Appendix A - Accelerator Safety Envelope

Approval Page
for the
Fermi National Accelerator Laboratory
Accelerator Safety Envelope

Revision 12
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		Signature	Date
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Revision History

Author	Rev. No.	Date	Description of Change
Maddie Schoell	12	August 25, 2020	Updated "Area" column for MuCool Test Area to reflect new name, MeV Test Area (MTA). Updated shielding assessment references for MeV Test Area. Updated safety envelope beam intensities for MeV Test Area, and updated associated reference. Updated "ASE Violation Determination and Actions" section to clarify deficiency in credited control and ASE violations.
Maddie Schoell	11	February 11, 2020	Updated shielding assessment references for the Muon Campus. Safety envelope beam intensities did not change. Updated "Area" column titles for Muon Campus areas for clarity.
John E. Anderson Jr.	10	November 12, 2019	Updated text for the "Control" section of the Operator Staffing section to reflect MCR responsibility for accelerator operations within the ASE beam intensity limits. Updated organizational name changes.
John E. Anderson Jr.	9	January 11, 2018	Removed Experimental ORC requirement from the ASE. Updated reference to the Routine Monitoring Program to reflect ESH Centralization. Clarified when shielding deficiencies would be an ASE violation.
John E. Anderson Jr.	8	August 28, 2017	Updated ASE energy limit for the Fermilab Accelerator Science and Technology (FAST) Facility.
John E. Anderson Jr.	7	March 3, 2017	Updated titles from ES&H reorganization, updated PPD ORC process to the FESHM ORC Process, and updated shielding assessment references for the Muon Campus and Booster accelerator areas. Safety envelope beam intensities did not change. Added Muon Campus 8 GeV beam on target intensity scaled from the 120 GeV intensity for clarity.
John E. Anderson Jr.	6	January 2, 2015	Added Safety Envelope beam intensity limits for the Advanced Superconducting Test Accelerator (ASTA) Injector. Changed Antiproton Source to Muon Campus. Updated references.
John E. Anderson Jr.	5	January 3, 2014	Updated ASE text to reflect recommendations from the Accelerator Readiness Review conducted October 1-3, 2013. Changes included moving numerical beam operating intensity limits from the ASE to a Division level document, scaling numerical beam safety envelope intensity limits to a 500 mrem accident condition, removing operating surveillance limits, and removing industrial hazards such as oxygen monitoring, cryogenic relief valve monitoring, and flammable gas system monitoring.
John E. Anderson Jr.	4	April 25, 2013	Updated Department of Energy (DOE) DOE Order 420.2B, *Safety of Accelerator Facilities*, to DOE O 420.2C. Updated ASE text to reflect credible accident scenarios. Modified Operating and Safety Envelope beam parameters for the Main

			Injector, Recycler, and NuMI. Updated shielding assessment references for the revised Main Injector, Recycler, and NuMI shielding assessments. Updated Linac groundwater limit reference to new MARS calculations. Removed Operating and Safety Envelope beam parameters for Tevatron Circulating Beam, A0 and C0 Abort Absorbers, and the Pelletron; placing the areas in standby. Removed the Booster Radiation Damage Facility Operating and Safety Envelope beam parameters.
John E. Anderson Jr.	3	February 15, 2012	Added Operating and Safety Envelope beam intensity limits for the Neutrino Area.
John E. Anderson Jr.	2	March 21, 2011	Added Operating and Safety Envelope beam intensity limits for the HINS Linac at MDB.
John E. Anderson Jr.	1	January 20, 2011	Added Operating and Safety Envelope beam intensity limits for the MuCool Test Area.
John E. Anderson Jr.	0	December 10, 2009	Initial release of the laboratory-wide Accelerator Safety Envelope (ASE). The ASE is derived from the Safety Class Structures, Systems, or Components section of Fermilab Environment Safety and Health Manual (FESHM) Chapter 3010, *Significant and Reportable Occurrences*, and the Safety Envelope section of the existing Fermilab Safety Assessment Documents (SADs). This document supersedes and replaces the Safety Envelope section of the existing Fermilab SADs. Completed Safety Envelope calculations for the 8 GeV Line and MiniBooNE areas and revised Safety Envelope. Revised 8 GeV Line and MiniBooNE Operating limits to support future program needs based on post assessment documents.

