NA	R: NA
11.10	Electrical Energy – Onsite-1 Facility Worker	R: *	R: *
11.11	Electrical Energy – Onsite-2 Co-located Worker	R: *	R: *
11.12	Electrical Energy – MOI Offsite	R: NA	R: NA
11.13	Thermal Energy – Onsite-1 Facility Worker	R: *	R: *
11.14	Thermal Energy – Onsite-2 Co-located Worker	R: *	R: *
11.15	Thermal Energy – MOI Offsite	R: NA	R: NA
11.16	Kinetic Energy – Onsite-1 Facility Worker	R: *	R: *
11.17	Kinetic Energy – Onsite-2 Co-located Worker	R: *	R: *
11.18	Kinetic Energy – MOI Offsite	R: NA	R: NA
11.19	Potential Energy- Onsite-1 Facility Worker	R: *	R: *
11.20	Potential Energy – Onsite-2 Co-located Worker	R: *	R: *
11.21	Potential Energy – MOI Offsite	R: NA	R: NA
11.22	Magnetic Fields – Onsite-1 Facility Worker	R: *	R: *
11.23	Magnetic Fields – Onsite-2 Co-located Worker	R: *	R: *
11.24	Magnetic Fields – MOI Offsite	R: NA	R: NA
11.25	Other Hazards – Onsite-1 Facility Worker	R: *	R: *
11.26	Other Hazards – Onsite-2 Co-located Worker	R: *	R: *
11.27	Other Hazards – MOI Offsite	R: NA	R: NA
11.28	Access & Egress – Onsite-1 Facility Worker	R: *	R: *
11.29	Access & Egress – Onsite-2 Co-located Worker	R: *	R: *
11.30	Access & Egress – MOI Offsite	R: NA	R: NA
11.31	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 Main Injector enclosure due to beam loss
  - The residual dose rate found in the Main Injector from initial entry surveys is historically less than 5 mrem/hr, exceptions include:
    - The injection and extraction areas
    - The collimation areas
  - 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

- Radioactive Water (RAW) system
  - The Main Injector Abort is cooled with water which becomes activated.
  - The system is self contained and heat exchanged with the MI LCW system
  - 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: M – Volume Monitoring M – Engineered Containment	L: BEU C: N R: IV

Non-Accelerator Specific Hazards - Radiological

- Air Activation
  - Air activation can occur at any area in the accelerator where high beam losses are present.
  - These areas are typically limited to the collimation and abort areas.
  - 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 M – Run Conditions P– Beam loss Monitoring M – Machine Protection System M – Engineered Air Flow	L: EU 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 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

- Radioactive Waste
  - Radioactive waste produced during Main Injector 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 – Locked Gates P – Key Control Program P – Postings M – Run Conditions M – Distance to Stored Material M – Material survey and release process	L:BEU C: N R: IV

Non-Accelerator Specific Hazards - Radiological

- Contamination/^{7}Be Contamination
  - The area in the immediate vicinity of the MI beam collimators between cells 301 and 309 are frequent 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 Main Injector 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 possible 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 MI & RR are 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)

MI/RR is behind obvious & operating barriers

Maximum Credible Incident (MCI) – Radiological

- The MCI for the Fermilab Main Injector enclosure is a beam with an intensity of 2.83 $x10^{17}$ protons per hour at an energy of 120 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 5.23 $x10^{7}$ 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 and 12 Booster batches to fill the Main Injector.
    - Booster intensity limitation
  - 1.067s repetition rate.
    - Hardware limit of the Main Injector power supplies.
  - Recycler and Main Injector transmission efficiency of 100%.
  - 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 RR or MI determined that a minimum of 20.7 equivalent feet of dirt (e.f.d.) 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: 20.7 e.f.d. shielding between the interior surface of the enclosure walls and the surface of the berm.**
- Movable Shielding
  - Concrete block wall separating the Main Injector enclosure are present in the P1 and decommissioned A1 line, between MI and F-sector. There are also shielding blocks at the MI30 area shielding the MI31 service building.
- Obvious and operating access barriers
  - Located West Wilson Hall parking lot, East Wilson Hall parking lot & Site 55.
- Penetration Shielding
  - The MI enclosure has utility and RF penetrations throughout the service buildings that are filled with either sand, poly beads, or covered with poly blocks.
  - Sight risers used for survey and alignment of the accelerator are filled with steel plugs and poly beads.

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 Main Injector 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 Recycler or Main Injector 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 2.83 x10^{17} protons/hr shall not be exceeded

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Thank you for your attention.

May I answer any questions?

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