Switchyard Fixed-Target Beam Lines

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Revision History

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John E. Anderson Jr. Craig Moore	Initial release of the Switchyard Fixed-Target Beam Lines Chapter for the Fermi National Accelerator Laboratory Safety Assessment Document (SAD).	Revision 0 October 15, 2013

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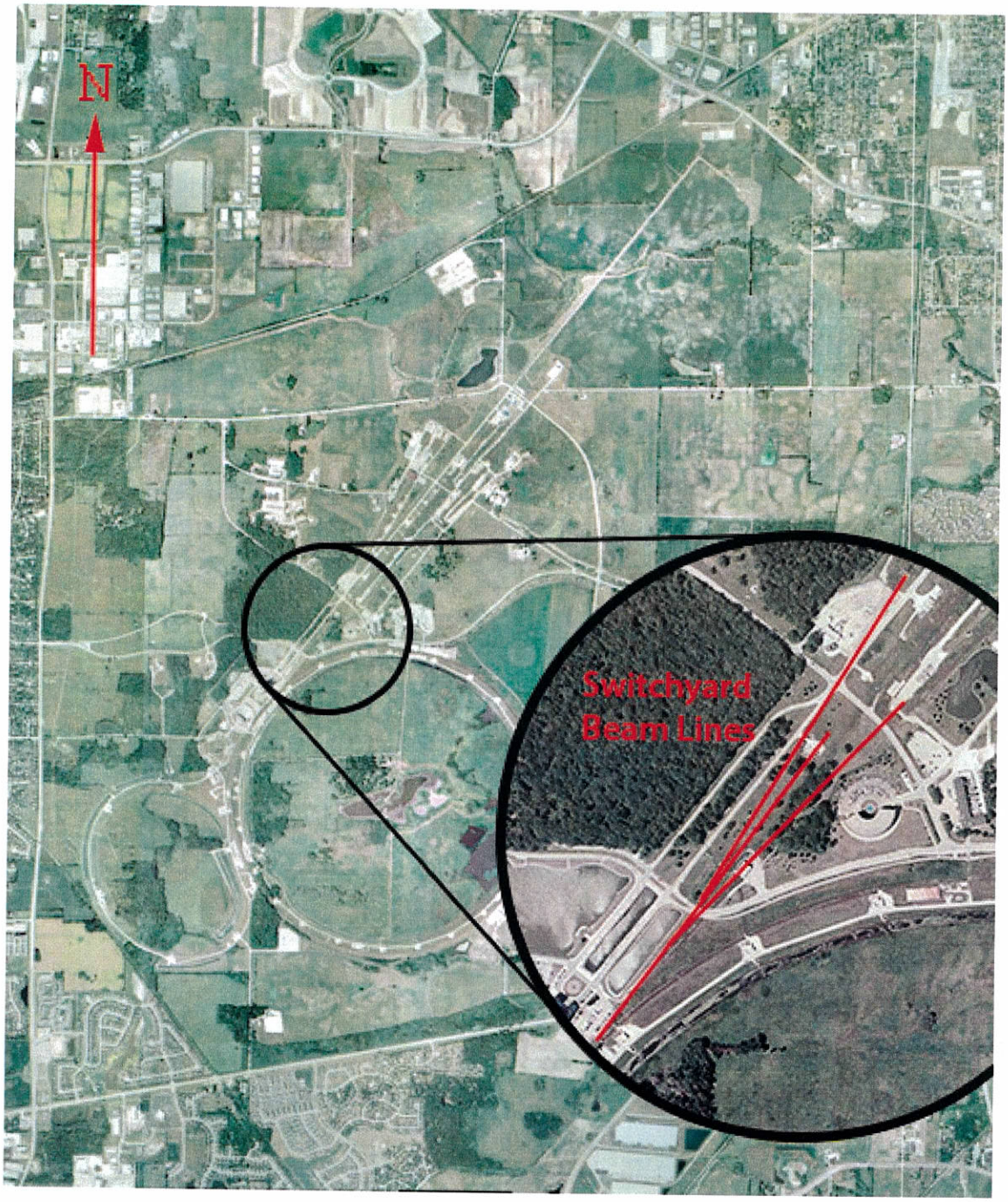
II - 14 Switchyard Area

II - 14.1 Switchyard Location on Fermi National Accelerator (Fermilab) Site

The following aerial photograph shows the location of the Switchyard area in relation to the Fermilab site.



