Appendix A - Accelerator Safety Envelope

Approval Page
for the
Fermi National Accelerator Laboratory
Accelerator Safety Envelope

Revision 4
April 25, 2013

		Signature	Date
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Revision History

Author	Rev. No.	Date	Description of Change
John E. Anderson Jr.	4	April 25, 2013	Updated DOE O 420.2B 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 (SCSSCs) section of Fermilab Environment Safety and Health Manual (FESHM) Chapter 3010 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), and 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 predetermined parameters or operating ranges, that no beam can be introduced into exclusion areas when occupied by people, and that radiation levels in posted areas do not exceed allowed 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.

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 an acceptable level. 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 area 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 operations, shutdown operations, or provide warning alarms 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. Variations that extend the surveillance interval by no more than 20% are acceptable. Several of the credited controls are specified at two levels: 1) the Safety Envelope, which corresponds to the ASE limits, and; 2) the Operating Envelope, which defines the limits for normal operations. Any variation beyond the level for an Operating Envelope is an operating deficiency and not an ASE violation. Any variation beyond the level for Safety Envelope surveillance is an ASE violation.

Table A-1 specifies the beam power limitations for each section of the Fermilab accelerator complex. The shielding assessments conducted for each beamline area with respect to the FRCM limits found that continuous operation at an intensity defined in the Operating Intensity limits along with the stated Beam Energy is safe and defines the normal Beam Permit operating limits.

The Basis listed in the table identifies what limits the beam intensity for each area. The term "Overburden" is used in Table A-1 when the Operating Intensity is limited by the shielding surrounding the beamline enclosure. The overburden intensity limits are specified in protons per hour since the concern here is prompt radiation exposures from beam operations. The term "Groundwater" is used when the intensity is limited to the number of particles where activation of unprotected soil surrounding the enclosures leads to radioactivity in the ground water. Ground water limits are cumulative effects and are expressed in protons per year.

Federal regulations, 10 CFR 835[1], and DOE O 5400.5[2] place an annual limit of 100 mrem/year on the total effective dose that can be delivered to a member of the public from DOE facilities. Since 1971 the Laboratory, as proclaimed by the Director, has implemented a goal of limiting the equivalent dose at the site boundary to a maximum of 10 mrem received by an actual person in any given calendar year. The shielding assessments assess a beam excursion for a credible accident scenario where a member of the public hypothetically present at the maximum beam excursion loss point outside the controlled areas could have received a 10 mrem dose for the Safety Envelope Intensity. Any variation beyond the Safety Envelope Intensity is an ASE violation. For areas where the shielding assessments have not performed a separate safety envelope calculation, the safety envelope is set to the operating envelope or the maximum calculated operating envelope.

Trained personnel of the Accelerator Division Operations Department utilize administrative controls to ensure that overall operations are maintained within the ASE as set forth in the Beam Permit and Run 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 Run 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

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 by the relevant division through the Accelerator Startup Documents or Operational Readiness Clearance for the experiment.

Movable shielding

The movable shielding is any shielding that can be moved for access to areas or equipment such as the shield walls between the CDF and D0 experiments and their respective assembly halls. 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.

Management

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 by the relevant division through the Accelerator Startup Documents or Operational Readiness Clearance for the experiment.

Penetration shielding

Penetrations, such as utility and RF waveguide routing between the exclusion areas and occupied areas, are shielded as necessary.

Surveillance

The integrity of the shielding shall be certified by the relevant division through the Accelerator Startup Documents or Operational Readiness Clearance for the experiment.

Radiation fencing

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 annually for operational areas in accordance with Accelerator Division (AD) Procedure ADDP-SH-1003, Accelerator Division Routine Monitoring Program.

Credited Active Engineered Controls

Radiation Safety Interlock System

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 power supplies and other hazards of this type. The principle 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 will not allow 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 in 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 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 annually.

Operating 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 every six months.