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Accelerator Safety Envelope

In accordance with the DOE Accelerator Safety Order, DOE O 420.2C, and as flowed down through the Fermilab Director's Policies, the Fermilab Environment Safety and Health Manual (FESHM) including the Fermilab Radiological Control Manual (FRCM), this appendix describes the credited physical and administrative controls that define the Accelerator Safety Envelope (ASE). The ASE is a set of engineered and administrative conditions that define the bounding conditions and limitations for safe and environmentally sound operations. Engineered safety systems are employed to ensure that the accelerator components operate within their accident condition safety basis, that no beam can be introduced into exclusion areas when occupied by people, and that radiation levels in posted areas do not exceed accident condition radiation levels. Administrative procedures provide specific instructions for carrying out activities that are critical for ensuring that the accelerator can be operated safely. Variations in operating conditions are permitted only if their extent, duration, and consequences do not exceed the bounds imposed by the safety envelope. These variations of the operating conditions include unplanned events, such as power outages, which may interrupt beam operations but do not compromise the safety of the facility. Unlike many nuclear facilities, turning off power to the accelerator places the accelerator in a safe state. Variations beyond these limits are a violation of the ASE.

In accordance with FRCM Article 236, Fermilab utilizes credited passive and active engineered controls whenever the maximum calculated accident condition can exceed 500 mrem in an hour. In addition to credited controls, a defense-in-depth approach is used to reduce the probability, duration, and likelihood of beam loss accident conditions. Defense-in-depth controls are part of the machine protection systems.

Credited Controls

Credited controls identified in the ASE are the primary controls that assure that the level of risk to all workers, the public, and the environment is maintained at acceptable levels. The credited controls listed in the ASE must be in place and functional for all operational areas. During periods of accelerator down time or maintenance, credited controls may be removed but must be replaced prior to resumption of operations. The assigned Radiation Safety Officer (RSO) may specify equivalent controls in accordance with the FRCM that do not reduce the level of safety to allow for maintenance or repairs.

The credited controls are divided up into three main categories: passive controls; active engineered controls; and administrative controls. Passive controls are elements that are part of the physical design of the facility that require no action to function properly. These are fixed elements of the accelerator that take human intervention to remove. Active engineered controls are systems designed to reduce the risks from accelerator operations to an acceptable level. These are automatic systems that limit or terminate operations when operating parameters are exceeded. Administrative controls encompass the human interactions that define safe operations. These are the accelerator operating policies and procedures that are followed to ensure safe accelerator operations.

The ASE specifies management and surveillance practices that must be performed to assure the continued effectiveness of the credited controls. Surveillances are to be carried out at the minimum specified interval. Any variation beyond the interval for surveillance is an ASE violation.

Trained personnel of the Accelerator Division (AD) Operations Department utilize administrative controls to ensure that overall operations are maintained within the ASE as set forth in the Beam Permit and Running Condition documents, which are issued for each running period and are subject to a formal approval process. Compliance with the requirements of the Beam Permit and Running Condition ensures that the level of risk to all workers, the public, and the environment is maintained at an acceptable level.

Credited Passive Controls

Permanent shielding including labyrinths

Applicability:
Beam on only

Control:
The permanent shielding encompasses the structural elements surrounding the beamline components and experiments, including the built-in design features such as the access labyrinths, penetrations, and earthen berms and overburden.

Surveillance
The integrity of the permanent shielding shall be certified through the Accelerator Startup Documents in AD Administrative Procedure ADAP-11-0001, *Beam Permits, Running Conditions, and Start-up*.