II - 14.2 Inventory of Hazards

The following table lists the identified hazards found in the Switchyard enclosures and support buildings. All hazards with an asterisk (*) have been addressed in Chapters 1-10 of the Fermilab SAD and are not addressed in this section of the SAD.

Radiation Ionizing radiation Residual activation Groundwater activation Surface water activation Particle interactions in soil Radioactive waste	**Kinetic Energy** Power tools * Pumps and motors *
Toxic Materials Lead shielding * Beryllium components *	**Potential Energy** Crane operations * Compressed gases * Vacuum / pressure vessels * Vacuum Pumps *
Flammable & Combustible Materials Cables *	**Magnetic Fields** Fringe fields *
Electrical Energy Stored energy exposure * High voltage exposure * Low voltage, high current exposure *	**Gaseous Hazards** Confined spaces *
Thermal Energy	**Access / Egress** Life Safety Egress *

II - 14.3 Introduction

This Section II, Chapter 14 of the Fermilab SAD covers the Switchyard area. The chapter has been prepared by the staff of the Fermilab Accelerator Division (AD) External Beams Department.

II - 14.3.1 *Purpose of the Switchyard Area*

The Switchyard area provides beams of accelerated particles to target stations located along the Fermilab fixed-target beam lines. A dipole magnet extracts 120 Giga-electron Volt (GeV) protons from the Main Injector and directs the proton beam toward the Switchyard. The beam is split in the Switchyard and redirected to fixed-target beam lines that have been historically designated the Meson, Neutrino, and Proton beam lines. Only the Meson and Neutrino areas are presently receiving beam from the Switchyard. The Proton experimental area is in standby status. The designations Meson, Neutrino and Proton beam line do not reflect the operational nature or type of beam line.

The Meson and Neutrino beam lines transport protons to specific target stations. The target stations produce secondary particles of various energies. A secondary beam line transports these particle beams to specific experimental areas. The energy, intensity, and type of the secondary beam are chosen to meet the particular needs of a given experiment. Each of the secondary beam lines may be operated independently in a number of different modes for a particular experiment.

II - 14.3.2 *Description of the Switchyard Area*

The Switchyard fixed-target beam lines start in the Tevatron F Sector enclosure and continue to the upstream end of the Meson, Neutrino, and Proton enclosures M01, N01, and P01 respectively. The Switchyard fixed-target beam lines are comprised of the following:

- Tevatron F sector from the F17B3 dipole through the Transfer Hall;
- Switchyard enclosures B, C, D, E, G1 Stub, and J;
- Meson beam line enclosures F1, F2, and F3;
- Neutrino beam line enclosure G2;
- Service Buildings F23, F2, F27, F3, F4, A0, Switchyard Service Building (SSB), and G2.

The Switchyard enclosures and associated beam lines are depicted in Figure 1.

