Fermi National Accelerator Laboratory Safety Assessment Document

Section 1
Overview of Fermilab Facilities

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Revision History

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I - 1 Executive Summary

The Fermi National Accelerator Laboratory (Fermilab) facilities are subject to the requirements of the Department of Energy (DOE) Accelerator Safety Order (ASO), DOE O 420.2C[1]. These requirements are promulgated through the Fermilab Director's Policy Manual[2], the Fermilab Environment, Safety, and Health Manual[3] (FESHM), the laboratory's Radiological Control Manual[4] (FRCM), and the Fermilab Quality Assurance Manual[5] (QAM). Fermilab is classified and designed as a low hazard facility. Low-hazard facilities are defined in DOE O 420.2C to be facilities with no more than minor on-site and negligible off-site impacts to people or the environment.

A detailed analysis of the hazards found at Fermilab has been conducted and documented in this Safety Assessment Document (SAD). The results presented in this SAD, along with the supporting documentation, describe the measures used in the Fermilab Accelerator Facility to conform to the standards presented in the FESHM, FRCM, and QAM such that the potential for hazards are reasonably minimized. From these analyses, the Accelerator Safety Envelope (ASE), Appendix A, has been developed to define the physical and administrative controls that define the bounding conditions for safe operation of the facility. Operations within the ASE provide adequate assurance that the hazards to employees, the public, and the environment from facility operations are negligible both onsite and offsite.

I - 2 Introduction

Fermilab is operated by the Fermi Research Alliance (FRA), LLC for the United States Department of Energy. This SAD has been prepared to meet the requirements and definitions of the DOE Accelerator Safety Order, DOE O 420.2C consistent with best practice outlined in DOE G 420.2-1A[6].

I - 2.1 Scope, Objective, and SAD Document Layout

The scope of this document covers the Fermilab facilities, experimental areas and experimental detectors, accelerator research and development areas, and radiological facilities serving accelerator operations.

The objective of this safety assessment is to document both the typical industrial and uniquely accelerator-specific hazards presented by the operation of the Fermilab facilities. The assessment conforms to the standards presented by the Fermilab Director's Policies, Fermilab Environment Safety and Health (ES&H) Manual, the Fermilab Radiological Control Manual, and the Fermilab Quality Assurance Manual. These documents contain Fermilab's implementation of all applicable ES&H laws, regulations, and contractual Work Smart Standards Set[7], and provide the framework for Fermilab's ES&H training program. This SAD provides the necessary information to demonstrate that operation of Fermilab's accelerators, associated experimental areas, and accelerator research and development areas can be conducted in a manner that will produce minimal risks to the health and safety of Fermilab personnel, visiting scientists, the public, and the environment.

The SAD is divided into five major sections and two appendices. Section I contains an overview of the Fermilab facilities. Section II contains a description of each accelerator module. An accelerator module is a distinct, stand-alone section of the Fermilab facilities. Section III describes the experimental areas and experimental detectors used at Fermilab. Section IV covers the advanced accelerator research and development areas. Section V covers the radiological support facilities that serve accelerator operations. Appendix A contains the ASE. Appendix B is the Fermilab Shielding Policy. The document layout creates the framework necessary to develop a SAD that is coherent; readily adaptable to the ever-changing program of accelerators, experiments, and their operations; internally consistent in both content and nomenclature; and non-redundant in content.

I - 2.2 Assessment Methodology

Section I Chapter 4 takes a systematic approach to identifying the conventional industrial and uniquely accelerator-specific hazards presented by accelerator operations at Fermilab. The conventional industrial hazards are discussed along with the Fermilab policies that are in place to mitigate those hazards. The measures used to control and mitigate conventional hazards conform to generally accepted national codes and/or standards.

The uniquely accelerator-specific hazards warrant further analysis. Section I, Chapter 4 provides an overview discussion of hazards in this category along with the mitigation measures used to reduce the risk to acceptably low levels. The hazards in this category form the basis for the credited controls that are necessary for safe accelerator operations and the set of all credited controls form the ASE detailed in Appendix A. Additional details and analysis of these uniquely accelerator-specific hazards for a specific area are contained in the individual chapters of Sections II through V.

I - 3 Site, Facility Design Criteria, and Operations

I - 3.1 Fermilab Purpose

The primary purpose of Fermilab is to produce particle beams in the accelerators and make them available to qualified experimenters conducting high energy physics and particle beam physics research. Fermilab is uniquely positioned at the energy and intensity frontiers providing proton and electron beams for this kind of basic research.

The mission of Fermilab is to advance the understanding of the fundamental nature of matter and energy by providing leadership and resources for qualified researchers conducting basic research at the frontiers of high energy physics and related disciplines. This mission is accomplished by Integrated Safety Management of operational and safety concerns at all levels of the laboratory organization. The laboratory is committed to excellence based on its use of best business management practices and continuous improvement in all aspects of its work. This includes ensuring the safety and health of staff and visitors, a safe work environment, and minimal impact to the environment.

I - 3.2 Site Overview

I - 3.2.1 Site Location

The Atomic Energy Commission acquired the 6,800-acre Fermilab site in the late 1960s from the State of Illinois; see section I-3.2.2 below for an aerial site map. The dividing line between Kane County and DuPage County passes through the site from north to south, with the majority of the site located in DuPage County.

The development of permanent facilities has generally followed the initial site planning, which was accomplished in the late 1960s and early 1970s, and has been modified periodically by programmatic needs to the current date. The Tevatron enclosure is located in the south-central portion of the site with the adjacent Linac, Booster, and Main Injector including the Recycler, located to the west along with the Muon Campus. Three major fixed-target beam line areas, Meson, Neutrino, and Proton extend from the Switchyard area which in turn extends from the northwest side of the Tevatron enclosure and points in a northeasterly direction. The two neutrino beamlines, Booster Neutrino Beam (BNB) and Neutrinos at the Main Injector (NuMI) extend from the northeast side of the Main Injector in a northwesterly direction. New facilities are assessed as they are developed, for environment, safety, and health considerations, early in the design process, according to the requirements of the FESHM.

I - 3.2.2 Site Map

Aerial view of Fermilab site with major accelerator sections overlaid.

I - 3.2.3 Site Design Criteria

The Fermilab facilities must conform fully to the requirements imposed by all applicable Federal, State and local laws, Executive and DOE orders, and regulations concerning Environment, Safety and Health as expressed in the Fermilab Work Smart Standards. The operations also shall conform fully to the requirements imposed by the FESHM, the FRCM, the QAM and the Fermilab Comprehensive Emergency Management Plan[8].

The civil construction phases follow all applicable building codes and standards at the time of construction. Where no specific codes or Fermilab standards exist, the designers use best engineering practices, peer review, and/or outside consultants during the design stage. In instances where applicable ES&H requirements are in conflict, the requirements leading to the higher level of safety are applied.

I - 3.2.3.1 Worker Safety Program

Fermilab policy states that employees, subcontractors and users will only perform work in a safe and environmentally sound manner. The Fermilab Worker Safety and Health Program[9] (WSHP) is the top-level document which describes management's commitment to, and the responsibility for, establishing a worker protection program that will reduce or prevent the potential for injuries, illnesses, and accidental losses by providing workers with a safe and healthful workplace. The WSHP implements DOE regulations found in Title 10, *Code of Federal Regulations (CFR),* Part 851[10] and encompasses the Work Smart Set of Standards (WSS) that have been incorporated into the Management and Operating contract between DOE and FRA.

Fermilab management and staff are committed to safe operations. The laboratory has established the following safety priorities: 1) the Chief Safety Officer is a member of the laboratory Directorate; 2) weekly senior staff meetings include safety discussions; 3) cutting edge communications and data management tools advance safety performance; 4) program documentation such as the Director's Policy Manual, the FESHM, the ES&H training program, and relevant databases and guidance are readily available on the ES&H website; and 5) employee input assures a more complete program tailored to the hazards and the work to be performed. Employee involvement also promotes employee acceptance of requirements and commitment to comply.

