**PROPOSED SAD/ASE CHAPTER OUTLINE FOR LINAC FACILITY (Meets External Validation Review Team Expectations and is based on BNL Tandem Accelerator structure and content)**

**SAD**

**1. Introduction**

**2. Executive Summary of the Safety Assessment**

**3. Site, Facility, and Operations Description**

3.1 Introduction

Sections 1, 2, 3.1-3.8 are self-explanatory

3.2 Facility Organization

3.3 Characterization of the Facility and Operations

3.4 Hazards from Adjacent Facilities, Structures, or Interfaces.

3.5 Services and Utilities

3.6 Non-Accelerator Specific Hazards (NASH)

3.7 Training and Qualification for Operators

3.8 Operating Procedures

Section 3.9 describes why there should be confidence that the controls determined safe today will be safe tomorrow – the facility and operating circumstances won’t be changed without proper review.

3.9 Configuration Management for the Facility

3.9.1 Credited Controls for the Facility

3.9.2 Radiation Safety Review Committee

3.9.3 Accelerator Safety Review Committee (Equivalent)

3.9.4 Experimental Safety Review Committee (Equivalent)

3.9.5 Configuration Management Unreviewed Safety Issues (USI)

**4. Safety Analysis**

4.1 Methodology

4.2 Non-Accelerator Specific Hazards Screening

4.3 Hazard Identification

4.4 Hazard Identification Screening

4.4.1 Radiation Hazards

4.4.1.1 Residual Activation

The hazards listed in Section 4.4 are those hazards determined to be non-accelerator specific hazards that cannot initiate a maximum credible event and are adequately prevented/mitigated by the ESH processes. They do not need Credited Controls in the ASE. This section will state that conclusion for each of these.

4.4.1.2 Groundwater Activation

4.4.1.3 Surface Water Activation

4.4.1.4 Radioactive Water (RAW) Systems

4.4.1.5 Air Activation

4.4.1.6 Closed Loop Air Cooling

4.4.1.7 Soil Interactions

4.4.1.8 Radioactive Waste

4.4.1.9 Contamination

4.4.1.10 Beryllium-7

4.4.1.11 Radioactive Sources

4.4.1.12 Nuclear Material

4.4.1.13 Radiation Generating Devices

4.4.1.14 Non-Ionizing Radiation Hazards

4.4.2 Chemical and Hazardous Materials

4.4.2.1 Lead

4.4.2.2 Beryllium

4.4.2.3 Liquid Scintillator Oil

4.4.2.4 Pseudocumene

4.4.2.5 Ammonia

(Repeat of description above.)

The hazards listed in Section 4.4 are those hazards determined to be non-accelerator specific hazards that cannot initiate a maximum credible event and are adequately prevented/mitigated by the ESH processes. They do not need Credited Controls in the ASE. This section will state that conclusion for each of these.

4.4.2.6 Nanoparticle Exposures

4.4.3 Additional Hazards

4.4.3.1 Confined Spaces

4.4.3.2 Noise

4.4.3.3 Silica

4.4.3.4 Ergonomics

4.4.3.5 Asbestos

4.4.3.6 Working at Heights

4.4.4 Stored Energy Hazards

4.4.5 Electrical Hazards

4.4.6.1 Stored Energy Exposure

4.4.6.2 High Voltage Exposure

4.4.6.3 Low Voltage, High Current Exposure

4.4.6 Mechanical Hazards

4.5 Hazards Analysis

The hazards listed in 4.5 are not so readily screened as being NASHs that cannot initiate a maximum credible event and, therefore, require additional analysis. If it is determined they are accelerator specific hazards or can initiate a maximum credible event, then they must be considered in the Event Analysis section

4.5.1 Event Identification

4.5.1.1 Frequency and Consequence Bins

4.5.2 Work Environmental/Nat. Phenomena Haz.

4.5.2.1 Natural Phenomena Hazards (NPH)

4.5.2.2 Fire

4.5.2.3 Fluorinert and Decomposition Products

4.6 Event Analysis

4.6.1 Event Analysis – Exposure to Radiation

4.6.1.1 Shielding Efficacy

Section 4.6, Event Analysis, consists of identifying limiting conditions for a suite of plausible events associated with each accelerator specific hazard or NASHs that can lead to a maximum credible event.

4.6.1.2 Penetrations, Labyrinths, and access points

4.6.1.3 Linac Space 1

4.6.1.4 Linac Space 2

4.6.1.5 Radiation Safety Interlock System (RSIS)

4.6.2 Event Analysis- Fluorinert and its decomposition products

4.6.2.1 Add subsections as needed to describe event analysis

4.6.3 Event Analysis – Beam Limit

Section 4.7 describes the events that may occur for accelerator specific hazards or NASHs that can lead to a maximum credible event, and the Credited Controls required to prevent the event.

4.7 Event/Scenario Descriptions

4.7.1 Scenario-Defining Assumptions

4.7.1.1 Secnario-1 Unplanned Radiation Exposure to Personnel Outside the Facility

4.7.1.2 Scenario-2 Personnel Exposed to High Levels of Radiation

4.7.1.3 Scenario-3 Personnel Exposed to Flourinert Decomposition Products

4.7.2 Summary of Event Scenarios Process

**5. Accelerator Safety Envelope and Bases of Credited Controls**

5.1 Introduction

5.2 Selection Method for Credited Controls

Section 5 organizes the results of the analyses in the previous sections to clearly lay out the when, what, and why for the Credited Controls. The contents of this section will be used essentially verbatim to populate the ASE. Therefore, the linkage between the SAD and the ASE will be clear.

5.3 Analysis and Control Assumptions

5.3.1 Exposure to Radiation

5.3.2 Exposure to Flourinert Decomposition Products

5.4 Passive Credited Controls

5.4.1 Shielding

5.4.2 Fencing

5.5 Active Engineered Credited Controls

5.5.1 RSIS and associated detectors

5.5.2 Fluorinert Filter

5.6 Administrative Credited Controls

5.6.1 Authorization Operating Document

5.6.2 Staffing

5.6.3 Bounding Parameters

5.7 Configuration Management for Credited Controls

5.8 Required Calibration, Testing, Maintenance, and Inspection Schedules for Credited Controls

5.8.1 Operation of all RSIS components shall be tested at an interval annually not to exceed 12 months.

5.8.2 Area radiation monitors must be functionally tested and calibrated as an interval, not to exceed 12 months.

5.8.3 Operation of all ODH monitoring and alarming components shall be functionally tested at an interval annually, not to exceed 12 months.

5.8.4 All shielding shall be inspected at an interval not to exceed 12 months.

5.8.5 All Fluorinert Filters shall be inspected at an interval not to exceed XX months.

5.8.6 All fencing shall be inspected at an interval not to exceed 12 months.

**6. Quality Management Programs**

6.1 Fermilab Quality Assurance Program

6.2 DOE Order 414.1D Quality assurance

6.3 Personnel Training and Qualifications

6.4 Quality Improvement

6.5 Documents and Records

6.6 Work Process

6.7 Design

6.7.1 Configuration Management (CM)

6.7.2 Configuration Managed SSCs and Documents

6.7.3 Change Control

6.8 Procurement

6.9 Inspection and Acceptance Testing

6.10 Management Assessment

6.11 Independent Assessment

6.12 Accelerator Safety Software

**7. Accelerator Facility Post Operations: Stabilization, Deactivation and Decommissioning Plans**

7.1 Introduction

7.2 Baseline Conditions

7.3 End-Point Goals

7.4 Regulatory Requirements

7.5 Decommissioning Methods

7.6 Waste Streams

**References**

**Appendix A – Risk Matrices**

Legend:

* *Italicized blue text in brackets in a standalone paragraph is description of content to be inserted*.
* Green text standing alone is example from BNL Tandem SAD/ASE or suggested wording for a paragraph to be inserted; may include information specific to Tandem which would need revision for Fermilab.
* *Italicized blue text in brackets followed on the same* line by green unitalicized text is a description of content with an example from Tandem SAD/ASE or suggested wording for that content
1. **Introduction**

*[Insert Short paragraph of facility mission]*

This safety assessment addresses both non-accelerator specific hazards (NASH) and accelerator specific hazards found in the Linac Facility, the safety analysis and maximum credible incidents associated with operations in the facility, and the credited controls implemented to mitigate the risks of the hazards. Controls for non-accelerator specific hazards are specified in the Fermilab ES&H Manual.