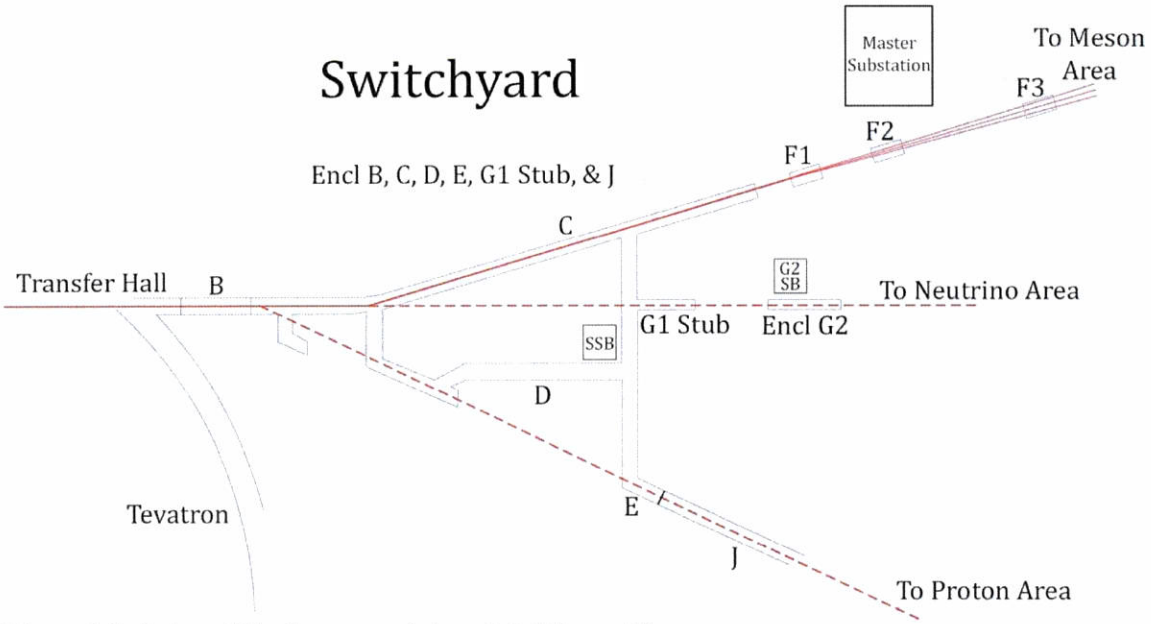


Figure 1 Switchyard Enclosures and Associated Beam Lines

II - 14.3.3 *Operating Modes*

The Switchyard receives a 120 GeV proton slow spill beam from the Main Injector and delivers it over a several-second duration to the Switchyard absorber for beam line tune up or to the Meson and or Neutrino experimental areas. The Meson beam lines currently service two experimental areas, Meson Test and Meson Center, for use in test beam research and development. The Neutrino beam lines currently service the SeaQuest experiment in the NM4 experimental hall.

The Switchyard fixed-target beam lines can safely transport up to 2.5×10^{15} 120 GeV protons/hour (hr). This upper limit on intensity is the outcome of detailed shielding assessments performed to address radiological concerns summarized in section 14.4.1. Changes in the running conditions at one of the experimental areas do not affect operations in the other experimental areas. Beam can be provided to any one experiment or all experiments simultaneously without special beam line configuration changes.

II - 14.4 Safety Assessment

This section analyzes the unique hazards associated with Switchyard operation.. The radiological hazards include ionizing radiation, residual activation, groundwater and surface water activation, particle interactions with soil, and radioactive waste.

II - 14.4.1 *Radiological Hazards*

Radiological hazards have been carefully considered in the design of the Switchyard fixed-target beam lines. There are two predominant radiological hazards. The first type of radiological hazard results from the interaction of the primary beam particles in the materials surrounding the beam pipes and beam line elements. The second type of radiological hazard results from the interaction of the primary beam with the Switchyard absorber and the subsequent interactions of the secondary beam with surrounding materials.

There are three categories of beam-induced radiation hazards:

- Prompt radiation levels inside and surrounding the enclosures that are present during beam transport. These levels may propagate offsite. The radiation includes neutrons, muons, and other energetic particles.
- Residual radiation due to activation of beam line components. Residual radiation can give rise to radiation exposures to personnel during accesses to the beam enclosures for repair, maintenance and inspection activities.
- Environmental radioactivity associated with activation of groundwater and soil due to the operation of the beam transport system.