I - 3.2.3.2 Radiation Safety Program

The operation of the Fermilab facilities conforms to the FRCM, and thus achieves conformance with applicable requirements of Title 10, *CFR*, Part 835[11]; keeps radiation exposures to personnel As Low As Reasonably Achievable (ALARA); maintains control of radioactive contamination and radioactive materials; complies with environmental radiation limits; and satisfies environmental monitoring requirements. Design, installation, use and maintenance of the following are also in conformance with the FRCM and are consistent with the Fermilab SAD: signs and posting of areas in which radiation may be present, radiation safety interlock systems, interlocked radiation detectors, search and secure procedures, controlled access procedures, personnel training, procedures for maintenance and testing of radiation safety interlock systems, and documentation of radiation safety interlock systems.

I - 3.2.3.3 Environmental Protection Program

All operations and maintenance activities shall conform to environmental protection requirements stated in the 8000 series chapters of the FESHM as well as applicable state and federal regulations (e.g., Title 40 of the *Code of Federal Regulations* and Title 35 of the *Illinois Administrative Code*). Chapter 8010 describes Fermilab's overall Environmental Management System that was developed to conform to ISO standard 14001. Specific environmental topics covered in the 8000 series include, but are not limited to, erosion control (8012), chemical and radioactive waste management (8021), wastewater discharges to sanitary sewers (8025), oil pollution prevention (8031), air emissions control (8080), and National Environmental Policy Act (NEPA) review (8060).

I - 3.2.3.4 Fire Protection Program

The operation and maintenance of the Fermilab facilities follows the fire safety requirements found in the FESHM. A computerized Fermilab Incident Reporting and Utility System (FIRUS) monitors the accelerator facility fire alarm systems. Fire protection-related equipment or status that FIRUS monitors includes: smoke and heat detectors, sprinkler flows, pull stations, High Sensitivity Air Sampling Detection (HSSD) systems, emergency power back-up generators, and redundant sump pumps. FIRUS also monitors other equipment not related to fire protection (e.g., site utility and security systems). The Communications Center continually monitors the FIRUS system and dispatches the on-site Fermilab Fire Department and other emergency services in response to an alarm.

The Fermilab Fire Department provides site fire suppression and emergency medical services (EMS). The Fire Department is certified by the State of Illinois and follows the National Fire Protection Association (NFPA) 1500, Standard on Fire Department Occupational Safety, Health and Wellness Program, and NFPA 1710, Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments, requirements for Fire Departments.

Buildings are designed to the International Building Code and applicable NFPA Codes and Standards and maintained under the code of record. Underground facilities are designed using NFPA 520, Standard on Subterranean Spaces. The Site-Wide Emergency Warning System (SEWS) provides mass emergency notification to all occupied buildings and remote personnel through integration with life safety voice systems and pagers.

I - 3.2.3.5 Other Design Criteria

The operation of the Fermilab facilities conforms to the Occupational Safety and Health requirements stated in the appropriate chapters of the FESHM. Topic areas addressed include: powered lifting equipment (10000 series); pressurized gas safety - including pressure vessels

(5000 series); general electrical safety (9000 series); chemical safety, industrial hygiene requirements, biological hazards, engineering controls, protective clothing and equipment, warning signs and devices (4000 series); and lock out and tag out procedures (Chapter 2100). Construction modifications or additions involving subcontracted labor to the Fermilab facilities also conform to the requirements stated in the 7000 series chapters of the FESHM.

I - 3.2.4 Organization

The Fermilab organization is based on a line management structure. The head of the Laboratory organization is the Director. The laboratory is further divided into Divisions and Sections (D/S) based on organizational and project needs.

The laboratory ES&H Section primarily advises the Directorate and the other D/S's on all ES&H matters, whereas the Director and heads of the Divisions and Sections implement ES&H policies through the line management organization. The ES&H responsibilities of the ES&H Section and the other D/S's are provided in detail in the FESHM.

The Laboratory Director has established the Fermilab Environment, Safety, and Health Committee (FESHCom). It is chaired by the Director and consists of a representative from each Division and Section. The FESHCom has established several standing subcommittees. These subcommittees are composed of technical and ES&H professionals with the subcommittee Chairs also being FESHCom members. The subcommittees provide a means for independent safety reviews of designs by people who are both technically knowledgeable and independent of the line managers who have direct line responsibility for the work that is under review.

The Chair of FESHCom has established a review subcommittee, the Safety Assessment Document review subcommittee. The subcommittee has the responsibility to review the results of each safety assessment document chapter for methodology, completeness, and compliance with the FESHM and FRCM.

I - 3.2.5 Experimental Programs

Scientists have identified three frontiers of scientific opportunity for the field of particle physics: the Energy Frontier, the Intensity Frontier and the Cosmic Frontier. Answers to the most challenging questions about the fundamental physics of the universe will come from combining the most powerful insights and discoveries at each of the three frontiers. Fermilab's scientific program pushes forward with world-leading research at all three interrelated frontiers.

I - 3.2.5.1 Energy Frontier Physics

Particle accelerators at the Energy Frontier produce high-energy collisions that signal new phenomena from the origin of mass to the nature of dark matter and extra dimensions of space. Fermilab is the U.S. host laboratory for the CMS experiment at the Large Hadron Collider (LHC) at CERN, in Geneva, Switzerland. Some 1,700 U.S. scientists from 87 universities and seven national laboratories carry out research at the LHC, the world's new energy-frontier accelerator.

I - 3.2.5.2 Intensity Frontier Physics

Scientists use intense beams from particle accelerators for intensity-frontier experiments that explore neutrino interactions and ultra-rare processes in nature. Neutrino discoveries are central to understanding key questions of 21st century physics: How did the universe come to be? What happened to the anti-matter? Do all the forces unify? Precise observations of nature's rarest processes open a doorway to realms of ultra-high energies beyond those that any particle accelerator could ever directly achieve, to the region where physicists believe all of nature's forces become one.

I - 3.2.5.3 Cosmic Frontier Physics

At the Cosmic Frontier, astrophysicists use the cosmos as a laboratory to investigate the fundamental laws of physics from a perspective that complements experiments at particle accelerators. Thus far, astrophysical observations, including the bending of light known as gravitational lensing and the properties of super-novae, reveal a universe consisting mostly of dark matter and dark energy. A combination of underground experiments and telescopes, both ground-and space-based, will explore these mysterious dark phenomena that constitute 95 percent of the universe.

I - 3.2.6 Operations

The Fermilab facilities are a complex of particle accelerators and beam transport enclosures used to provide the proton and muon beams used in the Laboratory's experimental research program. The main accelerator facilities produce beams of accelerated particles which are directed upon a number of stationary targets in various locations and are then distributed among some number of fixed-target beam lines. Each of the fixed-target beam lines can also operate in a variety of different modes depending on the needs of the experimenters using them.

There are a number of experimental research facilities that accelerate electron beams that are directed upon stationary fixed targets. Like the proton accelerator, these research facilities can operate in a variety of operating modes.

The Accelerator Division's Operations Department is responsible for the operation of the majority the accelerator and fixed target transport enclosures. The smaller experimental research facilities are operated by approved members of the experimental collaboration. The Fermilab Accelerator Science & Technology (FAST) facility is operated by a written Accelerator Division Administrative Procedure (ADAP), as described in Section IV Chapter 3 FAST for the specific reference.

I - 3.2.6.1 Commissioning Activities

Initial commissioning of new accelerator modules or experiments is conducted in phases. For accelerator modules, the beamline components are divided into three separate commissioning phases: a) system checkout, b) commissioning with primary beam to satisfy key performance indicator requirements, and c) commissioning with primary beam to satisfy physics requirements. The commissioning phases are described in detail in the accelerator module commissioning plans that are part of the Accelerator Readiness Review.