In-Place Oxygen Deficiency Monitors/Alarm Systems

In-Place Oxygen Deficiency Monitors/Alarm Systems are employed to protect personnel from oxygen deficient atmospheres resulting from cryogenic fluid leaks. The oxygen monitoring system provides continuous monitoring of oxygen concentrations at entry locations to potential oxygen deficient environments. The system utilizes redundant circuits for high reliability, separate upper and lower alarm limits to reduce undetected failures, and dual channels to allow for monitoring of two separate sensors. The unit provides both audible and visual alarms when the monitored oxygen concentration falls below pre-set levels. Auxiliary output relay contacts are provided for connection to external ventilation systems or equipment as necessary. To ensure reliable operations, functional testing and calibration of the systems need to be performed at periodic intervals.

Safety Envelope
Surveillance
The In-Place Oxygen Deficiency Monitors/Alarm Systems shall be tested and recertified annually.
The performance of the In-Place Oxygen Deficiency Monitors/Alarm Systems shall be monitored and calibrated as necessary.

Operating Envelope
Surveillance
The In-Place Oxygen Deficiency Monitors/Alarm Systems shall be tested and recertified annually.

Flammable Gas Detection Systems

Flammable Gas Detection Systems are utilized to protect personnel and property from explosive atmospheres and are designed in accordance with FESHM Chapter 6020.3. The systems continuously monitor the atmosphere for flammable gasses. The systems provide automatic shutoff of the gas supply when the monitored gas concentrations exceed pre-set levels. High level alarms no higher than 20% of the lower explosive limit automatically summon the Fire Department. Visual indicators at the storage location and experimental apparatus locations provide real time status of the "gas on" and "gas off" states. To ensure reliable operations, functional testing and calibration of the systems need to be performed at periodic intervals.

Safety Envelope
Surveillance
The Flammable Gas Detection Systems shall be tested and recertified annually.
The performance of the Flammable Gas Detection Systems shall be monitored and calibrated as necessary.

Operating Envelope
Surveillance
The Flammable Gas Detection Systems shall be tested and recertified annually.

Pressure Relief Systems for Cryogenic Vessels

Pressure Relief Systems are utilized to protect cryogenic vessels from over pressurization due to vaporization of liquids.

Surveillance
The Pressure Relief Systems for cryogenic vessels shall be inspected in accordance with FESHM 5031.4, Inspection and Testing of Relief Valves.

Credited Administrative Controls

Accelerator Operational Approvals

AD Administrative Procedure ADAP-11-0001, *Beam Permits, Run Conditions, and Startup*, 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 Run Condition documents identify the beam power and operating parameters allowed for the accelerator area within the current ASE. The beam power limits are determined and approved by the AD Head in consultation with the ES&H Department Head, AD Radiation Safety Officer (RSO), and Operations Department Head on the Beam Permit. The Run Conditions for the area identifying the operating configuration are reviewed by the AD RSO, AD Operations Head and approved by the AD Division Head.

Safety Envelope

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

Operating Envelope

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

Experiment Operational Approvals

The Operational Readiness Clearance (ORC), outlined in PPD ES&H procedure PPD-ESH-0006, *ES&H Reviews for Experiments*, is a permit approved by the Particle Physics Division (PPD) Head for the commissioning and unattended operation of an experiment system or detector. The ORC process requires documentation of potential hazards and their mitigation, a review of the documentation, and a walk-through inspection of the experiment installation. Sub-systems within a detector can be reviewed individually and granted a partial ORC. As detector installation progresses, partial ORCs are accumulated for all sub-systems. PPD ES&H assigns a review committee to conduct the sub-system reviews and inspections of installations.

Safety Envelope

Experiments in PPD experimental areas shall be operated only with an approved PPD ORC.

Operating Envelope

Experiments in PPD experimental areas shall be operated only with an approved PPD ORC.

Cryogenic System Approvals

Cryogenic systems are reviewed and approved in accordance with FESHM Chapter 5032 Cryogenic System Review. The safety analysis and review program for cryogenic systems utilizes the help of ad hoc External Cryogenic Review Committees and the on-going review of design and procedures by the Cryogenic Safety Subcommittee of the Laboratory Safety Committee. Cryogenic systems may only be operated after review by the designated Cryogenics Safety Subcommittee Review Panel followed by operational authorization from the division head responsible for the area.

Safety Envelope

Cryogenic Systems shall be operated only with authorization and all required oxygen deficiency hazard precautions.

Operating Envelope

Cryogenic Systems shall be operated only with authorization and all required oxygen deficiency hazard precautions.