Detailed shielding assessments [1, 2, 3] and post- assessment documents address these concerns. The assessments provide a detailed analysis of this facility, demonstrating the required overburden, use of signs, fences, and active interlocks to comply with the Fermilab Radiological Control Manual [4] (FRCM). The shielding assessments for the Switchyard include a section of the Tevatron F Sector; Switchyard enclosures B, C, D, E, G1 Stub, and J; Meson beamline enclosures F1, F2, F3, M01, M02, M03, M04, M05, MT6-1, MT6-2, MC6, MC7; Neutrino beamline enclosures G2, N01/NM1, NM2, NM3, and NM4; Service Buildings F23, F2, F27, F3, F4, A0, SSB, MS1, MS2, MS3, MS4, G2, NS1, NS7, and KTeV.

The shielding assessments consider groundwater and surface water activation; air activation; particle interactions in soil; radiation shielding requirements; labyrinth and penetration considerations; residual dose rates; and active and passive shielding controls and monitoring.

II - 14.4.1.1 Prompt Ionizing Radiation

Prompt ionizing radiation is the principle radiological hazard that arises when beam is transported through the Switchyard beam lines. In order to protect workers and the general public, the enclosures and beam pipes are surrounded either by sufficient amounts of shielding

(soil, concrete, or iron), and/or networks of interlocked detectors to keep any prompt radiation exposure within acceptable levels.

The Fermilab Shielding Review Subcommittee reviewed the detailed shielding assessments to address ionizing radiation concerns. The assessments provide a detailed analysis of the beam line; assess both passive and active shielding; assess required overburden or soil shielding; and review the use of signs, fences, and active interlocks to maintain any prompt radiation within acceptable levels.

Shielding assessments for the Switchyard beam lines have included analyses of injection, extraction, and absorption areas. The shielding assessments require that:

- *All penetrations must be filled with shielding as specified.*
- *All movable shielding blocks must be installed as specified.*
- *The average beam intensity in the Switchyard beam lines shall not exceed $2.5x10^{15}$ 120 GeV protons/hr.*
- *The radiation safety interlock system must be certified as working.*
- *Radiation detectors around the Switchyard beam lines are installed and interlocked to the radiation safety interlock system.*

II - 14.4.1.2 Residual Activation

The Switchyard beam absorber will be highly activated even when the Switchyard beam lines are not in operation or in a standby status. Access to beam absorber components will be tightly controlled with the control dependent on the level of residual radiation. The control measures include training and training verification, centralized access authorization, and key entry. Controls required for different levels of residual radiation are specified in the FRCM, and are detailed in the Radiological Work Permit (RWP) for the work to be performed.

In most situations, general RWPs for accesses will suffice. A job-specific RWP and an as-low-as-reasonably-achievable plan will be required for work on any highly activated equipment with a potential individual exposure greater than 200 mrem or potential job exposure greater than 1000 person milli-rem (mrem). These tasks will be supervised by members of the AD Radiation Protection Group under the direction of the AD Radiation Safety Officer (RSO).

II - 14.4.1.3 Groundwater and Surface Water Activation

Radioactivity is induced by the interaction of the high-energy particles with the soils that surrounds the beam line at the Switchyard beam absorber. Methodologies have been designed to

provide conservative estimates of groundwater and surface water activation. The ground and surface water methodologies calculate the estimated annual concentration and then calculates the concentration buildup for continuous operations over a 10 year period. The release estimate for surface and groundwater after 10 years of operation at an integrated intensity of 2.98×10^{17} protons per year will produce combined ^{3}H (tritium) and ^{22}Na (sodium-22) concentrations that are 23.0% of the surface water limits and a negligible fraction of the groundwater limits respectively[1]. The annual concentration estimates for ^{3}H and ^{22}Na surface water and groundwater from the Switchyard absorber are given in Table 1.

Table 1: Switchyard Absorber Surface Water and Groundwater ^{3}H and ^{22}Na Release Concentrations

Description	Annual Concentration Limits ((pico Curie (pCi)/milliliter (ml))		Annual Concentration Estimate (pCi/ml)	
	^{3}H	^{22}Na	^{3}H	^{22}Na
Switchyard Absorber Surface Water	1900	10	6.0×10^{0}	5.0×10^{-1}
Switchyard Absorber Groundwater	20	0.4	7.05×10^{-9}	6.27×10^{-10}
* 3H Regulatory Limit from 40CFR141 Federal Drinking Water Standards. 22Na Regulatory Limits from the DOE STD-1196-2011 Derived Concentration Standards.				