System checkout is performed after all necessary safety approvals are granted. An ESH/QA review committee oversees the review process for each project. When the project reviews are complete for systems that pose unique hazards, prior to the checkout phase, the review committee requests approval for initial system operation from the relevant D/S Head.

After all system checkouts are complete, the accelerator module is physically ready for beam. In accordance with AD Procedure ADAP-11-0001[12], the AD Head grants approval for start of commissioning after all necessary safety reviews have been completed, the Accelerator Safety Envelope has been approved, and the Beam Permit and Running Condition has been approved. The Beam Permit states the maximum beam intensity that is authorized for the area. The beamline Running Condition documents the radiation safety interlock status and any administrative controls that are required to be in place before the Operations Department is authorized to transport beam within that section of the facility.

Experiments approved for operation provide a Preliminary Hazard Assessment as part of their Technical Scope of Work with the Laboratory. The division hosting the experiment is responsible for conducting ES&H reviews of the systems identified in the Preliminary Hazard Assessment. Documentation of these reviews is the first part of the Operational Readiness

Clearance (ORC) described in FESHM 2005. The ORC is a permit approved by the relevant Division 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. The relevant division management and/or the Division Safety Officer (DSO) assigns a review committee to conduct the sub-system reviews and inspections of installations in the experimental areas.

The relevant Division Head grants a final ORC approval to the experiment, which has the following components:

- Sign-offs from the ES&H review committee(s). This is a collection of partial ORCs.
- Division management determination that the experiment is covered by this SAD. This statement specifies that the experiment complies with the requirements of a specific version of the Safety Assessment Document.
- Division management determination of the need for an experiment Conduct of Operations document. This statement documents the determination that sufficient engineered controls are in place to obviate the need for formal Conduct of Operations.
- Verification from spokesperson that any required procedures are approved and in effect. Where safety procedures are required, as determined by the partial ORC reviews, the experiment must demonstrate to the relevant Division Head that these procedures are in place and that appropriate training has been given.

I - 3.2.6.2 Normal Operations

The operational safety of accelerator and experimental areas is maintained through both administrative and hardware mechanisms. The hardware serves as the primary protection and the administrative procedures normally serve as a backup to support or reinforce the limits set through hardware. The exceptions are those administrative mechanisms through which the safety envelope is determined and enforced.

Governing accesses into enclosures is an important part of the responsibilities of the AD Operations Department. There are two basic types of access to these enclosures, supervised and controlled. A supervised access is used when there is a need for extensive work inside an enclosure. In this case, a full radiological survey is performed to document the hazards, and the hardware safety system is used to disable beam so that a Search and Secure of the enclosure needs to be performed before beam can be re-enabled. The AD Operations Department, along with the ES&H Section Radiation Physics Operations and Engineering Departments, are responsible for maintaining a current written Search and Secure procedure designed to ensure that all personnel have been cleared from an enclosure before a beam permit can be issued by the safety system.

A controlled access is used whenever limited work is being performed and it is desirable to maintain the security of the enclosure. This method of access limits the extent of the access and removes the need for a subsequent Search and Secure. All personnel entering a beam enclosure under Controlled Access conditions are required by the FRCM (Chapter 6) to complete Fermilab Controlled Access Training, or to be escorted by trained personnel. During a controlled access, each person entering the enclosure must have an enclosure Enter key in their possession at all times. The enclosure Enter key is interlocked to the radiation safety interlock system thereby disabling beam until the access is complete and the enclosure Enter key is returned. Current written procedures for Controlled Access are maintained by the ES&H Section.

The operators verify the training requirements for people making an access before issuing an enclosure Enter key. The access training may include such courses as Radiological Worker, Controlled Access, Oxygen Deficiency Hazard (ODH), Confined Spaces, and Lockout/Tagout (LOTO) Level 2.

Before maintenance is performed on devices connected to hazardous energy sources, Lockout/Tagout is performed in compliance with OSHA 29 CFR 1910.147 and FESHM 2100. In addition to LOTO, as a supplemental safety feature, power supplies with exposed connections and potentially hazardous devices are interlocked off via the safety system.

Administrative procedures and documents, such as Beam Permits and Running Conditions, are used to define safe operational parameters, such as intensity limits, energy limits, and repetition rates. An analysis of the level of protection afforded by the shielding over and around the enclosures is used to determine beam limitations which ensure conformance with the FRCM (Chapter 8). These limits are enforced by means of hardware settings that are controlled by the Operations Crew Chief. For the FAST accelerator, ASE beam intensity limits are monitored and enforced by the Main Control Room (MCR). The FAST Control Room is responsible for controlling and monitoring the pulse-by-pulse beam currents, intensity, losses, etc.

in accordance with an ADAP as described in Section IV Chapter 3 FAST for the specific reference.

The ES&H Section Radiation Physics Science Department keeps a log of the total beam intensities accelerated, transported, and/or delivered to targets, beam absorbers, and experiments. Summaries of these logs are included as part of the Environmental Monitoring Program described in Section I Chapter 6. This program defines administrative limits on the total amount of beam that can be delivered to these areas annually.

I - 3.2.6.3 Emergency Management

Emergencies affect normal operations. For on-site emergencies, the laboratory has an emergency management structure led by the Chief Operating Officer, members of the Emergency Operations Center (EOC) staff, and in conjunction with the Incident Commander in the field. The EOC interfaces with outside agencies, DOE Headquarters, the media, and coordinates emergency response assets and resources. Emergency response procedures are in the Fermilab Comprehensive Emergency Management Plan. The Hazard Assessment Document[13], updated triennially, contains details of the types of emergencies Fermilab can experience.

Emergencies requiring AD Operations Department response include such things as fire alarms, ODH alarms, radiation alarms, spills and leaks, flammable gas alarms, and other potentially dangerous situations affecting the facility. The AD Operations Department has emergency response procedures that are kept up to date and are consistent with the Fermilab Comprehensive Emergency Management Plan. These procedures consist of specific instructions and/or flowcharts for use by both the MCR staff and the operators responding to the emergency in support of the emergency response organization of the Laboratory.

Other events which are beyond the scope and control of the emergency management system include severe weather and offsite events having the potential to impact laboratory operations. The laboratory utilizes the SEWS to pass on information to personnel.

I - 3.2.6.4 Decommissioning Activities

Decommissioning is a general term for a formal process to remove an activity, operation, or facility from active status. As the Fermilab accelerator is developed over time, support facilities, accelerator and beamline equipment, and experiments (all "modules" of the Fermilab accelerator) will proceed through a life cycle. At the completion of the operational stage of the life cycle of a given module, decommissioning will be conducted. FESHM chapter 8070 is the relevant statement of Fermilab's policies on decontamination and decommissioning activities.

I – 3.2.6.4.1 The Forms of Decommissioning

Decommissioning activities can take several forms:

1. Placement of a given module in a state of preservation awaiting possible resumption of use in a configuration similar in kind to that previously operational state (so-called "mothballing");
2. Continued maintenance of the civil structure with removal of the equipment utilized during the operational state;
3. Removal of the previously operational equipment with the civil structure reconfigured to await some future purpose, defined or undefined at the time of decommissioning;
4. Removal of the equipment and civil structure and replacement with a new module;
5. Removal of the equipment and civil structure with restoration of the site to a condition similar to the pre-operational state; and
6. Removal of the equipment and civil structure with restoration of the site to a condition similar to that found before the creation of Fermilab.