Accelerator Operations Staffing

The AD Operations Department is responsible for the operation of all the accelerators and fixed target beam transport enclosures, as well as the associated power supplies, electronics, utilities, and control systems. The Main Control Room is staffed with trained personnel from the Operations Department around the clock every day. 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 reading materials, videotapes, lectures, walk-arounds, self-assessment quizzes, and on-the-job training (OJT).

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.

Operating Envelope

A minimum of three qualified personnel from the AD, including at least one person who has achieved the rank of Operator II or higher, must be on shift during periods of beam operation. During periods of limited machine operations, the Operations Department Head may reduce the required number of personnel on shift to no less than one qualified member of the Operations Department who has achieved the rank of Operator II or higher.

Table A-1 Accelerator Beam Intensity Limits

Area	Operating Intensity	Safety Envelope Intensity	Beam Energy	Basis
Linac to NTF	6.7 E17 protons/hour	6.7 E17 protons/hour	66 MeV	Overburden [3]
Linac	3.54 E17 protons/hour	3.54 E17 protons/hour	400 MeV	Overburden [3]
Linac Absorber #1	6.4 E20 protons/year	6.4 E20 protons/year	400 MeV	Groundwater [4]
Linac Absorber #2	6.4 E20 protons/year	6.4 E20 protons/year	400 MeV	Groundwater [4]
MuCool Test Area to Emittance Absorber (Emittance Mode)	9.6 E15 protons/hour	1.06 E17 protons/hour	400 MeV	Overburden [5]
MuCool Test Area to Final Beam Absorber (Experiment Mode)	9.6 E14 protons/hour	1.06 E17 protons/hour	400 MeV	Overburden [5]
MuCool Test Area Final Beam Absorber	7.75 E19 protons/year	7.75 E19 protons/year	400 MeV	Groundwater [5]

Area	Operating Intensity	Safety Envelope Intensity	Beam Energy	Basis
Booster & 8 GeV Line up to cell 803	1.8 E17 protons/hour	1.8 E17 protons/hour	8 GeV	Overburden [6]
Booster 8 GeV Absorber	6.9 E19 protons/year	6.9 E19 protons/year	8 GeV	Groundwater [6]
8 GeV Line from cell 803 to cell 850	2.84 E17 protons/hour	5.67 E17 protons/hour	8 GeV	Overburden [7]
8 GeV Line from cell 850 to the MiniBooNE Target Station	1.62 E17 protons/hour	3.24 E17 protons/hour	8 GeV	Overburden [7]
MiniBooNE Target Station	7.5 E20 protons/year	7.5 E20 protons/year	8 GeV	Groundwater [8]

Area	Operating Intensity	Safety Envelope Intensity	Beam Energy	Basis
Main Injector	1.39 E17 protons/hour*	7.45 E17 protons/hour*	8 GeV	Overburden [9]
Main Injector	1.39 E17 protons/hour	7.45 E17 protons/hour	120 GeV	Overburden [9]
Main Injector	1.16 E17 protons/hour	6.23 E17 protons/hour	150 GeV	Overburden [9]
MI-40 Abort	1.0 E19 protons/year	1.0 E19 protons/year	150 GeV	Groundwater [9]
Recycler	2.25 E17 protons/hour	1.27 E18 protons/hour	8 GeV	Overburden [10]
Pelletron	0.0 Amp electron beam	0.0 Amp electron beam	0 MeV	Area in Standby No Beam Allowed
NuMI	1.46 E17 protons/hour	9.57 E17 protons/hour	120 GeV	Overburden [11]
Main Injector to Antiproton Source	3.6 E13 protons/hour	3.6 E13 protons/hour	8 GeV	Overburden [12]
Main Injector to Antiproton Target	1.8 E16 protons/hour	1.8 E16 protons/hour	120 GeV	Overburden [12]
AP0 Target Station	2.15 E22 protons/year	2.15 E22 protons/year	120 GeV	Groundwater [13]

* 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.