*[Insert Very brief description of the facility (3-4 sentences)]*

The SAD is organized into seven chapters. Chapter 1 is an introduction. Chapter 2 contains the summary of the findings and conclusions of the safety analyses. Chapter 3 describes the characteristics of the facilities and the safety-related methods used to manage and operate the facility. Chapter 4 contains the quantitative and qualitative safety analyses, event scenarios, and identification of controls determined necessary to mitigate risk associated with facility and operational hazards. Chapter 5 describes the risk-based approach to determine credited controls for the Fermilab accelerator facilities and their safety bases found in the ASE. Chapter 6 describes the quality assurance (QA) program used to support Fermilab operations. Chapter 7 describes the approach to facilitate the decommissioning of the accelerators and support facilities.

**2. Executive Summary of the Safety Assessment**

The Safety Assessment Document (SAD) provides a safety assessment and descriptions for the following that comprise the Linac Facility:

*[Insert Bulletized list of facilities/boundaries/equipment]*

Administration and delineation of responsibilities for safety, health, and environmental protection are implemented using procedures and training to assure the safe, efficient operation of the Linac Facility. Facility staff and management update procedures for both routine operations and emergency conditions when changes occur or every three years.

The analysis contained in this SAD are integrated into the Accelerator Safety Envelope (ASE) for the Linac Facility and conclude that the mitigated hazards associated with facility operations pose no significant risks to the public and minimal risks to site personnel. The analysis identifies events and delineates controls deemed reasonable and prudent to provide protocols that reduce risks to an acceptable level. Based on this analysis it has been determined that the RSIS and shielding are required to prevent unplanned exposure to radiation; an alert system for an oxygen deficient environment along with associated ventilation system; and filtration for hazardous Fluorinert decomposition products are required.

**3. Site, Facility, and Operations Description**

**3.1 Introduction**

*[Insert more detailed description of segments capabilities and operations (see following example from BNL)]* The Tandem Van de Graaff Facility (Tandem or TVdG) at Brookhaven National Laboratory remains one of the world's largest electrostatic accelerator installations. The facility consists of dual Tandem Van de Graaff accelerators (MP6 and MP7). Both accelerators are capable of low-intensity, continuous beam and also high-intensity, pulsed beam. Both accelerators run at a maximum terminal voltage of 15 MV. The ion energies may range from 30 MeV protons to 375

MeV uranium ions. Beams produced at the Tandem can be transported (via the TtB transfer line) to the Booster. In addition, the Tandem facility has a local user program providing ion beams for a wide variety of industrial and space-related applications, including Single Event Upset (SEU), detector calibration, ion irradiation, ion implantation, and other ion-beam related applications. Each accelerator can be used for either the local user program or through the TtB. Although only one accelerator can deliver beam to the Target room or TtB at a time, it is possible for one Tandem to deliver beam to the target room while the other delivers beam through the TtB simultaneously. The Tandem facility’s capabilities of rapid energy and ion changes, well-controlled intensities, high-quality beams, and extraordinary reliability make it a versatile and productive experimental tool that enables research with high precision and detail.

**3.2 Linac Facility Organization**

*[Insert 3-4 sentences on the segment mission and how the segment’s organization does this safely]*

**3.3 Characterization of the Linac Facility and Operations**

*[Insert detailed description of the facility’s rooms, equipment, and construction including age, size/length/ and key components required for operation. Insert appropriate schematics/pictures (will likely take several pages) See Tandem ASE for degree of detail appropriate.]*

**3.4 Hazards from Adjacent Facilities, Structures, or Interfaces.**

*[Provide a detailed description of any risks from adjacent buildings or interfaces (see example from BNL following)]* Building 901A is separated from Building 901 by a masonry wall and a three-hour rated listed fire door. There is also a 1½-hour listed fire door between Building 901A and the modular building 901M. Activities from the adjacent buildings have minimal impact on 901A activities. The TtB has a minimal fire load and over 95% of the wiring installed will not self-propagate fire. Additionally, there is a sprinkler system throughout the tunnel and access buildings. There are smoke detectors above beam sections that have beam tuning elements. Smoke purge fans are located within the tunnel that blow air from the egresses to central points within the TtB. This allows a worker to be egressing with smoke being blown behind them. There is a fire door which prevents fire from Building 901A into the TtB. The only access to the Booster is a 24” diameter opening for the beam pipe. This opening is 10’ long and has sandbags (hand-moveable shielding) on both ends of the access tube. The hand moveable shielding also limits any potential smoke from the Booster entering the TtB. There is no ODH hazard from the Booster that could impact the TtB tunnel

**3.5 Services and Utilities**

*[Provide an overview of the segment’s utilities and services (see example from BNL following]* The Tandem buildings and utilities are managed and maintained by BNL’s Facilities & Operations (F&O) Directorate. The F&O supports research spaces and experimental and programmatic equipment, including:

* Operation of steam supply
* Maintenance of the AC power distribution systems including emergency power
* generators
* Well water for accelerator cooling and potable water systems
* Custodial services
* Air conditioning service and maintenance
* Building modifications

C-AD [C-AD stands for Collider - Accelerator Division, the equivalent of Fermilab’s Accelerator Directorate] along with Tandem staff review F&O work for impact on credited controls and approves maintenance work, new construction, or modification work on or near radiation shielding, activated or radioactive material, interlocked- and locked-accelerator enclosures, and systems that generate environmental emissions or those that impact the Tandem’s program schedule or operations.

**3.6 Non-Accelerator Specific Hazards**

Non-accelerator specific hazards (NASH) are those routinely encountered and accepted in general industry and for which national consensus codes and/or standards exist to guide their safe design and operation. Fermilab has incorporated these codes and standards into its Environmental, Safety, and Health programs**.** These are flowed down to the Accelerator Division. Robust controls are therefore in place for all NASH, and no special, facility-specific hazard analysis is needed so long as the NASH does not contribute to a Maximum Credible Incident for the facility. The Linac Facility uses controls for NASH based on the following hierarchy:

1. Elimination or substitution of the hazards where feasible and appropriate
2. Engineering controls where feasible and appropriate
3. Administrative controls such as work practices and procedures that limit workers’ exposures
4. Personal protective equipment (PPE)

Fermilab evaluates and implements controls for NASH risks via the FESHM, Job Risk Assessments, and Work Planning and Control programs.

**3.7 Training and Qualification for Linac Operators**

Linac Facility workers are trained following the requirements outlined in the **{enter training program formal name}** Training Program.

*[Insert a brief synopsis of how the training program is executed.]*

Training requirements are described, listed, assigned, and tracked in the **{Enter program system name}.** The system tracks the requirements, the due date for renewal of training, completion of training requirements, and sends reminders to supervisors and employees when training that is tracked in the system is coming due or has lapsed. All staff are required to maintain an awareness of their assigned training requirements. Staff whose training has lapsed in an area are required to inform their supervisor and shall not conduct activities related to the training until the training requirements have been satisfied. The **{Enter program system name}** also notifies supervisors of lapsed training. **{Fermilab needs to validate this is accurate}**

Linac Facility operators are trained in electrical safety, radiation safety, and LOTO. They also receive training in emergency responses, and ASE limits.

**3.8 Operating Procedures**

Operations procedures are found in the **{provide location of procedures}.** The **{provide location of procedures}** is divided into chapters that address various aspects of operations of the Fermilab complex including the Linac Facility, as well as accelerator- and equipment-specific procedures. Facility, equipment, and process procedures specific to the Linac facility are found in **{provide** **location of procedures}**. These procedures define the range of work activities performed and include the necessary checklists and log sheets where appropriate depending on the work activity. The format of the procedures, checklists, and log sheets is defined in Fermilab procedures.

**3.9 Configuration Management for the Linac Facility**

*[Insert the CM methodology used at the Linac Facility (see example from BNL following)]* C-AD controls configuration by methods that control the state of equipment and the accelerators, including version control of engineering drawings, operations procedures, work control processes, design review processes, safety review processes, and the Unreviewed Safety Issue (USI) screening and determination process based on the requirements of the SBMS Subject Areas: Accelerator Safety and Engineering Design.

The Tandem follows procedures to ensure the analysis, documentation, and authorization of all repair work or corrective maintenance have not infringed on safety. Chapter 13 of the C-AD OPM details the procedures that the Tandem follows for configuration management. For beam interlocking systems, the C-AD staff perform operational testing following configuration changes and maintenance to demonstrate that equipment and systems can perform their intended function. The C-AD document-control system ensures that staff have the latest revisions of procedures and drawings so they can properly control accelerator equipment.

**3.9.1 Credited Controls for the Linac Facility** *[Insert a summary of the Credited Controls]*

Passive credited controls include shielding and fencing. Engineered controls include the RSIS and Fluorinert decomposition product filter.