I – 3.2.6.4.2 Data Collection in Support of Decommissioning

The implementation of FESHM 8070 throughout the life cycle of a given module of the Fermilab accelerator, inclusive of all Fermilab support facilities, will ensure the collection of the information needed to effectively implement decommissioning, once that time in the life cycle is reached. In particular, this information should include for each module to be decommissioned:

1. Volumes, locations, and levels of radioactivity in radioactivated items of equipment, parts of the civil structure, and adjacent shielding components such as soil, concrete, and earth as well as levels of removable radioactivity from components;
2. Locations and quantities of hazardous and regulated chemicals;
3. Identification of possible areas of potential interference with utilities (electrical, domestic water lines, industrial cooling water systems, low conductivity water systems, cryogenic transfer lines, radiofrequency systems, fire protection systems, controls and communications systems, HVAC systems); and

4. Identification of any environmental monitoring points or locations crucial to environmental permit compliance.

I – 3.2.6.4.3 The Process of Decommissioning

Decommissioning will proceed through a sequence of stages tailored to the particular end objective of the process as defined by overall Fermilab plans. These stages are anticipated to meet the needs of a particular defined future use for a given module being decommissioned but, in alignment with any relevant DOE-specified project planning activities, would be expected to follow a process such as:

1. Identification of need and scope of decommissioning;
2. Compliance with NEPA requirements (FESHM 8060) as needed during the planning process;
3. Detailed planning including preparation for removal of regulated and hazardous materials, removable radioactivity, activated components and structures, and activated shielding materials as defined within the scope of decommissioning;
4. Planning for appropriate disposal of materials and components removed from the module;
5. Supervision of subcontractor services used to perform the decommissioning including documentation of all stages of the process, with special attention given to any structures and components that remain in place;
6. Documentation of the final state subsequent to completion of decommissioning; and
7. Certification of completion of decommissioning by Fermilab management including the Chief Safety Officer.

I - 4 Safety Assessment

This safety assessment is intended to document the conventional, accelerator-specific, and experimental detector hazards found at the Fermilab facilities. The conventional hazards section contains hazards that are generally found in most industrial environments. As such, they do not warrant a specific safety analysis since the measures used to control them conform to accepted national codes and/or standards. The accelerator-specific hazards section outlines the hazards and typical mitigation employed to control these hazards. This section forms the basis for the ASE and outlines the typical credited controls instituted to mitigate these hazards to acceptable levels.

I - 4.1 Conventional and Environmental Hazards

These sections describe various conventional and environmental hazards which, apart from exposed electrical bus, have been judged as not warranting specific individual safety analysis since the measures used to control and mitigate these hazards conform to accepted national codes and/or standards.

I - 4.1.1 Electrical Hazards

Construction or modification of electrical equipment at Fermilab conforms to the safety and design standards of the FESHM, the Fermilab Engineering Standards Manual[14], the National Electrical Code (NEC NFPA 70), the National Electrical Safety Code (ANSI C2-1984) and OSHA 29 CFR 1910.331-335 "Safety Related Work Practices" where applicable.

Electrical bus work is either protected by physical barriers or is de-energized by the electrical interlock system prior to personnel access to the area. Power supplies that feed power to exposed conductors are required by FESHM 9140 and AD ES&H procedures to be connected into the electrical interlock systems. The electrical interlock system provides an additional level of safety but does not replace the need for LOTO when working on hazardous energy sources.

I - 4.1.2 Mechanical Hazards

The service buildings that support accelerator operations contain rotating machinery in relatively small rooms. Mechanical guards and, in some cases, emergency stop switches are provided for personnel protection in each of these buildings.

Two kinds of transport vehicles used in the Tevatron and Main Injector enclosures could cause damage to the magnet system and generate possible equipment or personnel hazards. These are the motorized battery-powered carts used to transport employees working in the tunnel and the battery-powered magnet mover used in the tunnel. Fixed barriers have been installed to prevent the battery-powered carts from colliding with valves, gauges, exposed beam tubes, and other sensitive equipment.

Many service buildings and enclosures contain overhead bridge cranes, hoists, fork trucks, and aerial lifts. Facilities Engineering Services Section Operations & Maintenance Group maintains and inspects all cranes, hoists, and fork trucks. All crane and fork truck operators complete the appropriate training requirements as identified in their Individual Training Needs Assessments plan. Aerial lifts are maintained and lift operators are trained by the organization owning the lift.

I - 4.1.3 High Pressure Hazards

High pressure gas systems and pressure vessels are potential mechanical hazards. There are many such systems throughout the complex. The Laboratory has established policy for reviewing pressure vessel safety which is outlined in the FESHM 5000 series of chapters. Laboratory policy requires that pressure vessels purchased by or built at Fermilab be fabricated in accordance with the American Society for Mechanical Engineers (ASME) code, Section VIII. Pressure vessels built at Fermilab must be designed according to requirements of the ASME code and reviewed by an independent, qualified reviewer other than the designer and preferably from another group not reporting to the designer or his supervisor.

Engineering Notes are required of all pressure vessels in use at Fermilab and include details of design calculations, materials specifications, test data, operating procedures and welding information. Engineering Notes are retained by the D/S responsible for the equipment. The Laboratory Director is authorized to grant an exception from the Laboratory policy as stated in FESHM 1010 if that exception is explained and analyzed in the Engineering Notes. Documentation associated with these exceptions remains with the Engineering Note.

I - 4.1.4 Fire Prevention

The accelerator areas are classified as a conventional hazard in terms of fire prevention. Fire prevention and protection is enhanced by independent fire department inspections, Highly Protected Risk Assessments, and prompt on-site fire department response. Continuous monitoring of systems by the AD Operations Department also contributes to quick detection of problems. Equipment is designed with the application of the criterion that minimizes or eliminates combustible material.

Service buildings and beamline enclosures are constructed primarily of non-combustible material. The primary fire hazard is from the numerous power and signal cables that are distributed throughout the buildings and tunnels. Extensive tests of fire propagation in horizontal cable trays were conducted. The results indicate that cable tray fires propagate extremely slowly, generate only low temperatures, and self-extinguish. The major concern is smoke propagation. Where possible, penetrations between services buildings or equipment galleries and enclosures are sealed.

Fire detection and suppression systems for service buildings and beamline enclosures were installed at initial construction. These systems were based on the fire loading, codes, and/or design criteria in place at the time of construction. Additional systems have been installed and upgrades to pre-existing systems have been made in conjunction with facility modifications and the application of more stringent criteria. For instance:

- Alarm systems consisting of manual pull stations are located in all service buildings and enclosures with a few minor exceptions.
- Ionization smoke detection systems are present in most service buildings.
- Other service buildings and some beamline enclosures have HSSD systems.
- Linear heat detector systems are in some beamline enclosures.
- Wet-pipe sprinkler systems are in several service buildings and in alcove areas of the Main Injector beamline enclosure.
- Selected helium compressor buildings have special total-flooding type suppression systems, which utilize water mist or a dry chemical extinguishing agent.
- Halon protection has been maintained in the Main Control Room and two central computer rooms.
- Activation of the detection or suppression systems initiates local alarms and a central alarm is also transmitted via the FIRUS system to the Fermilab Emergency Dispatcher.

General housekeeping is the responsibility of line management. The Building/Area Manager Program and scheduled walk-through inspections of all areas contributes to the monitoring and minimization of excessive accumulations of flammable and combustible materials. Minimization of excess material and proper housekeeping for the enclosures is specifically addressed by radiological worker training and waste minimization practices. Flammable materials are stored in approved flammable storage cabinets. Hazardous operations, such as welding, cutting, and brazing, are regulated by appropriate permits issued by the Fermilab Fire Department.

I - 4.1.5 Flooding Protection

The beamline enclosures have sump water-level alarms with remote readout in the Main Control Room. Flooding in these enclosures does not pose a threat to personnel safety but does represent a minor threat to equipment. Capability exists for remote operation of these sumps with a mobile generator in the event of an extended power outage.

I - 4.1.6 Industrial Hygiene

Controlling industrial hygiene hazards is addressed through the application of the relevant OSHA standards and other applicable standards (such as ANSI and ACGIH). The Fermilab facilities areas have numerous industrial hygiene issues including lasers, hazardous atmospheres, confined spaces, and hazardous materials.

The Laboratory employs a professional ES&H staff that monitors industrial hygiene hazards for compliance with the national standards and the FESHM 4000 series requirements. When necessary, the ES&H staff develops additional procedures to mitigate the hazards.