Movable shielding

Applicability:
Beam on only

Control:
The movable shielding is any shielding that can be moved for access to areas or equipment such as the shield wall between the NuMI Target Hall and the Target Hall Access Shaft. Movable shielding includes temporary shielding placed as needed where permanent shielding is impractical or insufficient, such as, shielding placed around highly radioactive components or shielding placed to absorb x-rays from testing of equipment or beamline components. Movable shielding shall be used as necessary in accordance with the Fermilab shielding policies specified in the FESHM and the FRCM. Movable shielding shall be identified and locked in place or equivalent controls placed to assure the correct placement of movable or temporary shielding is maintained.

Surveillance
The integrity of the shielding shall be certified through the Accelerator Startup Documents in AD Administrative Procedure ADAP-11-0001, *Beam Permits, Running Conditions, and Start-up*.

Penetration shielding

Applicability:
Beam on only

Control:
Penetrations, such as utility and Radio frequency waveguide routing between the exclusion areas and occupied areas, are shielded as necessary.

Surveillance
The integrity of the shielding shall be certified through the Accelerator Startup Documents in AD Administrative Procedure ADAP-11-0001, *Beam Permits, Running Conditions, and Start-up*.

Radiation fencing

Applicability:
Beam on only

Control:
Fences are used and posted to designate potential radiation areas during machine operations.

Surveillance

The integrity of the fences and postings on the fences shall be verified at least once in each calendar year for operational areas in accordance with ES&H Procedure ESHQ-RPE-001, *ESHQ RPE Routine Monitoring Program*.

Credited Active Engineered Controls

Radiation Safety Interlock System

Applicability:
Beam on only

Control:
Radiation Safety Interlock Systems are used to prevent injury, death, or serious over-exposure from beam-on radiation, x-rays, and high voltage / high current devices, and other hazards of this type. The principal method employed by the interlock systems is to establish and maintain exclusion areas surrounding accelerator operating areas. The interlock barriers are established such that sufficient distance is maintained between beamline operating components and the closest point of approach. If there is a potential for personnel to be within the defined exclusion area, the Radiation Safety Interlock System is designed to inhibit operations that can create hazardous conditions.

The interlock systems utilize a modular redundant design where no single component failure will result in a loss of protection. To accomplish this, two separate circuits are used to detect specific conditions. For example, each door that is monitored uses two separate switches to detect the status of the door. Each of these switches is connected to separate control circuits. If a failure occurred in one switch, the other would still operate providing the necessary protection. Another key characteristic used in designing the system is the concept of fail-safe circuits. All circuits are designed in such a way that if a circuit fails, the failure would most likely initiate a system shutdown resulting in a safe condition. Since not all component failures can be detected by the interlock systems, functional testing in accordance with FRCM Article 1004, *Required Procedures*, needs to be performed at periodic intervals to ensure reliable operations.

Safety Envelope

The Radiation Safety Interlock System shall have no known loss of safety function in any section where beam operations are in progress.

Surveillance

The Radiation Safety Interlock System for operational areas shall be tested and recertified with the maximum interval between tests of 12 months.

Credited Administrative Controls

Accelerator Operational Approvals

Applicability
Beam transport to the approved area

Control:
AD Administrative Procedure ADAP-11-0001, *Beam Permits, Running Conditions, and Start-up,* defines how each section of the accelerator complex is turned back on after extended down periods of generally 30 days or more, or turned on for new facilities. Prior to initiating beam in any section of the accelerator, a System Start-Up Sign-Off sheet is prepared for the area. This document is used to get formal approval from each support department head indicating that all work has been completed and the system is ready to accept beam. This document is also used to certify in writing, by the department head responsible for the accelerator area covered by the document, that all required radiation shielding is in place and configured as described in the current radiation shielding assessment.