Administrative credited controls include staffing and beam limits.

All changes to credited controls, including drawings, must undergo a USI determination.

**3.9.2 Radiation Safety Review Committee** *[Sections 3.9.2, 3.9.3, and 3.9.4 describe review processes that ensure changes to credited controls do not impact safety. The text below is for the processes in place at BNL Tandem accelerator. The review elements for Fermilab likely differ. The appropriate processes for Fermilab should be specified in these sections.]*

The Radiation Safety Committee (RSC) reviews and approves all changes to the ACS for C-AD accelerator enclosures. They approve the critical devices that must remove the beam from the enclosure and establish the radiological conditions that the ACS must address. The RSC reviews shielding calculations and approves all changes to the shielding for the accelerator room, target rooms, or TtB, and ensures they do not involve an Unreviewed Safety Issue (USI). The Radiation Control Division (RADCON) determines the radiological postings. The RSC reviews fault studies during commissioning periods for new or modified accelerator facilities to verify the adequacy of the shielding. The RSC, or delegates, in conjunction with RADCON staff, may direct radiation measurements to confirm the radiological classification of facilities in addition to confirming shielding calculations. For example, for different radiation levels, the RSC decides the nature of the enclosure’s barrier, the entry requirements, the enclosure’s sweep and reset requirements consistent with the BNL Radiological Control Manual requirements, and the protections required to prevent both the enclosed and adjacent areas from faulting to higher-than-allowed levels of radiation.

**3.9.3 Accelerator Safety Review Committee (Equivalent)** *[See note for 3.9.2]*

The C-AD Accelerator Systems Safety Review Committee (ASSRC) reviews conventional safety aspects and hazard control of new and modified Tandem accelerator systems, including equipment obtained from outside facilities for use at BNL. The ASSRC requires a completed hazard-review questionnaire before the Committee meets to discuss the safety issues. After that meeting and before equipment start-up, the ASSRC examines the equipment at its operational location. The ASSRC assures that the new or modified accelerator system’s design meets safety requirements

**3.9.4 Experimental Safety Review Committee (Equivalent)** *[See note for 3.9.2]*

All experiments must be reviewed for safety prior to startup. A C-AD Experimental Review Coordinator (ERC) reviews each experiment to ensure all hazards are mitigated prior to startup .If the ERC is unsure if the hazards have been mitigated, then the review is passed to the C-AD Experimental Safety Review Committee (ESRC) chair to determine if the experiment requires a full C-AD ESRC review. All Tandem users must complete the Tandem Users Experimental Safety Approval Form prior to commencement of their experiment. All hazards and work to be performed must be included on the completed form. Once the form is complete, the experiment is reviewed in compliance the SBMS subject area Work Planning and Control: Experiments”9 and CAD OPMs. Configuration Management Unreviewed Safety Issues (USI).

**3.9.5 Configuration Management Unreviewed Safety Issues (USI)** *[Describe Fermilab’s USI process. Example from BNL Tandem is below]*

The Unreviewed Safety Issue Process is outlined in C-A-OPM 1.10.1, Procedure for Identifying Unreviewed Safety Issues. No activity or modification to systems, components, operations, or the facility may compromise the previously accepted/approved risks defined in the SAD or ASE. Proposed modifications, changes, or discovered conditions are screened for hazards that lie outside the bounds of those considered in the SAD and ASE or would compromise previously accepted accelerator risks. Within the Tandem, the Tandem Operations Coordinator is responsible for preparing the USI screening and evaluation. Any changes in the references, standards, procedures, processes, checklists, etc., referenced in this SAD shall undergo USI review prior to implementation for potential impact to this SAD and the associated ASE. Discoveries may present an unacceptable level of safety risk in a facility’s current operations and need to be communicated to the Brookhaven Site Office (BHSO) as soon as the issue is validated and prior to completing the formal USI evaluation. Following validation and communication of a discovery, C-AD works with BHSO to determine if the operation causing the unacceptable level of risk must be stopped or if existing controls are adequate to allow continued operations. It may be necessary to implement additional interim controls to allow continued operations. Any activity violating the ASE must be terminated immediately and the affected portion of the facility placed in a safe and stable configuration.

**4. Safety Analysis**

This safety analysis is intended to document the non-accelerator specific and accelerator-specific hazards found at the Fermilab facilities. For each facility, each hazard is either declared as non-applicable or a hazard risk matrix table exists either by reference or prepared specifically for that facility.

The non-accelerator specific hazards section contains hazards that are generally found in most industrial environments. For those NASH that are generally handled the same way across the lab, a common hazard risk matrix table is generated using the methodology and criteria of DOE HDBK 1163-2020. These tables are in Appendix C and specify the unmitigated risk, the preventive and mitigative measures in place, and the resultant residual risk. In the SAD Chapter for each facility, the facility identifies for each SIH if that hazard exists in that facility. If it does, the facility evaluates if any aspect of the hazard or the preventive and mitigative measures applicable to the facility differs from the information in the lab-wide hazard risk matrix for that SIH. If there are no differences, the SAD Chapter refers to the lab-wide hazard risk matrix. If there are differences, the differences are described. If a lab-wide hazard risk matrix table does not exist, the facility has prepared a facility-specific hazard risk matrix table.

The accelerator-specific hazards section outlines the accelerator-specific hazards and typical preventive and mitigative measures employed to control these hazards. The SAD Chapter for each facility identifies the accelerator-specific hazards that apply to that facility and by generation of a hazard risk matrix table using the methodology and criteria of DOE HDBK 1163-2020, identify the preventive and mitigative measures for each hazard and the resultant residual risk. The preventive and mitigative measures listed in the individual SAD Chapters for accelerator-specific hazards form the basis for the ASE.

The table below includes the complete list of hazards evaluated in the SAD. Hazards in bolded purple font (Prompt Ionizing Radiation, Cryogenics ODH, and Flourinert and Its Byproducts) are considered accelerator-specific hazards. The remaining hazards are treated as SIHs. Lab-wide hazard risk matrix tables have been generated for all the SIHs except for those in the Radiological category. Because the specifics of the radiological hazard vary from facility to facility, a common hazard risk matrix table was not deemed useful. Each facility will address these hazards specifically for their facility in their SAD Chapter.

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

**4.1 Methodology**

The safety analysis documents the hazard analysis process and results, describes the process used to systematically identify and assess hazards based on the potential internal, man-made external, and natural events that can cause the identified hazards to develop into accidents, and provides the results of the hazards identification and assessment process.

This section reviews the key elements used to perform the various hazard analyses in this Safety Assessment Document (SAD). A hazard analysis is a multi-step process that includes identifying, screening, and evaluating hazards applicable to the Linac.

This methodology considers the hazards, including natural phenomena and external man-made events, which can initiate and contribute to uncontrolled releases of radioactive or hazardous material, or any hazard that can significantly impact the public or workers.

This information allows consideration of off-normal events and accident scenarios. The consequences are estimated, both unmitigated and mitigated. Development of accident scenarios also enhances understanding of factors that influence accident frequency and magnitude, as well as those structures, systems, and components (SSC) and procedural controls that prevent and mitigate accidents.

**4.2 Non-Accelerator Specific Hazard Screening**

NASH are those hazards routinely encountered in general industry and construction, and for which national consensus codes and/or standards exist to guide safe design and operations without the need for special analysis to define safe design and/or operational parameters.

Because of the engineered and procedural controls incorporated into the facility design and operation, the Linac facility presents minor potential for on-site and negligible off-site impacts to people and the environment. The primary hazard is radiation from beams generated from the accelerator. These radiation fields are well-shielded and are reduced to low levels through the implementation of various management systems and controls.

In the analyses that follows, NASH are screened from further consideration if a mechanism to be a contributor to or an initiator of a significant release of hazardous material does not exist. However, if an SIH can contribute to a significant release of a hazard, it will not be screened out and will be evaluated further in Section 4.5, Hazards Analysis.

**4.3 Hazards Identification**

The risks at the Linac facility are confined to Building XXXX, where the accelerator is located and supporting facilities. The primary hazard is radiation associated with beam operations. The implications of this hazard representing the potential for accidental radiation are evaluated qualitatively and semi-quantitatively. Hazards associated with the accelerator and its operations, predominantly tasks needed to produce ions, are compiled in the sections below. They include a list of operational events, related hazards and their sources, and the controls available to minimize both the likelihood and consequences of events related to the accelerator’s operation and downstream processes. The hazards identification is comprehensive, resulting from facility walk-downs and input from subject matter experts, experimenters, operations personnel, and safety professionals familiar with the processes involved.