I - 4.1.7 Personnel Exposure to Magnetic Fields

In general, administrative rules, enforced by use of the electrical interlock system, prohibit personnel from being in enclosures when electromagnets, other than small powered correction elements, are energized. The fields associated with permanent magnets used in certain accelerator and beamline applications and the small powered correction elements that might be energized during normal access are normally confined to the interior of the magnets. Leakage fields from such magnets do not present a significant exposure hazard. Under most conditions, there can be no possibility of personnel exposure to high strength magnetic fields. In some cases, however, specialty magnets in the enclosures need to remain on. In those cases, access to the magnetic fields is restricted and areas above the action levels stated in FESHM 4270 are posted.

I - 4.1.8 Environmental Hazards

Environmental hazards are addressed through compliance with legal and regulatory requirements imposed by DOE Orders, Federal/State/local regulations, and FESHM 8000 series.

Numerous activities at Fermilab have the potential to produce environmental impacts. These include air emission sources such as fuel combustion, component cleaning, paint spray booths, soil erosion from construction activities, oil spills from transformers and generators utilized within the electrical distribution system, and glycol spills from various cooling systems. The laboratory has an IEPA-approved air emissions permit and a Spill Prevention, Control and Countermeasures Plan (SPCC) that has been certified by a registered Professional Engineer. New activities are reviewed for potential environmental and regulatory issues as part of the NEPA process.

I - 4.1.9 Cryogenics

Superconducting and other cryogenically-cooled components are used in the Fermilab facilities. They are cooled by liquid helium, liquid nitrogen, and/or liquid argon distribution systems. The design and operation of the components, their power supplies, and the associated low-temperature cryogen distribution systems considers the following potential hazards arising from the use of the cold, pressurized, liquid helium, nitrogen and argon:

1. High speed gas flow from venting;
2. Freezing from contact with the extremely cold fluids and gases or material in contact with them; and
3. Suffocation from the displacement of oxygen by these inert gases.

The high-speed gas flow from venting hazard exists at the roof of operational compressor buildings. Sudden venting activity has the potential of significantly startling personnel who might be present on the roof to the extent that they might fall off the roof. This hazard is mitigated by procedurally restricting access to the roofs of operational compressor buildings.

The freezing hazard posed by extremely cold fluids and gases is addressed in training for affected personnel and by requirements for wearing of personal protective equipment (PPE) in performing work with, or in the vicinity of, cryogens. PPE requirements are addressed in cryogenic operating and maintenance procedures. The hazard of suffocation is addressed below in the Oxygen Deficiency Hazards section.

The safety analysis and review program for cryogenic systems has been developed at Fermilab with the help of ad hoc External Cryogenic Review. Details of this program are described in the FESHM 5032.

Cryogenic systems may only be operated after review by the designated Cryogenics Safety Subcommittee Review Panel followed by operational authorization from the D/S Head responsible for the area. The cryogenic system operational authorization documentation is maintained by the respective Division or Section.

I - 4.1.10 Oxygen Deficiency Hazards

A comprehensive study has been made of conceivable types of incidents involving cryogens for all Fermilab Facility areas. A safety analysis for each cryogenic subsystem is reviewed by the Cryogenic Safety Subcommittee Review Panel. The D/S Head approves operations based on the recommendations of the Panel. The following items of documentation are provided by the system designers for review by the subcommittee: a system description including engineering design criteria, system schematics, preliminary operating procedures, results of system operating tests, and hazards analyses such as "failure mode and effects" analyses and "what-if" analyses.

The Laboratory has developed a policy detailed in FESHM 4240 and procedures for addressing potential oxygen deficiency hazards. The policy requires that, in potential ODH areas, the probability of a fatality shall be clearly below the value for workers in U.S. industry as a whole. The ODH policy also requires a calculation for each such work area and specifies the appropriate administrative controls and protective measures.

The potential exists under certain failure conditions in the cryogenic systems for an oxygen deficiency in the atmosphere in the surrounding workspaces. Each operation or event with the potential for causing oxygen deficiency in a given enclosure or service building is evaluated for its probability of occurrence and the associated ODH consequences. In addition, enclosures or service buildings adjacent to potential event areas, which have a leakage path, are evaluated, and an appropriate ODH Class is assigned. FESHM 4240 describes the procedures used to determine the ODH Class. The Accelerator Division ODH Assessment[15] documents the ODH analysis and classifications within the Fermilab facilities.

Fermilab is able to mitigate oxygen deficiency hazards, so that potential impacts to personnel on site are minor and are nonexistent off site. The D/S Cryogenics Department or Group maintains both the documented analyses for determining the ODH classifications and the pertinent review panel correspondence. Engineered controls, safety analyses and reviews, resulting determination of ODH Classification, and adherence to established policies and procedures related to ODH area entry collectively mitigate the oxygen deficiency hazards posed by operating a cryogenic system.

Oxygen deficiency hazards from the use of Sulfur Hexafluoride (SF_6) as a dielectric insulating gas is also assessed in accordance with FESHM 4240. The resultant risk assessment is reviewed by an independent engineer and approved by the D/S Head. The oxygen deficiency hazards posed by the use of SF_6 are mitigated by engineered controls, risk assessment and reviews, resulting determination of ODH Classification, and adherence to established policies and procedures related to ODH area entry. This, in conjunction with review and necessary authorization by the D/S Head to transfer SF_6 gas, effectively mitigates oxygen deficiency hazards so that potential impacts to personnel are minor on site and no impact off site.

I - 4.1.11 Flammable Gases

The use of flammable gases in physics experiments presents a unique type of installation, requiring special considerations. In many cases, mixing of gases is involved. Large volumes of gases may be present; thus, even small leaks or ruptures of thin windows may cause incursions into the flammable concentration region with a large inventory to support fire. Some flammable gases may be stored in the liquid state, increasing the inventory. Electrical equipment is an integral part of such installations and can thus provide an ignition source if such a system is improperly designed, fabricated, or operated.

FESHM 6020.3 outlines the requirements for storage and use of flammable gases. The chapter requires that a risk analysis be developed, and a review of the system be performed by the designated Fire Safety Subcommittee, followed by operational authorization from the D/S Head responsible for the area. The operational authorization documentation is maintained by the respective D/S. The risk analysis, independent review, and operational authorization effectively mitigates the hazards from the use of flammable gasses so that potential impacts to personnel are minor on site and there is no potential impact off site.

I - 4.2 Accelerator-Specific Hazards

This section describes the accelerator-specific hazards and outlines the mitigation employed to control these hazards. This section forms the basis for the ASE and outlines the typical credited controls instituted to mitigate these hazards to acceptable levels.

Each chapter in Sections II – V has a hazard table at the beginning of the chapter outlining the hazards found within that section of the facility. The hazard table outlines both the conventional and accelerator-specific hazards found within a specific portion of the facility. Not all areas will contain all of the accelerator-specific hazards outlined below. In the case where an accelerator-specific hazard exists within an area, additional safety analysis is warranted and will be described further in the relevant section of the chapter.

I - 4.2.1 Radiological Hazards

The predominant radiation hazard in the Fermilab accelerator areas is caused by the interaction of beam particles in the materials surrounding the beam pipes and beam line elements. Additional radiation hazards involve the handling and use of radioactive sources and X-ray producing devices. The FRCM describes the policies and procedures that must be followed in order to provide appropriate protection of personnel against radiation hazards.

The ES&H Section Radiation Physics Science, Operations and Engineering Departments administer and monitor access control procedures, radiation interlocks, and personnel training that have been developed to protect personnel from possible exposure to radiation inside the beam enclosures. This program follows the prescribed Work Smart Standards Set and ALARA principles specified in the FRCM.

There are three categories of beam-induced radiation hazards:

1. Prompt radiation levels inside and surrounding the enclosures, which are present during beam transport, may propagate offsite;
2. Residual radiation due to activation of beamline components, which can give rise to radiation exposures to personnel during accesses to the beam enclosures for repair, maintenance and inspection activities; and
3. Environmental radioactivity due to the operation of the accelerators and beam transport systems, particularly at the beam absorbers and targets such as the activation of air, soil, and groundwater.