Area	Operating Intensity	Safety Envelope Intensity	Beam Energy	Basis
Tevatron Circulating Beam	0.0 protons/hour	0.0 protons/hour	0 TeV	Area in Standby No Beam Allowed
A0 Absorber	0.0 protons/year	0.0 protons/year	0 TeV	Area in Standby No Beam Allowed
C0 Absorber	0.0 protons/year	0.0 protons/year	0 TeV	Area in Standby No Beam Allowed
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	2.5 E15 protons/hour	2.5 E15 protons/hour	120 GeV	Overburden [14]
Meson Center beam from M01-M05 and MC6	2.5 E15 protons/hour	2.5 E15 protons/hour	120 GeV	Overburden [15]
Neutrino Experimental Area	6.0 E14 protons/hour	1.36 E15 protons/hour	120 GeV	Overburden [16]
Proton Experimental Area beyond the Switchyard Enclosure D	0.0 E0 protons/hour	0.0 E0 protons/hour	0 GeV	Area in Standby No Beam Allowed
A0 Photoinjector	2.88 E17 electrons/hour	2.88 E17 electrons/hour	25 MeV	Overburden [17]
HINS Linac	6.1 E18 protons or H- ions/hour	2.6 E20 protons or H- ions/hour	10 MeV	Overburden [18]

ASE Violation Determination and Actions

Operation of the accelerators without the specified credited controls in place and functional, or beyond the intensity limits specified as the safety envelope 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 ES&H Section and the DOE-Fermi Site Office.

A violation of the ASE is typically very clear. However, there may be minor failures of controls that are less obvious but still constitute a violation of the ASE. Determining whether a condition is a violation or a deficiency 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.
- Penetration shielding or other movable shielding is not in place when beam is permitted in an accelerator or experimental area.
- Both of the redundant channels of the Radiation Safety Interlock System are inoperable at the same entry location and beam continues to be delivered to the affected accelerator or experimental area.
- Accelerator operations or experiments are conducted without the required authorizations.
- Accelerator operations are conducted without the minimum specified staffing levels.

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

- Surveillance of an Operating Limit is not conducted within the time intervals specified in the ASE.
- A single radiation monitoring instrument is not functioning.
- An interlock system component fail-safe failure that results in a system shutdown.
- A radiation sign posting found missing during a routine surveillance.

Questions regarding determining if a control deficiency is an ASE violation or an operating deficiency shall be addressed to the ESH Director in consultation with the area line management and ES&H staff.

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 effected 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 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 ES&H Director and the DOE-Fermi Site Office.

References

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[2] **DOE Order 5400.5**, Change 2, Chapter II.1.a, January 7, 1993.

[3] **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.

[4] **Linac Momentum Beam Dump Vacuum**, L. Allen, J. Fulgham, F.G. Garcia, M. Gerardi, B. Higgins, K. Vaziri, G. Lauten, A. Lee, D. Newhart, B. Ogert, I. Rakhno, R. Reilly, D. Reitzner, November 2011.

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[6] **1998 Booster Shielding Assessment**, Robert C. Webber, page B.1, March 4, 1999. **MiniBooNE-Era Doses for MI8 Labyrinths & Penetrations**, B. Higgins, June 3, 2002.

[7] **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. **Safety Envelope for 8 GeV Line and MiniBooNE Operation**, Michael A. Gerardi, December 4, 2009. **8GeV Line and MiniBooNE Nova-Era Operational Limits**, Michael A. Gerardi, December 4, 2009.

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

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[12] **Antiproton Source 2000 Shielding Assessment,** Pbar Source Department, page 1, June 2000. **MiniBooNE-Era Doses for MI8 Labyrinths & Penetrations**, B. Higgins, June 3, 2002.

[13] **EP Note #8,** J. Donald Cossairt, page 17, December 1, 1994. **EP Note #17,** J. Donald Cossairt, A. J. Elwin, P. Kesich, A. Malensek, N. Mokhov, and A. Wehmann June 24, 1999. **Shielding Calculations for the AntiProton Target Area,** J. D. Cossairt and P. Yurista, TM-1136, page 2, September 1982.

[14] **2002 Shielding Assessment for the Switchyard 120 Project**, C. Brown, T. Kobilarcik, G. Koizumi, E. Ramberg, and W. Higgins, April 8, 2003.

[15] **Addendum to the SY 120 Shielding Assessment to add the MCenter branch to the beam line**, C. Brown and D. Jensen, February 5, 2004.

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

[18] **HINS Linac Shielding Assessment,** P. Kasper, January 26, 2011. ESH Section Document Database, ESH-doc-1480.