The sources for hazards identification included:

* Design and operating information for the Linac accelerator facility, including emergency procedures
* Fermilab historical documents
* Past Linac safety assessment and safety analysis documents
* Past events and issues that have occurred during operations
* Linac accelerator facility walk-downs to identify potential hazards that could adversely affect workers and the environment
* Group discussions with staff at the Linac accelerator facilities and safety professionals
* Work observations

All applicable NASH are screened, and those that may contribute to a hazard event beyond what is

controlled via ESH Program are further examined: namely radiation.

**4.4 Hazard Identification Screening**

**4.4.1 Radiation Hazards**

There are two sources of ionizing radiation in the Linac. The first is the beam and radiation induced from beam impingement on targets or other materials in the event of a beam malfunction (prompt ionizing radiation). This hazard is discussed in detail in Section 4.6.1. The other source is residual radioactivity due to activation of material from interaction with the beam.

The Fermilab Radiological Control Manual (FRCM) establishes practices for the conduct of radiological control activities at the Fermi National Accelerator Laboratory. It states Fermilab’s positions and views on the best courses of action currently available in the area of radiological controls. The FRCM has been endorsed by the Fermilab Director, the contractor senior site executive. It is considered to be part of the FESHM and thus conforms to all other documented safety plans required under the DOE-FRA contract. The FRCM is kept current and is a controlled document maintained by the Environment, Safety, Health (ES&H) Division. Even when an accelerator and/or segments of the accelerator 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 the FRCM. A feature of the access control procedures for these areas is that the access keys (“enclosure Enter keys”) are issued only to individuals who have received the required training or have received explicit approval for a waiver of the required training(s) by the DSO or Radiation Safety Officer (RSO) and have a qualified escort.

Work in High Radiation Areas (>100 mrem/hr) is further restricted through Radiological Work Permits (RWPs) and specific RSO 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.

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 Division 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 enclosure. 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 radiological 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 (RWPs), when necessary, are made available to personnel in the Main Control Room (MCR) or at the point of entry for review prior to entering the enclosures.

*[The below sections should be the hazards that either are not accelerator specific hazards and which clearly cannot lead to a maximum credible accident. For each of these, provide a description of where the hazard comes from and what is done to mitigate the risk for each of the areas. The information in the current SAD should be useful in filling in these sections. If the hazard is not applicable to Linac, state “This hazard is not applicable to the Linac and requires no further analysis or action.”* *For those hazards that are applicable, each section should end with the following statement:* “*This hazard is effectively addressed by implementation of Fermilab ESH policies and procedures. This hazard does not contribute to maximum credible incidents.” If this statement cannot be made, the hazard needs to be addressed in Section 4.5.2 and not in this section.]*

**4.4.1.1 Residual Activation**

**4.4.1.2 Groundwater Activation**

**4.4.1.3 Surface Water Activation**

**4.4.1.4 Radioactive Water (RAW) Systems**

**4.4.1.5 Air Activation**

**4.4.1.6 Closed Loop Air Cooling**

**4.4.1.7 Soil Interactions**

**4.4.1.8 Radioactive Waste**

**4.4.1.9 Contamination**

**4.4.1.10 Beryllium-7**

**4.4.1.11 Radioactive Sources**

**4.4.1.12 Nuclear Material**

**4.4.1.13 Radiation Generating Devices**

**4.4.1.14 Non-Ionizing Radiation Hazards**

**4.4.2 Chemical and Hazardous Materials**

**4.4.2.1 Lead**

**4.4.2.2 Beryllium**

**4.4.2.3 Liquid Scintillator Oil**

**4.4.2.4 Pseudocumene**

**4.4.2.5 Ammonia**

**4.4.2.6 Nanoparticle Exposures**

**4.4.3 Additional Hazards**

**4.4.3.1 Confined Spaces**

**4.4.3.2 Noise**

**4.4.3.3 Silica**

**4.4.3.4 Ergonomics**

**4.4.3.5 Asbestos**

**4.4.3.6 Working at Heights**

**4.4.4 Stored Energy Hazards (other than electrical)**

**4.4.5 Electrical Hazards**

**4.4.6.1 Stored Energy Exposure**

**4.4.6.2 High Voltage Exposure**

**4.4.6.3 Low Voltage, High Current Exposure**

**4.4.6 Mechanical Hazards**

**4.5 Hazards Analysis**

*[Provide a description of screening the hazards discussed in sections 4.3 and 4.4 to identify those that constitute accelerator specific hazards. The hazards that end up being screened as accelerator specific hazards will then be discussed in the Event Analysis section, Section 4.6. The words below are from the Tandem SAD and may not be strictly true for Fermilab Linac. This section should describe what Fermilab actually did.]*

The hazards identified in section 4.4 have been screened as not contributing to maximum credible incidents. Those hazards that remain require further evaluation in this section. Every existing hazard from the hazards identification process was subjected to a “multidisciplinary, what-if process,” resulting in a set of postulated potential event scenarios comprising an overall risk-limiting profile. Each accelerator hazard event is evaluated as to its frequency and consequence based on a qualitative and semi-quantitative assessment addressing the following:

• Quantities of hazardous materials

• Potential worst-case radiation fields

• Energy associated with possible hazardous material release events

• Quantities or fractions of overall hazardous materials potentially involved in the event (i.e., material at risk or MAR)

• Factors limiting the fraction of material that may be released outside the facility in release events

• Controls available to mitigate the respective risk for each event

**4.5.1 Event Identification**

Based upon the unmitigated risk determination for accelerator specific hazards, unique controls that may be deemed necessary and/or that provide substantial defense-in-depth protocols are identified and derived to address unacceptable consequences and frequency associated with the risk-limiting events. The controls identified in the hazard evaluation process and their effect on event frequency and consequence are also presented for the mitigated event risk-level determination. The collective impact of the controls is estimated conservatively, considering the availability and effectiveness of a given control and all available controls in the context of the likelihood and extent they may prevent or mitigate a given event. Credited controls are derived from the safety analysis as those that are essential to protect personnel and the environment. The control selection preferences are consistent with the nominal safety industry practice of ranking controls. The hierarchy of controls model is based on efficacy by selecting design for safe operation first, followed by preference of preventive over mitigative controls, passive overactive controls, engineered over procedural controls, and the use of PPE as the last layer of protection.

**4.5.1.1 Frequency and Consequence Bins**

Each event defined in section 4.7 is analyzed in an unmitigated fashion (i.e., without any controls) and assigned a consequence severity rank from Table 4-11 for each receptor: public or worker. Workers include facility workers who are in the immediate vicinity of an event, typically the closest located building on the local site area. Consequence severity categories are assessed semi-quantitatively, considering factors such as type, form, quantity of Material at Risk (MAR), and the energy associated with the accident phenomena that act on the material.

The hazards identified in sections 4.3 and 4.4 were evaluated using the methodology of DOE HDBK 1163-2020, including frequency and consequence criteria. Section 1, Chapter 4 of this document describes this analysis. [*Check to see if this section needs to be expanded to describe the bin structure and criteria from 1163 and contains the information currently in Section 4.5/4.5.1 of the Tandem SAD.*]

**4.5.2 Work Environmental/Nat. Phenomena Haz.** *[This section should include the hazards not included in Section 4. These are hazards that needed additional analysis to confirm if they are accelerator specific hazards or if they could lead to a maximum credible incident. For each one, a discussion of the potential for these hazards should be provided. And, if true, a statement made that they cannot contribute to a maximum credible incident.]*

**4.5.2.1 Natural Phenomena Hazards (NPH)** *[Discuss natural phenomena that may occur at the site. Conclude that they are rare and operations can be ceased. End with the statement that they cannot contribute to a maximum credible incident. Example words from the Tandem ASE, with some modifications for Fermilab, are below.]*

Fermilab Natural Phenomena Hazards1(NPH) include tornadoes, thunderstorms, lightning, snowstorms, ice storms, and earthquakes. Tornadoes, hailstorms, thunderstorms, rainstorms, snowstorms, and ice storms occasionally occur and potentially could cause damage. Fermilab has experienced thunderstorms, rainstorms, snowstorms, and ice storms over the last 40 years and has not sustained any significant damage.

Earthquakes at the Fermilab site are extremely rare. The probable occurrence of an earthquake sufficiently intense (> 5.6 on the Richter scale) to damage buildings and accelerator structures in the Fermilab area was investigated during planning before construction of the major accelerator structures. Seismologists expect no significant earthquakes in the foreseeable future. No active earthquake-producing faults are known in the area. Further information is available in the Brookhaven National Laboratory Natural Phenomena Hazards Evaluation.