I - 4.2.1.1 Ionizing Radiation

In order to protect workers and the general public, the enclosures and beam pipes are generally surrounded by sufficient amounts of shielding (earth, concrete, or iron). The shielding creates exclusion areas that are interlocked by the Radiation Safety Interlock System. In areas where there is insufficient shielding, networks of interlocked detectors keep any prompt radiation within acceptable levels. Detailed shielding analyses have been performed and are updated as necessary to determine that the shielding is adequate during beam operations. Guidelines for performing these analyses are given in Chapter 8 of the FRCM. This particular type of analysis is referred to as a shielding assessment. The Fermilab ES&H Section maintains the complete documentation of the shielding assessments and their review.

Accident conditions occur when the beam is lost in an area which is not intended for use as a beam absorber or when the operational beam limitations are exceeded. In many cases, the increased levels of radiation produced by an accident condition will be detected by an appropriately positioned and interlocked radiation detector that will automatically disable the beam. The detectors are subject to administrative procedures defining beam restart to ensure that the maximum possible hourly dose rates do not exceed acceptable limits. The shielding around the enclosures and the number, position, and trip settings of the interlocked radiation detectors are chosen so that no radiation protection guidelines can be exceeded under accident conditions.

Losing beam for an extended period of time on devices not designated as beam absorbers is not an immediate safety concern if the shielding over and around the enclosures is adequate. However, it can cause excessive activation within the enclosure. Enclosures in which such an accident could conceivably occur are surveyed for excessive radiation levels. If excessive radiation levels are found, they are noted and posted accordingly. Additional restrictions are imposed if work needs to be done in these areas.

The shielding assessment is intended to assure the effectiveness of the ASE for containing a beam-on radiation hazard. The general methodology used follows the approach described below.

1. A maximum limiting beam condition in terms of beam power is chosen and a general and conservative guideline for the amount of shielding required is calculated and applied to an entire area. For those locations satisfying the general guideline, the radiation shielding is adequate for the chosen beam condition, and no further analysis is necessary.

2. For those locations found to have insufficient shielding, calculations specific to the location are performed. If the shielding is found to be adequate, no further analysis is needed for that location.

3. For locations where specific calculations indicate the shielding to be insufficient, either radiation measurements are performed to verify the adequacy of the shielding or corrective actions must be taken. Possible corrective actions include adding additional shielding around the location, adding radiation detectors to the

Radiation Safety Interlock System, or increasing the level of access control to the areas outside the shielding as described in the FRCM.

Radiation exposure to personnel is possible for those in enclosures during beam operation. This hazard is averted by excluding access to the enclosures when beam is potentially present. In addition to the training of all personnel, the principal means of protection of personnel against this hazard is a fail-safe, redundant system of interlocked access gates, doors, and critical devices. Critical devices, which are interfaced to this system, are driven to such a state so as to prohibit beam from entering an enclosure for which the Radiation Safety Interlock has been broken. Critical devices include such equipment as bending magnet power supplies, beam stops, and collimators. The design, review, approval, and operating criteria for the Radiation Safety Interlock System are described in Chapter 10 of the FRCM. The Radiation Safety Interlock System test procedures and results are kept as part of Fermilab's permanent records.

I - 4.2.1.2 Residual Activation

Even when the accelerators and beam transport systems are not in operation, many enclosures remain radiological areas because of residual activation, and therefore access is tightly controlled. These controls include verification of training, centralized authorization, and key entry. The level of control depends on the level of residual radiation. The controls required for different radiation levels are detailed in Chapter 3 of the FRCM.

A feature of the access control procedures for these areas is that the access keys are issued only to workers from approved lists of personnel who have received the required training.

Work in high radiation areas (>100 mrem/hr) is further restricted through Radiological Work Permits (RWPs) and specific Radiation Safety Officer approval.

The bulk of radioactivity produced is at locations selected by beamline design that include beam collimators, primary target stations, and beam absorbers. Other locations that routinely exhibit high levels of radioactivity are those areas where the particle beam is altered from its normal circulating, accelerating or transport path.

Large radiation doses to personnel are usually avoided by simply delaying any required work in these areas and allowing for a period of time for radiation levels to decay for the typical accelerator-produced radioisotopes.

In order to locate areas that contain residual radioactivity, radiation rates are measured during controlled accesses, and radiation surveys are performed and documented prior to allowing supervised accesses. The procedures for performing, documenting, and filing the surveys are approved by the ES&H Section Radiation Physics Operations Department. During the survey, all areas with dose rates at or exceeding limits specified in the procedures are posted with dose rate information. Pre-printed survey maps are used to log this information in the respective beam enclosures. In addition to checking for dose rates, the survey crew also checks for loose surface radioactive contamination and, where appropriate, decontamination procedures are subsequently employed.

After the survey is complete and acceptable radiological conditions are verified, qualified personnel may enter the enclosures on supervised access. The two-primary means of understanding the hazards present in the enclosures are by referring to the survey maps and by taking note of the local postings where work is to be performed. Survey maps and Radiological Work Permits, when necessary, are made available to personnel in the Main Control Room or at the point of entry for review prior to entering the enclosures.

I - 4.2.1.3 Non-Ionizing Radiation

The two common types of non-ionizing radiation hazards found in use at the laboratory are radiofrequency (RF) radiation and coherent light sources (e.g., lasers). RF systems are utilized throughout the accelerator complex to accelerate particle beams. The primary mechanism to protect personnel from exposure is to contain the RF waves inside of coax cabling or waveguide. Periodic surveys are performed by the ES&H Section Industrial Hygiene Group for stray RF fields.

Lasers are used in some beamlines and experiments to provide light sources for beam diagnostics, detector calibration or provide photo-cathode light excitation to an electron gun. The use of lasers is governed by the requirements found in Chapter 4260 of the FESHM. Most lasers are Class 1, Class 2, or 3R where it is unlikely that the laser would cause an inadvertent injury. In the locations where Class 3B or 4 lasers are used, additional measures, including approval by the laboratory Laser Safety Officer prior to operation, are in place to control this hazard. In summary, non-ionizing radiation has the potential for no more than minor impact on-site and no impact off-site.

I - 4.2.1.4 Environmental Radiation Hazards

The environmental radiation hazards considered include off-site radiation doses from muons produced by proton interactions with targets, activation of the air in enclosures which is subsequently released to the environment, and irradiation of unprotected soil surrounding the enclosures leading to radioactivity in the groundwater or surface water.

These hazards are concentrated at the target stations and beam absorbers. By limiting the total amount of beam that may be sent to these areas, the amount of radiation that is released into the environment is kept within the limits specified in Chapter 11 of the FRCM. The total beam limitations due to activation of air, groundwater, surface water, soil, and external exposure have been determined for each of the accelerator enclosures, target stations, and beam absorbers. The most limiting is included in determining the ASE. Target and absorber locations routinely incorporate "Closed Loop" water systems to contain the activated water for proper disposal in accordance with FRCM Chapter 11.

Locations where there is a potential for the release of airborne radionuclides in measurable concentrations are identified and appropriately monitored to insure compliance with applicable standards. Groundwater and surface water are monitored on an as needed basis by the assigned RSO or the ES&H Section to insure compliance with the FRCM and applicable standards.

I - 4.2.2 Unique High Pressure or Vacuum Hazards

For most accelerator beamlines and experiments, high pressure vessels or vacuum vessels include routine industrial hazards that are covered within the section I - 4.1.3, High Pressure Hazards, above. Occasionally, experiments or beamlines have unique requirements for large pressure or vacuum vessels that are not typically found in the industrial environment, such as very large volume beam pipes under vacuum.