The ^{3}H and ^{22}Na surface and groundwater concentration estimates are a negligible fraction of FRCM limits. Groundwater is sampled as part of the Fermilab Environment, Safety, Health, and Quality Section Environmental Monitoring Program. Sump discharges and pond surface waters are sampled as part of the AD Departmental Safety and Health Procedure ADDP-SH-1003, *Routine Monitoring Program.*

II - 14.4.1.4 Particle Interactions in Soil

A forward cone, with angles on the order of 5 milliradians (mrad) of energetic penetrating muons is created whenever a 120 GeV proton beam is absorbed in the Switchyard beam absorber. There is no significant flux of pions and kaons produced at energies above 100 GeV and hence no significant flux of muons produced at energies above 80 GeV. The 80 GeV

muons have a specific ionization energy loss of 4 mega-electron volt (MeV)/centimeter (cm) and can only penetrate up to 200 meters (m) of earth equivalent shielding.

The Switchyard beam absorber is followed by steel and earth shielding. There is shielding well over 200 m earth equivalent in thickness in the forward direction for production angles of less than 5 mrad. This amount of shielding is sufficient to stop the muon plumes that arise from penetrating above grade.

The soil surrounding the Switchyard area will be sampled during decommissioning to document activation levels as required by the Fermilab Environment, Safety, and Health (ES&H) Manual (FESHM)[5].

II - 14.4.1.5 Radioactive Waste

Switchyard radioactive waste hazards and waste disposal will be managed within the program established for the Fermilab accelerator complex and as prescribed in the FRCM. Waste minimization is an objective of the equipment design and operational procedures. Although production of radioactive material is not an operational function of the Switchyard area, beam loss and, in the case of some beam diagnostics devices, intentional interception of the beam will result in activation of beam line elements. Activated items will be reused when feasible. Activated items that cannot be reused will be disposed of as radioactive waste according to the FRCM requirements.

II - 14.5 Credited Controls

II - 14.5.1 *Passive Controls*

Passive controls are accelerator elements that are part of the physical design of the facility that require no action to function properly. These passive controls are fixed elements of the beam line that take direct human intervention to remove. The Switchyard was designed with a concrete and earth covered radiation shield to protect personnel from radiological exposure during beam operations.

II - 14.5.1.1 Permanent Shielding

The Switchyard beam lines transverse and longitudinal shielding summary indicates that all transverse and longitudinal ranges provide adequate shielding and are within FRCM requirements for operations up to 2.5×10^{15} protons/hr[1]. The single exception is the Transfer

Gallery Head House that is an occupied building. Two interlocked integrating radiation detectors mitigate this concern.

II - 14.5.1.2 Labyrinth and Penetration Shielding

The details of the Switchyard labyrinth and penetration assessments have been documented [1]. The shielding summary details the mitigations necessary for each penetration to comply with the requirements of the FRCM. Interlocked integrating radiation detectors are installed in the F23, F2, F3, and F4 service buildings and at the A0 ramp to mitigate these concerns.

II - 14.5.1.3 Movable Shielding

The Switchyard area has moveable shielding placed in the equipment drop hatches adjacent to the SSB, at the downstream end of the G2 enclosure, and at the upstream end of the F2 enclosure. The shielding is controlled by the AD RSO by locking the drop hatch covers in place in accordance with AD ESH Procedure ADSP-10-0102 *Non-Interlocked Beam Enclosure Equipment Access Hatch Administrative Control Lockout.*

II - 14.5.1.4 Radiation Fences

The Switchyard area has posted and locked radiological fences to prohibit access to outside berm areas. These include the fences at the South Booster Road, Gate A0PSA1, Gate inside ring at Transfer Hall, Gate A0PAA1, Gate B/CPA1, Fenced penetrations at Road D, Gate SSBVA1, Gate SSBVA2, Gate FNCLCPA1, F1 enclosure equipment hatch F1MPA1, F2 personnel hatch F2MPA1, Gate M01PAW, Gate G2PA1, Gate G2PA2, Gate G2VA1, Gate G2PA3, Gate M01 PAE, and Gate M01PAW.