While the Tandem facilities contain quantities of activated, radioactive, and hazardous chemical materials, the impact of an NPH causing significant damage would be mission-related (worker injury, equipment or building damage, local release of hazardous materials, or programmatic impact) and would not pose a hazard to the public or the environment. In fact, the NPH mitigation Performance Category for the Tandem facilities is PC-1 based on the guidance in DOE-STD-1020- 2012, Natural Phenomena Hazards Performance Categorization Guidelines for Structures, Systems, and Components21.

While credible NPH events are considered operational emergencies, they typically do not involve loss of operational control or significant releases of hazardous or radiological material. In such an emergency, Fermilab management would decide whether to shut down operating facilities, shelter workers, or evacuate workers from the site. NPH do not contribute to any maximum credible incidents.

**4.5.2.2 Fire - Combustible Materials and Injury Hazards** *[Start with the text previously developed for this section; strengthen the discussion as needed to be similar to the level of detail in the sample words from the Tandem SAD below. End with the statement that fire does not contribute to a maximum credible accident.]*

**4.5.2.2.1 Combustible Materials**

**4.5.2.2.2 Flammable Materials**

The fire detection and suppression systems at the Tandem facility vary from area to area depending on such factors as combustible loading, normal personnel occupancy, and equipment concentration levels. Fire detection systems include rate-of-rise detectors, smoke, and product-of-combustion (POC) detectors, and fixed-temperature detectors. The system’s level of response to these sensors also varies but always includes activation of local alarms and automatic notification of the BNL Fire & Rescue Group via a central control and annunciator panel located in the building 901A lobby. Fire suppression systems include multipurpose fire extinguishers, automatic Halon systems, and wet sprinklers.

The Halon system has a 30-second predischarge alarm to signal evacuation of the area. The density of Halon is designed to be 6% in air. In the event of a Halon release, the breathable O2 levels would be greater than 19.6%. “Standard on Halon 1301 Fire Extinguishing”, which can be found in the NPFA 12A-2020 addition, states potential hazards to individuals include, noise, turbulence, and cold temperature. It also states Halon 1301 has a very low toxicity and exposure in the 5-7% range produces little to no effect on a person. It also states that there has never been a death or any permanent injury associated with exposure to Halon 1301.

A standpipe system is also provided. Water is brought into the building in the Basement Equipment (BE) Room via a 6″ pipe and then distributed via a 3″ pipe to the east, west, and central portions of Building 901A. At the center of the building, a single-valved standpipe connection is provided on each floor level (Main Hall, EE Room, and BE Room), being fed from 1.5″ pipes which branch off the local 3″ pipe. Single-valved standpipe connections are also located at the east and west ends of the BE Room, and the east end of the building main hallway (in Lab 3), each fed from 1.5″ pipes. A 2.5″ pipe also connects the main 6″ feed to a Siamese connection located outside the building 901A main entrance. This allows the BNL Fire/Rescue Group pumper truck to augment the water flow in the system.

The automatic sprinkler system is provided only in the BE Room, as this is the only area of Building 901A where storage of significant quantities of combustible materials is permitted. The wet pipe sprinkler system is fed separately from the building standpipe system via a 6" pipe entering the BE Room at the west end. The system design complies with NFPA 13 for ordinary hazard occupancies. The sprinkler water control valve is monitored by a tamper switch. Upon activation of a sprinkler head, water flow is sensed automatically, and an alarm is transmitted to the BNL Fire/Rescue Group via the main annunciator panel in the 901A lobby. The alarm system complies with NFPA 72 for a style 7D system. Combustible storage in the BE Room is limited to cardboard boxes, wood, etc. Combustible polystyrene ductwork also contributes to the fire loading. Storage of significant quantities of flammable liquids or chemicals is only permitted in certain properly identified cabinets in designated areas of 901A.

The Halon fire protection systems provide fire suppression for the Electrical Equipment (EE) Room. This area presents the most serious potential for dollar and program losses by virtue of the concentration of electrical equipment and cabling. Activation and discharge of the Halon occurs in response to tripping of a fixed temperature heat sensor or a local pull box station. Operations staff can exercise an override of the system and, should a fire occur, activate the discharge manually using their own discretion. The Halon system has been designed to only displace 6% of the air, thus no hazard is generated with the release of the halon. Placing the Halon system under manual control does not prevent any alarm from being automatically transmitted to the BNL Fire Group.

The risk of fire damage to the Tandem facility has been reviewed and deemed acceptable in the BNL Strategic Fire Safety Plan (Official Use Only) and is effectively addressed by implementation of institutional and departmental procedures. Fire does not contribute to any maximum credible incidents.

**4.5.2.3 Fluorinert and its Byproducts** *[Describe briefly the hazard from Fluorinert decomposition products and state this is an accelerator specific hazard and will be discussed in more detail in Section 4.6.]*

**4.6 Linac Event Analysis**

*[Identify the accelerator specific hazards evaluated and how the analysis was done.]*

Event analysis consists of identifying limiting conditions for a suite of plausible events associated with accelerator specific equipment and operations. The unique risks associated with the Linac facility are the processes and equipment that revolve around the production of accelerated particles. These processes are considered in the limiting events evaluated for preventive and mitigating features that may reduce either the frequency or consequence of the postulated event. The frequency and consequence notations and risk level associated with the frequency and consequence are based on the methodology and criteria of DOE HDBK 1163-2020. Based on the analysis described in Sections 4.3 and 4.4, the accelerator specific hazards in the Linac facility are: radiation exposure due to prompt ionizing radiation and exposure to hazardous gases from decomposition products of Flourinert liquid used as an electrically insulating heat transfer medium.

**4.6.1 Event Analysis- Exposure to Radiation**

*[Short general discussion of the control of dose due to accelerator operations. Example of appropriate level of detail is in example below.]*

Typically, dose rates are calculated in a conservative manner that overestimates the potential dose. Similarly, the radiation-source terms and the duration of beam operations were overvalued. The retained records of archival calculations in the archival SADs, in technical notes, in memoranda to the Radiation Safety Committee (RSC), and in the RSC Committee’s minutes. The dose estimates determine the requirements for shielding, soil capping, radiological posting, access controls, potential for activated water, and air-emission monitoring during the design phase of a project or following a facility modification. The Accelerator Directorate conducts beam fault studies after a construction or modification to ensure adequate designs and maintains the records of the fault studies. Finally, operators monitor the following to assure that the accelerator and accelerator facilities operate within their approved safety basis:

• Check-off lists for each area are completed to verify the area has the correct shielding, and/or enclosure configuration before starting beam operations after a shutdown.

• Periodic dose-rate surveys are conducted and documented by qualified Radiological Control Technicians (RCTs) during beam operations.

**4.6.1.1 Shielding Efficacy** *[Provide a detailed description of the shielding design and the shielding analysis. Reference to the shielding analysis is appropriate, but this section should, at a minimum, address the following:*

* *Assumed beam strength and composition*
* *Design levels for shielding*
* *Use of fencing vs. shielding and why*

*Appropriate level of detail in example below from BNL Tandem Van der Graff accelerator.]*

While the original shielding basis is not known, several fault studies and surveys have been completed to determine the efficacy of the shielding. Appendix 1 shows the results of two fault studies. [Appendix 1 contains the full fault studies reports.]The Tandem facility can accelerate a large variety of ions over a wide range of energies. The available energies range from 30 MeV protons to 375 MeV uranium. These values correspond to 30 MeV per nucleon for protons and 1.6 MeV per nucleon for uranium. Ions lighter than niobium can reach energies that exceed the Coulomb barrier in collisions with the beam pipe or beam stops and thus produce appreciable numbers of fast neutrons and gamma-rays. The radiation levels produced by maximum energy protons and deuterons exceeds the levels that can be reached with any of the heavier ions (Table 4-15 ). Recent calculations were done assuming a deuteron beam of 30 MeV impinges directly (at 90°) on a cylinder of normal concrete of 4’ or 6’ with a radius of 5 cm, the dose rate would be two mrem/hour.23 The thickness of the walls which separate the accelerator hall and target rooms is 6’ thick. Calculations were done assuming a deuteron beam of 30 MeV impinges directly (at 90°) on a cylinder of normal concrete of 4’ or 6’ with a radius of five cm, the dose rate would be one µrem/hour. The radiation shielding of the accelerators and local target areas is adequate for protecting personnel under any circumstances as was established with extensive fault studies in Appendix 1. The calculations and fault studies demonstrate that the shielding complies with C-AD shielding policy.