I - 4.2.3 Unique Electrical or Magnetic Field Hazards

For most accelerator beamlines and experiments, electrical and magnetic field hazards are routine industrial hazards that are covered within the section I - 4.1.1, Electrical Hazards, or section I - 4.1.7, Personnel Exposure to Magnetic Fields, above. Occasionally, experiments or beamlines have unique electrical requirements or significant magnetic field hazards that are not typically found in the industrial environment, such as very large analyzing magnets.

I - 4.3 Credited Controls

Credited controls 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.

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, procedures, and beam energy and intensity limitations that are followed to ensure safe accelerator operations.

I - 4.3.1 Passive Controls

Passive engineered controls reflect features that are part of the physical design of the accelerator facilities or other features that are incorporated into the fundamental design of the accelerators that require no action to function properly. These are the fixed elements of the accelerator. The passive controls considered necessary to ensure safe accelerator operations are discussed below.

I - 4.3.1.1 Passive Shielding

The passive shielding is the radiation shielding that is located between the exclusion areas and occupied areas to keep personal exposure to ionizing radiation within the limits specified in Chapter 2 of the FRCM. This shielding includes the concrete structure (e.g. walls, floors, and labyrinths) and the earth overburden surrounding the structure.

I - 4.3.1.2 Movable Shielding

The movable shielding is the radiation shielding that is placed between exclusion areas and occupied areas during accelerator operations to keep personnel exposure to ionizing radiation within the limits defined in Chapter 2 of the FRCM. This shielding is a credited control that may be moved during maintenance periods for equipment access.

I - 4.3.1.3 Penetration Shielding

The penetration shielding is the radiation shielding that is placed in penetrations, such as utility and RF waveguide routing, between the exclusion areas and occupied areas during accelerator operations to keep personnel exposure to ionizing radiation within the limits defined in Chapter 2 of the FRCM. This shielding is a credited control that may be moved during maintenance periods for installation of additional utilities or equipment access.

I - 4.3.1.4 Radiation Fencing

Fences are barriers used and posted to designate potential radiological areas during machine operations defining an exclusion area to keep personnel exposure to ionizing radiation within the limits defined in Chapter 2 of the FRCM.

I - 4.3.1.5 Guards, Postings, and Other Access Controls

From time-to-time, additional temporary or permanent controls are utilized to insure conformance with the FRCM. For example, guards and/or postings may be utilized to prevent access to a temporary radiological area in support of component radiography. Postings and locked barriers may be utilized to segregate contaminated accelerator items. The use of guards, postings, or other access controls are utilized within the limits defined in Chapter 2 of the FRCM.

I - 4.3.2 Active Controls

Active engineered controls are systems designed to reduce the risks from accelerator operations to an acceptable level. These are automatic systems that limit operations, shut down operations, or provide warning alarms when operating parameters are exceeded. The active engineered controls considered necessary to ensure safe accelerator operations are discussed below.

I - 4.3.2.1 Radiation Safety Interlock System

Radiation Safety Interlock Systems are used to prevent injury, death, or serious over-exposure from beam-on radiation, x-rays, 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 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 the interlock system cannot detect all component failures, periodic functional testing in accordance with Chapter 10 of the FRCM is necessary to ensure reliable operations.

I - 4.3.3 Administrative Controls

Administrative controls are the approved procedures that encompass the human interactions that define safe accelerator operations. Approved procedures govern all accelerator operations at Fermilab that can potentially affect the safety of employees, researchers, or the public, or adversely affect the environment. The administrative procedures and programs considered necessary to ensure safe accelerator operations are discussed below.

I - 4.3.3.1 Accelerator Operational Approvals

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 before system startup.

The Beam Permit and Running 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 Radiation Physics Operations Department Head, assigned Radiation Safety Officer (RSO), Operations Department Head, and Department Head responsible for the area on the Beam Permit. The Running Conditions for the area identifying the operating configuration are reviewed by the assigned RSO, AD Operations Head, Department Head responsible for the area, and approved by the AD Head.

I - 4.3.3.2 Accelerator Staffing Levels

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 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 other shift operators can consist of accelerator or beamline physicists that are experts in the operating area, Operations Department Specialists that are experts in individual operating areas, and Operator I's and II's that are working under the direct supervision of more experienced operations personnel. 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.

I - 5 Accelerator Safety Envelope Basis

The ASE is a set of physical and administrative conditions based on ES&H considerations as defined in the DOE Accelerator Safety Order, DOE O 420.2C, consistent with best management practices outlined in DOE G 420.2-1A. The ASE establishes and defines the boundaries within which an accelerator and its experiments may be operated. Operations performed within the boundaries of the ASE provide for protection of the laboratory staff, scientific users, the general public, and the environment. The operating limits are designed to prevent the effects of unscheduled, but anticipated events from causing violations of the ASE. For example, an accelerator facility can experience an unplanned event, such as a power outage, that may interrupt operations but does not compromise the safety of the facility.

The ASE is composed of engineered and administrative controls applicable to the Fermilab accelerator facilities and provides for safe operation of the laboratory's accelerators and experimental areas. The credited controls are included in the ASE to mitigate the accelerator-specific hazards identified for the facility in Chapter 4. Some of the controls, such as shielding, apply to all of the accelerator facilities, whereas others are specific to each accelerator module. Significant changes to these controls, operating conditions, or the facility that involve an unreviewed safety issue (USI) will require a revision or supplement to this SAD.

Because the facility operations necessarily take place with variability in the numerous operating modes, operating envelopes are used to provide assurance that the ASE is not exceeded as the operating conditions change. Fermilab has considerable experience operating the accelerator facilities. This operating experience shows that where operating envelopes are defined, each operating envelope limit affords time for corrective action response before the respective safety envelope is reached. By defining the limits beyond which the operating conditions would require corrective actions, operating envelopes serve as administrative controls to keep operations within the ASE. Variation of operating conditions parameters within the operating envelopes is normal. Variations beyond the boundaries of the ASE are treated as off-normal occurrences that must be reported to the DOE.

While credited controls provide a sufficient safety margin, as a conservative approach, some conditions are managed with additional controls to provide a defense-in-depth strategy that provides additional assurance of safe accelerator operations.

I - 6 Environmental Monitoring

The strategy for environmental monitoring and surveillance at Fermilab is established in the Fermilab Environmental Monitoring Program[16]. This program ensures compliance with legal and regulatory requirements imposed by DOE Orders, Federal, State, and local agencies, confirms adherence to permit conditions, provides data for permit revision/renewal, detects unplanned releases to the environment, and provides data to support environmental management decisions. The comprehensive site-wide monitoring program assesses the effect of past, current, and future activities by measuring and monitoring effluents and emissions from Fermilab operations and by calculating the effects of those operations on the environment and public health. An important consideration in the development and implementation of the monitoring program has been to ensure that the monitoring activities at specific sites are appropriate for individual facility operations.

The scope of the environmental surveillance conducted on-site encompasses potential and identified effluents to air, surface waters, drinking water, storm and sanitary sewers, soil, and groundwater and includes analyses for both chemicals and beam-produced radionuclides. Penetrating radiation outside of the shielded areas is also monitored. Samples are collected and analyzed according to a predefined schedule. Measured concentrations of radioactive materials and chemicals are compared to applicable standards, concentration guides, natural levels, and previous results.

A detailed description of the environmental monitoring and surveillance program can be found in "The Report to the Director on the Fermilab Environment"[17]. This report, which is prepared for each calendar year, contains an annual summary of monitoring results, subsequent exposure pathway analysis, and dose assessment, where applicable. Approved environmental sampling procedures have been established. Protection of groundwater resources is addressed in the Fermilab Groundwater Management Plan[18]. The environmental monitoring programs are utilized to track, trend, and evaluate process environmental discharges of air and water, along with accelerator operating intensities of the individual areas, for compliance with all applicable standards and in support of the laboratory environmental monitoring program.