The Beam Permit and Running Condition documents identify the beam power and operating parameters allowed for the accelerator area within the current ASE and consistent with the approved shielding assessment. A summary listing of approved beam operating intensity limits can be found in AD Administrative Procedure ADAP-11-0003, *Approved Accelerator Beam Intensity Operating Limits*. The beam power limits are determined and approved by the AD Head in consultation with the Radiation Physics Operations Department Head, assigned RSO, and Operations Department Head on the Beam Permit. The Running Conditions for the area identifying the operating configuration are reviewed by the assigned RSO, AD Operations Head, the applicable AD Accelerator Department Head and approved by the AD Head.

Safety Envelope
The AD will not transmit beam without an authorized Beam Permit and Running Condition specifying the beam power equivalent limitations.

Accelerator Operations Staffing

Applicability:
Beam transport operations

Control:
The AD Operations Department is responsible for maintaining the operation of the accelerators and fixed target beam transport enclosures within the ASE beam intensity limits. The Main Control Room is staffed with trained personnel from the Operations Department around the clock at all times. The lead person on shift, the Crew Chief, has responsibility for machine operations and directs the activities of the other on-shift operators. The department has a long-standing, well-documented training program for its personnel, consisting of components such as: required reading materials, videos, lectures, walk-arounds, self-assessment quizzes, and on-the-job training.

Safety Envelope
To ensure robust knowledge of accelerator systems during both normal and off-normal machine operations, there shall be no less than one qualified member of the Operations Department who has achieved the rank of Operator II or higher on shift. There shall be no less than one member of the Operations Department present in the Main Control Room during beam transport operations.

Accelerator Beam Intensity Limits

Applicability:
Beam transport operations to the approved area

Control:
The AD Operations Department uses the accelerator control system to monitor beam intensity for operating beam lines. The table below identifies the beam intensity for each area that would need to be lost in a point source, at the same place, continuously for one hour to produce a 500 mrem accident condition[1] outside of the accelerator shielding. This accident condition is generally not considered credible since such a high beam power lost in a point source would likely degrade the accelerator vacuum such that continued operations would not be possible. However, it does provide an upper limit on the allowable beam intensity to identify when credited passive or active engineered controls are necessary. The intensity limits are specified in protons or electrons per hour since the concern is prompt radiation exposures from beam operations.

Safety Envelope

To ensure that off-normal machine operations do not produce accident conditions greater than 500 mrem per hour, beam intensities in each portion of the accelerator are monitored. The following table specifies the maximum beam intensity and energy necessary to produce an accident condition outside of the accelerator shielding.

Area	Safety Envelope Intensity	Beam Energy
Linac to NTF	6.70 E18 protons/hour [2, 3]	66 MeV
Linac	1.77 E19 protons/hour [2]	400 MeV
MeV Test Area	2.11 E16 protons/hour [4]	400 MeV
Booster & 8 GeV Line up to cell 803	1.80 E19 protons/hour [5]	8 GeV
8 GeV Line from cell 803 to cell 850	2.35 E19 protons/hour [6]	8 GeV
8 GeV Line from cell 850 to the MiniBooNE Target Station	9.00 E18 protons/hour [6]	8 GeV
Main Injector	7.45 E17 protons/hour * [7]	8 GeV
Main Injector	7.45 E17 protons/hour [7]	120 GeV
Main Injector	6.23 E17 protons/hour [7]	150 GeV
Recycler	1.27 E18 protons/hour [8]	8 GeV

Area	Safety Envelope Intensity	Beam Energy
NuMI	7.45 E17 protons/hour [9]	120 GeV
Main Injector to Muon Campus through Delivery Ring Extraction (V907)	1.80 E14 protons/hour [10]	8 GeV
M4 beamline from V907 to Diagnostic Absorber	1.80 E14 protons/hour [10]	8 GeV
Main Injector to Muon Campus AP0 Target to g-2 Storage Ring	1.35 E18 protons/hour [10]	8 GeV
Main Injector to Muon Campus AP0 Target	9.00 E16 protons/hour [10]	120 GeV
Beam to the Switchyard 120 Beamlines including Meson Test (P3 line, SY120 interconnect region, and the SY 120 beamline in enclosures B and C), M01-M05	1.03 E16 protons/hour [11]	120 GeV
Meson Center beam from M01-M05 and MC6	9.60 E16 protons/hour [12]	120 GeV
Neutrino Experimental Area	8.64 E15 protons/hour [13]	120 GeV
A0 Photoinjector	2.88 E19 electrons/hour [14]	25 MeV
Fermilab Accelerator Science and Technology (FAST) Facility	1.96 E19 electrons/hour [15, 16]	300 MeV