A series of calculations has been completed to verify the radiation generated at the maximum terminal voltage (15 MV) for different ions. The simulations assumed the accelerated ions impinged on a piece of steel with 0.5 cm in thickness and a cross-section of two cm × two cm. The equivalent doses are calculated at one foot (or 30.48 cm) from the steel piece in the forward direction. The results of the equivalent dose rates (with their respective uncertainties) in the simulation are listed below.

**Table 4-15 — Maximum Radiation Levels Per Ion for Different Species**

|  |  |  |
| --- | --- | --- |
| Species  | Total Beam Energy  | Radiation per Ion |
| Proton  | 30 MeV  | 2.9×10-14 rem/proton ± 1% |
| Deuteron  | 30 MeV  | 3.4×10-14 rem/deuteron ± 1% |
| He-3  | 45MeV  | 5.3×10-15 rem/He-3 ± 2% |
| He-4  | 45 MeV  | 5×10-15 rem/He-4 ± 3% |
| Li-7  | 60 MeV  | ≲ 2×10-17 rem/Li-7 |
| C-12  | 105 MeV  | ≲ 2×10-18 rem/C-12 |

Table 4-15 indicates that for a given terminal voltage, as the mass of the ion increases, the amount of radiation per ion decreases. Elements heavier than carbon, will have an even lower dose rate.

To determine the maximum radiological hazard, a comparison has been done. The ionization efficiency for different atomic species varies, so the number of ions accelerated also needs to be considered. Figure 4-6 shows the amount of particle beam current required to match the dose rate for deuterium. The highest particle beam accelerated output of each ion is also listed.



**Figure 4-6: Estimated Particle Beam Currents to Produce Equivalent Radiation from a 30 MeV, 4** µ**A Deuterium Beam**

To determine if these currents were possible, the output of the ion sources were used as a reference as well as beam transmission through the accelerator. Figure 4-6 is generated from the negative ion production for the ions listed in Table 4-15.

The Tandem ASE is based on shielding calculations and on fault studies performed with a four µA, 30 MeV deuteron beam. This intensity would be difficult or impossible to duplicate at present and is twice as large as the two µA limit defined and enforced by operational procedures. The question then arises about the limits for other beam species. The blue bars in the graph show the estimated intensities of other beam species that would be required to generate the same dose rates as a four µA, 30 MeV deuterium beam. These values were derived from MCNPX 2.7.0 and MCNP 6.2 simulations documented in an RSC memo dated 10/11/2021 and revised 11/4/202124. The ion energies that were used for these simulations are 30 MeV for protons, 45 MeV for helium, 60 MeV for lithium and 105 MeV for carbon. These are the maximum energies available when the terminal voltage is at its maximum value of 15 MV.

For 30 MeV protons, the intensity required to produce the same dose-rate as 4 µA deuterons is 4.7 µA as shown in the graph. We however adopt the same operational limit of 2 µA as for deuterons. For He-3 and He-4, the maximum intensity of negative ions available from the ion source is 2 µA, and therefore no operational limit is required. The same is true for lithium, carbon, and all the heavier ions. In all these latter cases the required intensities would be orders of magnitude above both the ion-source and the accelerator capabilities

**4.6.1.2 Penetrations, Labyrinths, and access points** *[One paragraph discussion with some details about controlling radiation through penetrations, via labyrinths, and access points. Appropriate level of detail in the example below.]*

The facility was carefully laid out to minimize exposure to personnel while running. Penetrations, labyrinths, and access points (door plugs) were located to eliminate radiation exposure from these points. Penetrations in the wall are filled with equal or denser material than the concrete wall. Door plugs are 4 feet thick and reduce the MCI to 2 mrem per hour. The only labyrinth to the accelerator room floor is from target room 4 to the accelerator room 2 (Figure 4-7). It has two 90-degree bends and the two doors are 12 feet apart. Both doors are interlocked to insert the beam stops if they are opened. The doors only allow access from the accelerator room to target room 4. Labyrinths in the pits are used for cable access and have locked gates which prevent access. The radiation from beam is in the accelerator rooms and active target rooms and at the MCI the dose rate at the target room labyrinth door would be 3.4 mrem/hour.

*[Insert a section for each specific space in the facility for which the shielding analysis differs. A few paragraph description of the basis of the shielding analysis for each area in which the analysis differs based on source or shielding concept. Degree of detail appropriate can be seen for the two spaces discussed below for the BNL accelerator. Include sections for as many spaces as appropriate.]*

**4.6.1.3. Linac Space 1** *[Words below are from Tandem SAD for Tandem and Target Rooms]*

In estimating the degree of radiation risk, the shielding has been designed assuming the maximum operating beam for each accelerator and the target rooms. The facility has been designed so the vault walls are the shielding. The walls which separate the accelerator hall and the target rooms are four-feet thick. The RSC determined, based on fault studies, the location of the chipmunks.

The shielding is designed to mitigate the greatest radiation hazard, which is deuterium from Table 4-15. Thus, the shield is more than adequate for protection against heavier-ion loss because their intensity and/or individual nucleon energies are much less by comparison.

A fault study was conducted in the early nineties27 to validate the original shield design. There were several areas where elevated radiation was detected. Hand moveable shielding was added to target room 3 to reduce these levels. Large concrete blocks were also installed outside of 901A. This shielding is under configuration management.

**4.6.1.4. Linac Space 2** *[Words below are from Tandem SAD for Tandem to Booster Space]*

The TtB shielding (berm) alone is more than adequate for protection against high-mass heavy-ion losses because heavy-ion beam intensity and/or individual nucleon energies are much less by comparison. Only ions below mass 12 (carbon) produce radiation from the Tandem.

As stated above, 30 MeV proton generates about 85% of the radiation as 30 MeV deuteron beams. All other beams are an at least an order of magnitude less. Therefore D+ was chosen for the shielding analysis. A full fault calculation from the Tandem (4 µA, 30 MeV, deuterons) hitting iron would generate a dose rate of 90 rem/hour just outside the TtB tunnel wall (with no shielding)24.

With a minimum equivalence 3.4 feet of earthen shielding (berm) on top of the TtB, the radiation from a full fault reduced to 450 mrem/hour, 99.5% of the unmitigated dose. Work planning and procedures are used to comply with ALARA (As Low as Reasonably Achievable). Table 4-16 summarizes the results of the calculations.

Table 4-16 — Radiation Levels for Deuterium in Tandem Accelerator Room and TtB Tunnel24

|  |  |  |  |
| --- | --- | --- | --- |
| Loss Description  | Deuteron Current (DC equivalent) | Terminal Voltage | Dose Rate [rem/h] |
| TtB Full Energy Beam, Point Loss above the Tunnel (No berm \*) | 4,000 nA  | 15 MV  | 90 |
| TtB Full Energy Beam, Point Loss above the Tunnel (With berm \*) | 4,000 nA  | 15 MV  | 0.45 |
| TtB typical condition (With berm)  | 67 nA  | 9 MV  | .00 |
| TtB during fault condition (With berm \*)  | 200 nA  | 9 MV  | 0.005 |
| TVdG and Full Energy Beam (1foot 90° \*)  | 4,000 nA  | 15 MV  | 3,300 |

\* Assuming beam is point source stopped on at a ferrite material

Since a beam fault occur for 15 minutes, MCI dose is calculated to be is approximately 115 mrem for a person on the berm over the fault. The probability of this event is extremely low. Deuterons have only been run through the TtB three times over the past 20 years. Deuterons are transported through TtB on demand, averaging a few minutes over the course of a day. The maximum running conditions for deuterons in the TtB are 20MeV and 200nA DC equivalent. The estimated dose rate during a fault on top of 3.4 feet of soil is approximately 7 mrem/hour. An 18 MeV 40nA DC equivalent proton beam runs about five weeks a year through TtB, based on NSRL requirements. The estimated dose rate during a fault on top of 3.4 feet of soil is approximately 0.85 mrem/hour.

CAD OPMs require a Tandem operator to be in the Tandem control room during beam operations. Additionally, the MCR is operating the booster, which accepts the beam from the TtB. This further reduces the risk of an extended fault condition with multiple operators monitoring the beam conditions.

The berm is generally unoccupied and not posted for radiological conditions, though access is not controlled. A person would need to stand directly over the fault to receive the full dose. Though the expected dose in the MCI fault is above the CAD shielding policy, the chances of anyone receiving this dose is small because of the limited time protons and deuterons are used, operating conditions are far from the MCI, multiple operators are watching for faults, and the lack of personnel on the berm.

For all ions, except deuterons and protons, any radiation that could be generated would not penetrate the 3.4 feet of berm. As Table 4-16 states, the fault conditions conform to the C-AD radiation dose limits.