II - 14.5.2 *Active Controls*

Active engineered controls are systems designed to reduce the risks from accelerator operations to acceptable levels. These automatic systems limit operations, shut down operations, or provide warning alarms when operating parameters are exceeded. The active controls in place for the Switchyard area include Switchyard beam loss controls and a radiation safety interlock system.

II - 14.5.2.1 Switchyard Beam Loss Controls

Beam Loss Monitors routinely determine when beam is being lost in unacceptable regions. Beam Position Monitors and Segmented Wire Ionization Chambers determine the

trajectories of the beam so that the Main Control Room may control losses. The Beam Budget Monitor continually monitors the integrated beam delivered to the beam lines and the Switchyard Beam Absorber on an hourly basis.

The radiation detectors limit the radiation flux from one-pulse accidents to less than the limit appropriate to each Switchyard area. The detectors are set so that a beam loss producing a radiation flux that exceeds the allowable limit will trip critical devices designed to provide radiation protection for those in the area.

The spill rate to the Switchyard area is controlled by a Repetition Rate Monitor (RRM). This device currently inhibits beam extraction to the Switchyard enclosures if the extraction power supply is energized for more than four seconds in any sixty second period. Thus, beam cannot be transported to any of the Switchyard experimental areas, including the Meson and Neutrino beam lines, at a frequency greater that once per minute. The spill rate interval monitored by the RRM may be changed from the initial set point at the discretion of the AD RSO in conformance with the FRCM.

The use of fences, gates, and locks in addition to the aforementioned controls provide necessary and sufficient protection for those working in the Switchyard areas. The design, installation, use and maintenance of all signs and posting of areas where radiation may be present, search and secure procedures, controlled access procedures, and personnel training systems are in conformance with the requirements of the FRCM.

II - 14.5.2.2 Radiation Safety Interlock System

The Switchyard beam line employs a Radiation Safety Interlock System (RSIS). The characteristics of the system are described in Section I of the Fermilab SAD.

The RSIS inhibits beam transport by controlling redundant critical devices, HP3US and HP3DS, which are dipole bend strings located in the Tevatron F-Sector beam line at the F3 Service Building. HP3US and HP3DS are a string of 104 twenty foot magnets providing a bend angle of 450 milliradians and 360 milliradians respectively. Beam cannot traverse even the first two magnets in either string when off. In the event of a critical device failure, the system has a failure mode function that will reach back and disable the upstream Main Injector P150 Extraction RSIS preventing beam extraction from the Main Injector. The Switchyard RSIS prevents personnel access to Tevatron Transfer Hall, Enclosures B, C, D, E, G1 Stub, and J with beam enabled. Access is not allowed to these areas unless the critical devices are disabled.

The spill rate to the Switchyard beam lines are controlled by a RRM interlocked to the Switchyard RSIS. This device inhibits beam extraction to the Switchyard enclosures if the extraction power supply is energized for more than four seconds in any sixty second period. Beam cannot be transported to any of the experimental areas at a frequency rate greater that once per minute.

Radiation detectors are placed around the Switchyard area. The alarm levels of radiation detectors are interlocked to the Main Injector P150 Extraction RSIS to ensure compliance with FRCM requirements. Such detectors are capable of disabling beam within one second of exceeding a predetermined level.

Trained and qualified personnel from the AD Operations Department are required to search and secure the enclosures before permits from the RSIS can be reestablished following any personnel access to the area except under strictly specified controlled access conditions. The RSIS including requirements for hardware and system testing, inventory of interlock keys, search and secure procedures for the beam line, controlled access procedures, personnel training requirements, and procedures for maintenance of interlock systems are maintained in conformance with the requirements stated in the FRCM.