* It is noted that although energy scaling of the 8 GeV intensity could be substantially higher, there is no operational need for a higher 8 GeV intensity. Therefore, the 8 GeV intensity limit has been chosen to match the 120 GeV intensity limit.

ASE Violation Determination and Actions

Operation of the accelerators without the specified credited controls in place and functional is a violation of the ASE. If the ASE is violated, affected accelerator operations shall cease and not resume until after the situation has been investigated and an analysis of the impact of the excursion on people and the environment determines that operations may safely resume in consultation with the Chief Safety Officer and the DOE Fermi Site Office.

A violation of the ASE is typically very clear. However, there may be minor failures of credited controls that are less obvious but still constitute a violation of the ASE. Determining whether a condition is a violation of the ASE may be subjective. The following examples of ASE violations are not a comprehensive list of violations, but rather intended to serve as guidance to facilitate such determinations.

- Surveillance of credited controls is not conducted within the time intervals specified in the ASE.
- One of the redundant channels of the Radiation Safety Interlock System is known to be inoperable and beam is allowed to be delivered to the affected accelerator or experimental area.
- Accelerator operations are conducted without the required authorizations.
- Accelerator operations are conducted without the minimum specified staffing levels.
- The hourly beam intensity limits are exceeded.

The following are examples of deficiencies found in credited controls that would *not* constitute an ASE violation.

- An interlock system component fail-safe failure that results in a system shutdown.
- An interlock system fail-unsafe failure found during interlock system testing.
- A radiation area posting found missing during a routine surveillance.
- A radiation area fence found damaged during a routine surveillance.

If permanent shielding, penetration shielding or other movable shielding is not in place when beam is permitted in an accelerator or experimental area, an Unreviewed Safety Issue Determination is needed to assess if the shielding deficiency, combined with the approved accelerator operating limit, could have resulted in an accident condition greater than 500 mrem/hr.

Questions regarding determining if a deficiency in a credited control is an ASE violation or an operating deficiency shall be addressed to the Chief Safety Officer in consultation with the area line management and ES&H staff. Any deficiencies found in a credited control that are not an ASE violation are handled in accordance with FESHM and FRCM requirements.

In the event that the ASE is violated, affected accelerator operations shall cease and not resume until the circumstances of the event are reviewed and approval to resume operations is received. In response to potential ASE violations, the AD Operations Department Crew Chief follows AD Safety Procedure ADSP-02-0101, *Response to Violations of the Accelerator Safety Envelope*. This procedure outlines the initial actions to be taken along with the appropriate safety and management personnel to be notified.

In the initial response, the Crew Chief is to take reasonable actions to return the complex to a safe operating condition by disabling all beam transfer operations. The Crew Chief next determines and locates any affected personnel. After the complex is in a safe condition and affected personnel are located, the Crew Chief follows the notification tree in the procedure while gathering sufficient data so as to properly analyze the excursion and its ES&H impacts. Sections of the accelerator or events that have not violated the ASE may resume operations pending Division Head approval. Events determined to be ASE violations follow FESHM Chapter 3010 *Significant and Reportable Occurrences*, to provide the appropriate DOE notification and reporting. Accelerator operations for the affected area are not to resume until after division management determines operations may safely resume in consultation with the Chief Safety Officer and the DOE Fermi Site Office.