The original section of the TtB (HITL) had the possibility of radiation coming from the AGS into the HITL tunnel through the beamline penetration. The amount of radiation was calculated28 in 1989. Sandbags were added to the AGS side of the beamline and cement blocks on the TtB side.

Fault calculations29 were done at the interface between the TtB (section 29) and Linac tunnel. Based on these calculations, sandbags were added to both ends of the penetration and a steel grate is covering the TtB side. Both sides are under configuration management

**4.6.1.5 RSIS** *[Provide a complete description of the RSIS. Appropriate details are as described in the example below from the BNL Tandem accelerator.]*

The Accelerator Directorate applies five basic design criteria for the ACS for accelerator enclosures:

* Either the radiation is disabled, or the enclosure is secured to prevent access
* Only wires, switches, relays, programmable-logic controllers (PLCs) and RSC-approved active fail-safe devices must be used in the critical circuits of the system
* The system must be designed to be fail-safe; for example, where relays are used, the deenergized state of a relay is the fail-safe state
* Redundant critical devices must be used to disable the beam and redundant ACSs must be used to secure the area if the external dose rate can exceed 50 rem/h
* If a beam fails to be disabled when required, then the upstream beam is disabled; that is, the ACS must have backup or what is sometimes called “reach-back”

For accelerator enclosures, the Accelerator Directorate typically allows three modes of control: Access Prohibited, Restricted Access, and Controlled Access. The control of each access mode is under the purview of operators in the Control Room who select the appropriate mode depending on the schedule of operations or maintenance. In Restricted Access mode, the access-control system locks doors to an enclosure. Personnel require a controlled key, magnetic card, or equivalent for entry. In the Controlled Access mode, the Tandem operators ‘sweep’ the area clear of all personnel, then allow trained and authorized persons to enter and exit an area while keeping a log-in/log-out record and using an entrance watch or a key-tree to count entrants. The key tree is in the Tandem control room. The operator may be stationed at the entrance or in the control room and able to view an entrant via video camera. The operator controls the opening of the entry doors to beam enclosures. In many cases, the access control system incorporates access systems to log entry and exit into an area under Controlled Access and to permit the individual to take a key from a key tree, which is in the Tandem control room.

Tandem operators can place an accelerator enclosure in the Access Prohibited mode and subsequently enable the beam only after they sweep the enclosure and complete the sweep-area resets; this applies to local resets and remote resets. An area-reset state ensures that the sweep status of the enclosure has not changed, i.e., entrants have not gone into the enclosure after the sweep. Upon a Tandem operator resetting a beam enclosure, the ACS displays a visual warning in the enclosure, sounds an audible warning, and starts a 90-second timer before allowing the beam into the enclosure. If a person remains inside a reset area, they can use emergency-stops (crashbuttons or crash-cords) located throughout the accelerator enclosures. The stops are visible under emergency lighting conditions. Using an emergency stop requires local resetting. The ACS displays the status of emergency stops in the Tandem Control Room.

The ACS inhibits beam via hardwired critical devices or critical circuits. These systems use two independent critical devices or interlock systems. The C-AD isolates each system from the other when they perform the safety function such that any single failure will not result in the loss of protection. Fail-safe means that the system’s predictable failures leave the ACS in a safe mode; the de-energized state of any portion of it results in a fail-safe. The critical devices in tandem are the source and TtB beam stops which prevent beam from entering the accelerator and TtB respectively. A critical circuit is attached to the power of the ion source pre-accelerator power supplies. This circuit will remove power from the supply and stop the beam from entering the accelerator if the source beam stops do not function. Beam plugs, which prevent entry into the target rooms, are also critical devices. Only one plug can be retracted at a time, and they are monitored by critical circuits. If a beam plug is retracted, the corresponding target room must be swept before the source beam stops can be removed. The beam stops, beam plugs, and critical circuits are included in the ACS annual functional testing certification.

**4.6.2 Event Analysis – Fluorinert and its decomposition products**

*[Describe the hazardous decomposition products of Fluorinert and under what conditions these decomposition products form. If possible, estimate the quantities of the decomposition products. Describe the controls in place to remove these products and avoid their release, specifically the filter in the system. Describe the work controls to be used during maintenance on the Fluorinert system that ensures workers will not be exposed to hazardous constituents above regulatory values. These controls may not currently be specified, but need to be developed to allow fully addressing this hazard in the SAD.]*

**4.6.3 Event Analysis – Beam Limit**

*[Insert description of the controls that maintain the beam within the strength used in the shielding analysis. These controls will ultimately become credited controls, so the description should be specific enough that the reader will know what to expect in the credited controls.]*

**4.7 Event/Scenario Descriptions** *[This introductory section identifies the hazards from Sections 4.4 and 4.5 which relate to accelerator specific hazards and for which credited controls will be developed to prevent or mitigate the risk of these hazards.]*

Most of the hazards identified in Section 4.4 and 4.5 have been screened and found to be non-accelerator hazards that are adequately prevented and/or mitigated (achieve an acceptable risk level) by the safety programs at Fermilab, as documented in the hazard risk tables for these hazards. The remaining hazards are considered accelerator specific hazards and require further evaluation in this section. Event analysis consists of identifying limiting conditions for a suite of plausible events associated with the Linac facility equipment and operations. The unique risks associated with the Linac facility are oxygen deficient atmospheres from cryogenics, prompt ionizing radiation from beam operation, and exposure to hazardous decomposition products from Fluorinert. These conditions are incorporated into the limiting events found in Table 4-17 below. Preventive and mitigating features that may reduce either the frequency or consequence of the postulated event are also listed in the table. The frequency and consequence notations and resulted risk levels are from DOE HDBK 1163-2020.

An initial condition assumption is that permanent shielding and structures (including the shielding provided by the building structure) are assumed to exist.

Without controls, the frequency for each scenario is judged to be Anticipated, defined by HDBK 1163-2020 as “Events that may occur several times during the lifetime of the facility.”

**4.7.1 Scenario-Defining Assumptions**

**4.7.1.1 Scenario-1 Unplanned Radiation Exposure to Personnel Outside the Facility**

*[Specify the event being considered (be specific as to beam strength and what went wrong), the frequency and consequences to the three receptor groups without controls, the Credited Controls being applied to reduce the frequency or mitigate the consequences, and the Defense in Depth controls in place. Then report the resulting frequency and consequence values and the associated risk for the three receptor groups with the credited controls in place.*

*An example from the BNL Tandem facility is below. Note that as a result of Fermilab’s open campus, the public risk is likely to be different. The frequency and consequence both before and after controls need to be specified in terms from DOE HDBK 11063-2020.]*

A facility worker is postulated to be exposed to radiation outside of the TtB shielding berm. Maximum unshielded radiation levels are produced above the TtB tunnel when a focused deuteron beam hits an iron-based material in the beamline generating a dose 90-degrees from the beam direction. Radiation is only produced during a fault condition. The MP accelerator beam intensity limit is four µA of 30 MeV for deuterons. An individual standing on top of the tunnel would receive a dose rate of 90 Rem in one hour24 with no shielding.

The frequency of such an event would be occasional (O) in accordance with Table 4-12 criteria. The consequences to the facility worker are medium (M), and public consequences are extremely low (4), in accordance with Table 4-11 criteria. In accordance with Table 4-13 criteria, the risk level for the facility worker is categorized as medium (M), and the risk level for the public is categorized as extremely low (EL).

Mitigation of this event includes:

* Shielding, minimum of 3.4 feet of berm, reduces dose rate by 99.5% **(Credited Control)**
* Operator on duty **(Credited Control)**
* Beam limits **(Credited Control)**

Defense-in-depth considerations associated with this event:

• Work planning and control procedures

These controls, including the credited controls, will reduce the consequence of the event and, therefore, the associated risk. The frequency of such a mitigated event would be occasional (O) in accordance with Table 4-12 criteria. The mitigated consequences to the facility worker are low (L), and public consequences are extremely low (EL), in accordance with Table 4-11 criteria. In accordance with Table 4-13 criteria, the risk level for the facility worker is categorized as low (L), and the risk level for the public is categorized as extremely low (EL)

**4.7.1.2 Scenario-2 Personnel Exposed to High Levels of Radiation**

*[Repeat the format from the section above for a scenario of exposure of personnel to high levels of radiation from the beam. Specify the event being considered (be specific as to beam strength and what went wrong), the frequency and consequences to the three receptor groups without controls, the Credited Controls being applied to reduce the frequency or mitigate the consequences, and the Defense in Depth controls in place. Then report the resulting frequency and consequence values and the associated risk for the three receptor groups with the credited controls in place.*

*An example from the BNL Tandem facility is below. Note that as a result of Fermilab’s open campus, the public risk may be different. Note also that the example uses a different frequency and consequence grading system than Fermilab is using. The frequency and consequence both before and after controls need to be specified in terms from DOE HDBK 11063-2020.]*

A facility worker is exposed to radiation from accelerated beam during a fault. Maximum radiation levels are produced within the Tandem facility when a focused deuteron beam hits an iron-based material in the beamline generating a 90-degree fault. This fault would cause an acute whole-body exposure resulting in a dose of 3,300 rem/hour at one foot24 from the beamline.