II - 14.5.3 *Administrative Controls*

All Switchyard area operations with the potential to affect the safety of employees, researchers, or the public or to adversely affect the environment are performed using approved laboratory, division, or department procedures. These procedures are the administrative controls that encompass the human interactions that define safe accelerator operations.

II - 14.5.3.1 Beam Permits and Run Conditions

In accordance with AD Administrative Procedure on *Beam Permits, Run Conditions, and Startup* (ADAP-11-0001), beam will not be transported to the Switchyard without an approved Beam Permit and Run Condition. The Beam Permit specifies beam power limits as determined and approved by the AD Division Head in consultation with the AD ES&H Department Head, AD RSO, AD Operations Department Head, and AD External Beams Department Head. The Run Conditions list the operating modes and safety envelope for the Switchyard area. Run Conditions are issued by the AD ES&H Department, and are signed by the AD Operations Department Head, AD RSO, and AD Division Head.

In order to run beam in the Switchyard areas, the Tevatron Transfer Hall, Switchyard Enclosure B, C, D, E, G1 Stub, and J must be secure, and the RRM must be active.

II - 14.5.3.2 Summary of Beam Operating and Safety Envelope Parameters

The Switchyard fixed-target beam lines have been assessed from the standpoint of beam operating and safety envelope parameters. The beam lines were assessed for operations up to 2.5×10^{15} 120 GeV protons/hr delivered from the Main Injector.

Accelerator operational approvals shall be obtained by following the AD Procedure ADAP-11-0001, administered by the AD ES&H Department and AD Division Head. Beam Permit and Run Condition documents shall identify the beam power and operating parameters allowed within the current Accelerator Safety Envelope. The Beam Permit specifies beam power limits as determined and approved by the AD Division Head in consultation with the AD ES&H Department Head, AD RSO, AD Operations Department Head, and AD External Beams Department Head. The Run Condition for the Switchyard area describes the operating configuration as reviewed by the AD RSO, AD Operations Department Head, and as approved by the AD Division Head.

II - 14.6 Summary and Conclusion

Specific hazards associated with the operation of the Switchyard area enclosures are identified and assessed in this chapter of the Fermilab SAD. The designs, controls, and procedures to mitigate Switchyard specific hazards are identified and described. The Switchyard area is subject to the safety requirements, controls and procedures outlined in Section I of the Fermilab SAD.

The preceding discussion of the hazards presented by Switchyard operations and the credited controls established to mitigate those hazards demonstrate that the area 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.

II - 14.7 Glossary, Acronyms

AD	Accelerator Division
Ci	Curie
cm	centimeter
ES&H	Environment, Safety, and Health
Fermilab	Fermi National Accelerator Laboratory
FESHM	Fermilab Environment, Safety, and Health Manual
FRCM	Fermilab Radiological Control Manual
GeV	Giga-electron volt
^{3}H	Tritium
hr	hour
m	meter
MeV	Mega-electron volt
mrad	milli-radian
mrem	milli-rem
mrem/hr	milli-rem per hour
^{22}Na	Sodium-22
pCi/ml	pico-Curie per milliliter
RRM	Repetition Rate Monitor
RSIS	Radiation Safety Interlock System
RSO	Radiation Safety Officer
RWP	Radiation Work Permit
SAD	Safety Assessment Document
SSB	Switchyard Service Building

II - 14.8 References

1 **2003 Shielding Assessment for the Switchyard 120 Project**, C. Brown, T. Kobilarcik, G. Koizumi, E. Ramberg, and W. Higgins, April 8 2003.

2 **Addendum to the SY 120 Shielding Assessment to add the MCenter Branch to the Beam Line,** C. Brown, D. Jensen, February 2004.

3 **Neutrino Muon Beamline Shielding Assessment,** T. Kobilarcik, M. Geelhoed, February 2012.

4 **Fermilab Radiological Control Manual**. - The web link is: http://esh.fnal.gov/xms/FRCM

5 **Fermilab Environment Safety & Health Manual**. - The web link is: http://esh.fnal.gov/xms/FESHM