References

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[2] **Memo, "Completion of the Linac Shielding Assessment and Verification of Operation at Full Intensity"**, from G. Dugan to D. Cossairt, page 2, June 28, 1991. **Radiation Shielding Assessment of the Linac High Energy Enclosure Following the 1993 Upgrade Installation and Low Intensity Commissioning**, Charles Schmidt and Thomas Kroc, September 21, 1993.

[3] **Neutron Therapy Facility 1992 Shielding Assessment**, Arlene J. Lennox, April 10, 1992.

[4] **Shielding Assessment Document for the MeV Test Area at the Fermilab Linac Endstation,** J. M. St. John, August 24, 2020.

[5] **Booster Shielding Assessment Version 6**, January 17, 2017.

[6] **8 GeV Fixed Target Shielding Assessment,** C. Moore, page 1, April 19, 2002. **MiniBooNE-Era Doses for MI8 Labyrinths & Penetrations**, B. Higgins, June 3, 2002.

[7] **Main Injector Incremental Shielding Assessment 700 kW,** Wayne A. Schmitt, William S. Higgins, Michael C. Vincent, Roger Zimmermann, August 2012.

[8] **Recycler Ring Incremental Shielding Assessment 2.25 x10^{17} protons/hour**, Wayne A. Schmitt, William S. Higgins, Michael C. Vincent, Roger Zimmermann, October 3, 2012.

[9] N. Grossman, **NuMI Beam Line & MINOS Hall Shielding Assessment**, July 2004. K. Vaziri, **Addendum to NuMI Shielding Assessment**, June 2007. Bob Ducar, Jim Hylen, Andy Stefanic, **Collection of condensate from NuMI chase re-circulating air cooling system**, February 7, 2007. K. Vaziri, **Radiological issues associated with venting tritiated air from NuMI SR3**, February 12, 2007. K. Vaziri, Addendum to NuMI Shielding Assessment, October 2007. K. Vaziri, **Tritium Release from NuMI MI-65 Stack**, April 16, 2007. K. Vaziri, **Radiological issues associated with helium in the NuMI Decay Pipe at 500 kW**, October 2007. **Neutrino at Main Injector (NuMI) Beam Line Shielding Assessment for 778 kilowatt (kW) Operation of Neutrino Off-axis Electron Neutrino (ve) Appearance (NOvA) Experiment**, K. Vaziri, February 2013.

[10] **Antiproton Source 2000 Shielding Assessment,** Pbar Source Department, page 1, June 2000. **MiniBooNE-Era Doses for MI8 Labyrinths & Penetrations**, B. Higgins, June 3, 2002. **Muon Campus Operation Utilizing The Antiproton Source 2000 Shielding Assessment**, A. Leveling, April 22, 2016. **Muon g-2 Shielding Assessment**, February 7, 2017. **Muon Campus Shielding Assessment for 8 GeV Beam Transmission to the Diagnostic Absorber**, A. Leveling, February 5, 2020.

[11] **2003 Shielding Assessment for the Switchyard 120 Project**, C. Brown, T. Kobilarcik, G. Koizumi, E. Ramberg, and W. Higgins, April 8, 2003.

[12] **Addendum to the SY 120 Shielding Assessment to add the MCenter branch to the beam line**, C. Brown and D. Jensen, February 5, 2004. **Addendum to the SY 120 Shielding Assessment for Continued Operation of the Meson Center Beam Line**, Thomas R. Kobilarcik and Wayne Schmitt, Edited by William S. Higgins and Michael Vincent, November 25, 2013.

[13] **Neutrino Muon Beam Line Shielding Assessment**, Thomas R. Kobilarcik and Michael Geelhoed, February 24, 2012.

[14] **A0 Photoinjector SAD**, H. Edwards, page 4, April 1997.

[15] **Shielding Assessment for the Advanced Superconducting Test Accelerator (ASTA) injector**, M. Church, I. Rakhno, E. Harms, December 12, 2014.

[16] **Shielding Assessment for IOTA/FAST Electron Injector at 300 MeV**, D. Broemmelseik, August 2017