I - 7 Quality Assurance

Quality assurance applies to all work conducted at Fermilab. It enables the laboratory to maintain programs in a high state of readiness, reliability, and sustainability to support the Nation's efforts of using high-energy physics to advance our understanding of the fundamental nature of matter and energy. Fermilab uses a graded approach to define and integrate the appropriate level of quality controls based upon risk of the subject initiative or operation. Using a graded approach is paramount to an effective and efficient quality program to ensure that the effort expended provides value to the organization based on the analysis of identified risks.

Fermilab's Integrated Quality Assurance program is composed of the Integrated Quality Assurance (IQA) program document, Quality Assurance Manual chapters, and division and section implementing procedures. The IQA Program is a key component of the Quality Management System supporting the Fermilab Contractor Assurance System (CAS) required by the prime contract between the Department of Energy and the Fermilab Research Alliance, LLC.

The IQA establishes the requirements necessary to implement and comply with DOE Order 414.1D[19]. This IQA applies to Fermi Research Alliance, LLC and all employees, contractors, subcontractors, and Fermilab users when performing work that affects the laboratory. It identifies quality requirements necessary to consistently meet the DOE contract obligations throughout the laboratory's divisions, sections, and projects and ensures that quality, safety, health, security, cyber-security, environmental, facilities/infrastructure maintenance and performance of research are integrated into all work conducted under the contract. The IQA program provides a system to monitor, control, and continually improve the laboratory's activities, processes, and systems.

I - 8 Post-Operations Planning

It is Fermilab's policy as outlined in FESHM Chapter 8070 to maintain information necessary for future decontamination and decommissioning (D&D) of any or all of the laboratory facilities. This documentation is maintained by the ES&H Section to provide adequate safeguards against injury or illness for employees, sub-contractors and the public or damage to the environment at such time that facilities are demolished.

Each D/S head is responsible for informing the Chief Safety Officer, who is responsible for the Laboratory's master D&D files, concerning any activities affecting possible future D&D activities. This includes updating the Radiological Facility Use records on at least an annual basis to identify any hazardous materials, other chemicals, and radioactivity in their facilities that are not removable. "As built" drawings are maintained to show the location and inventory of contamination. The Chief Safety Officer is notified of any changes of facility usage, for inclusion in the D&D files.

All actions taken to decontaminate a facility or to fix contamination prior to actual D&D work are documented by the laboratory organization that supervises the D&D work and transmitted to the ES&H Section prior to commencing actual D&D activities. Items to be documented include the means for accomplishing the D&D and may include, as necessary, regular environmental reviews, Radiological Facility Use reports, and activity-specific communications.

The Laboratory has comprehensive programs for the handling, storage, and disposal of both radioactive wastes and hazardous chemical wastes. The various waste programs are described in the FRCM Chapter 4 (Radioactive Materials), the FESHM 8000 series (Environmental Protection), and the FESHM 4000 series (Industrial Hygiene).

I - 9 Acronyms

ACGIH	American Conference of Industrial Hygienists
AD	Accelerator Division
ADAP	Accelerator Division Administrative Procedure
ALARA	As Low As Reasonably Achievable
ANSI	American National Standards Institute
ASE	Accelerator Safety Envelope
ASME	American Society of Mechanical Engineers
ASO	Accelerator Safety Order
BNB	Booster Neutrino Beam
CERN	European Organization for Nuclear Research
CFR	Code of Federal Regulations (United States)
CX	Categorically Excluded
D&D	Decontamination and Decommissioning
DOE	Department of Energy
DSO	Division Safety Officer
D/S	Division/Section
EA	Environmental Assessment
EENF	Environmental Evaluation Notification Form
EOC	Emergency Operations Center
ESH	Environment, Safety and Health
ES&H	Environment, Safety and Health
ESH/QA	Environment, Safety and Health / Quality Assurance
Fermilab	Fermi National Accelerator Laboratory
FESHCom	Fermilab Environment, Safety and Health Committee
FESHM	Fermilab ES&H Manual
FIRUS	Fermilab Incident Reporting and Utility System
FNAL	Fermi National Accelerator Laboratory
FRA	Fermi Research Alliance, LLC.

FRCM	Fermilab Radiological Control Manual
GeV	Giga or billion electron Volts
HSSD	High Sensitivity Air Sampling Detection
HVAC	Heating, ventilation and air conditioning system
IQA	Integrated Quality Assurance
LHC	Large Hadron Collider
LOTO	Lock out/Tag out
MCR	Main Control Room
MI	Main Injector
mrem/hr	Millirem per hour
mrem/yr	Millirem per year
NEC	National Electrical Code
NFPA	National Fire Protection Association
NEC	National Electrical Code
NEPA	National Environmental Policy Act
NuMI	Neutrinos at the Main Injector
ODH	Oxygen Deficient Hazard
ORC	Operational Readiness Clearance
OSHA	Occupational Safety and Health Administration
PE	Professional Engineer
PPE	Personal Protective Equipment
QA	Quality Assurance
QAM	Quality Assurance Manual
RAW	Radioactive Water
RF	Radiofrequency Wave
RSO	Radiation Safety Officer
RWP	Radiological Work Permit
SAD	Safety Assessment Document
SEWS	Site-Wide Emergency Warning System

USI	Unreviewed Safety Issue
WSHP	Worker Safety and Health Program
WSS	Work Smart Standards

I - 10 References

[1] DOE O 420.2C, Safety of Accelerator Facilities, July 21, 2011. The current web link is: https://www.directives.doe.gov/directives-documents/400-series/0420.2-BOrder-c

[2] Fermilab Director's Policy Manual. The current web link is: http://www.fnal.gov/directorate/Policy_Manual.html

[3] Fermilab ES&H Manual. The current web link is: http://esh.fnal.gov/xms/ESHQ-Manuals/FESHM

[4] Fermilab Radiological Control Manual. The current web link is: http://esh.fnal.gov/xms/ESHQ-Manuals/FRCM

[5] Fermilab Quality Assurance Manual. The current web link is: http://esh.fnal.gov/xms/ESHQ-Manuals/QAM

[6] DOE G 420.2-1A, Accelerator Facility Safety Implementation Guide for DOE O 420.2C, Safety of Accelerator Facilities, August 1, 2014. The web link is: https://www.directives.doe.gov/directives-documents/400-series/0420.2-EGuide-1a

[7] Fermilab Work Smart Standards Set. - The current web link is: http://www.fnal.gov/directorate/Legal/files/Appendix_1_20160119.pdf

[8] Fermilab Comprehensive Emergency Management Plan. The current web link is: https://esh-docdb.fnal.gov:440/cgi-bin/ShowDocument?docid=829

[9] Fermi National Accelerator Laboratory (Fermilab) Worker Safety and Health Plan. https://esh-docdb.fnal.gov:440/cgi-bin/ShowDocument?docid=250

[10] Title 10 of the Code of Federal Regulations, Part 851 (10 CFR 851), Worker Safety and Health Program, June 28, 2006.

[11] Title 10 of the Code of Federal Regulations, Part 835 (10 CFR 835), Occupational Radiation Protection Program, Sept. 11, 2017.

[12] ADAP-11-0001, Accelerator Division Administrative Procedure, Beam Permits, Run Conditions, and Startup.

[13] Hazard Assessment Document – current version.

[14] Fermilab Engineering Standards Manual. The current web link is: http://www-esh.fnal.gov:8001/FESM/Default.html

[15] Accelerator Division ODH Assessment, March, 1999.

[16] Fermilab Environmental Monitoring Program. The current link to ESHQ DocDB is: https://esh-docdb.fnal.gov:440/cgi-bin/ShowDocument?docid=1810

[17] The Report to the Director on the Fermilab Environment. – The current web link is: http://www-esh.fnal.gov/pls/default/esh_home_page.page?this_page=12831

[18] Fermilab Ground Water Management Plan. – The current web link is: https://esh-docdb.fnal.gov:440/cgi-bin/ShowDocument?docid=1689

[19] DOE O 414.1D Change 1, Quality Assurance, Issued April 25, 2011. The current web link is: https://www.directives.doe.gov/@@search?DirStatus=Current&DocID=414.1D