The frequency of such an unmitigated event would be probable (P) in accordance with Table 4-12 criteria. The unmitigated consequences to the facility worker are high (H), and public consequences are extremely low (EL), in accordance with Table 4-11 criteria. In accordance with Table 4-13 criteria, the risk level for the facility worker is categorized as high (H), and the risk level for the public is categorized as extremely low (EL).

Mitigation of this event includes:

* Access control system, including radiation monitors **(Credited Control)**
* Beam intensity limits **(Credited Control)**
* Operator on duty **(Credited Control)**
* Shielding **(Credited Control)**

Defense-in-depth considerations associated with this event:

* Training Staff in the ACS and radiation safety
* Work planning and procedures
* Implementation of the Radiation Protection Program

These controls, including the credited controls, will reduce the frequency of the event, and therefore, the associated risk. The frequency of such a mitigated event would be improbable (I) in accordance with Table 4-12 criteria. The mitigated consequences to the facility worker are high (H), and public consequences are extremely low (EL), in accordance with Table 4-11 criteria. In accordance with Table 4-13 criteria, the risk level for the facility worker is categorized as extremely low (EL), and the risk level for the public is categorized as extremely low (EL).

**4.7.1.3 Scenario-3 Fluorinert and its decomposition products**

*[Repeat the format from the section above for a scenario of exposure of personnel outside the facility, for example on berm, to radiation. Specify the event being considered (under what conditions are the decomposition products released, how much of each gas type is there, what concentration of each gas results in the worker’s breathing zone), the frequency and consequences to the three receptor groups without controls, the Credited Controls being applied to reduce the frequency or mitigate the consequences, and the Defense in Depth controls in place. Then report the resulting frequency and consequence values and the associated risk for the three receptor groups with the credited controls in place.*

*Describe the event and the resulting concentrations of gas that can result.*

*Specify the frequency and consequences for each of the three receptor groups.*

*List controls, Credited and Defense in Depth.*

*Specify the frequency and consequences for each of the three receptor groups are Credited Controls are in place.]*

**4.7.2 Summary of Event Scenarios Process**

*[This section summarizes the results of the four scenarios analyzed in a form very similar to the Hazard Risk Tables already generated. The major difference is the distinguishing between Credited Controls and Defense in Depth measures. The wording and content of this section should be very similar to the example below from the BNL Tandem SAD. The table (4-17) would be revised to specify the Fermilab events and HDBK 1163 frequency and consequence nomenclature.]*

A comprehensive list of hazards was evaluated to identify all that are present at the Tandem facility.

* For those present, the nature of the hazards was described to verify if they were adequately controlled by the institutional ESH programs already in place. This evaluation included an analysis if these hazards could act as credible initiators of an accelerator specific hazard.
* Hazards that were not completely covered by an existing ESH program were then subjected to a more detailed technical analysis.
* This analysis identified credible accident scenarios using a “what-if” methodology, expert judgement, and operational experience.
* From this list of scenarios, bounding scenarios were evaluated to identify maximum credible unmitigated risks.
* The set of controls, including selected credited controls, to effectively mitigate the consequences and sufficiently reduce these risks to acceptable levels were then identified.
* The Accelerator Directorate has determined that hazard controls within the Tandem facility can be managed under the requirements of the Occupational Worker Safety and Health Program rule 10 CFR Part 851), Occupational Radiation Protection rule (10 CFR Part 835), and DOE Order 420.2, Safety of Accelerator Facilities.

A summary of the detailed analyses for these bounding scenarios is included Table 4-17. *[This table is from the Tandem SAD. The events, frequency/consequence/risk level before controls, and frequency/consequence/risk level with controls should be changed to align with the Fermilab analyzed events.]*



**5. Accelerator Safety Envelope and Bases of Credited Controls**

**5.1 Introduction**

*[Make a general statement about the ASE. The words below from the BNL Tandem ASE can be used virtually verbatim.]*

Operations at the [insert facility name] facility, performed within the boundaries of the Accelerator Safety Envelope (ASE), pose acceptably low risks to workers, users, the public, and the environment. This chapter describes the credited controls derived for the activities of the [insert name of the facility] facility determined appropriate for minimization of risk as described in the Safety Assessment Document (SAD). These controls were selected according to the methodology indicated in DOE O 420.2D, Safety of Accelerator Facilities. The Order defines credited controls as those “…determined through safety analysis to be essential for safe operation directly related to the protection of personnel or the environment.” The ASE also identifies the requirements for operability, testing, and surveillance of credited controls, as needed, to ensure they reliably perform their designated safety function. The Accelerator Directorate considers a variation away from the credited controls and their supports as a violation of the ASE and must be treated as a reportable occurrence. If a credited control is not satisfied, then the pertinent activity must be halted in a safe manner as soon as the equipment can be placed in a safe condition. The Accelerator Directorate employs an Unreviewed Safety Issue (USI) process to screen planned changes and discovered events and conditions to [enter facility name] operations or equipment to ensure these changes do not violate ASE requirements.

**5.2 Selection Method for Credited Controls**

*[Insert a discussion on how credited controls were derived. The words below from the Tandem ASE can be used virtually verbatim.]*

The process of selecting the credited controls follows the safety analysis presented in the SAD. The analysis consisted of identifying limiting conditions for a suite of plausible events associated with equipment and operations at the subject facility. The accelerator specific risks at these facilities are associated with (1) prompt ionizing radiation from the accelerator beam and (2) hazardous byproducts created from radiation induced decomposition of Flourinert heat transfer fluid. Not all the accelerator specific risks exist at all facilities. After these risks were characterized, preventive and mitigative features were identified to reduce the risks of these activities. Following the hierarchy of controls, engineering controls were chosen over administrative controls where possible. PPE is used when required but is the lowest level of a control. Several of these features were designated as credited controls due to their central role in reducing either the frequency or the consequence of these risks. In selecting credited controls, the Accelerator Directorate has chosen an essential set of controls that ensures safe operation and the protection of personnel and the environment. This set of controls is limited to ensure that high attention and focus can be devoted to their maintenance and support of safe operations. The selection of credited controls is based on risk and relies on the analysis and risk calculations detailed in the SAD, as well as the judgement, knowledge, education, experience, and expertise of the people involved in the operation of the accelerator facilities, Fermilab safety professionals, and operations professionals.

One or more credited controls have been applied to each applicable event described in Table 4-13 of the SAD to reduce the risks of these events in unmitigated risk categories I and II and to acceptable risk categories III and IV after prevention/mitigation. Preventive measures listed in Table 4-17 features both credited and non-credited controls—including Fermilab and Accelerator Directorate safety management procedures and programs—to reduce the risk of events to acceptable levels (risk levels III and IV). This selection process is further described in the SAD.

**5.3 Analysis and Control Assumptions**

*[A couple of sentences summarizing the hazards being addressed]*

The ASE assumes, and is based on, the risks presented by accelerator operations as depicted in the SAD. The most significant accelerator specific hazards that such operations represent are the potential exposure of facility workers to high radiation levels associated with prompt ionizing radiation from the accelerator beam and being exposed to hazardous decomposition products from Fluorinert heat transfer fluid.

**5.3.1 Exposure to Radiation**

*[This should summarize in a few sentences the basis for the credited controls by identifying the hazard strength and the measures chosen as credited controls to limit the risk of the radiation hazard to acceptable levels. A suggested set of words is given below.]*

The potential for radiation exposure is limited by the numerous shielding and isolation systems (RSIS and fencing) linked with the administrative infrastructure configured to minimize the potential of such accidental exposure. It was determined that these controls be identified as credited controls.

The radiation source term and resultant radiation levels increase with beam strength. Therefore, controls that are used to ensure beam strength remains within the limits assumed in the shielding analysis are essential for safe operations and have been included as credited controls.

**5.3.2 Exposure to hazardous constituents from decomposition of Flourinert coolant**

*[This should summarize in a few sentences the basis for the credited controls by identifying the hazard from Flourinert decomposition products and the measures chosen as credited controls to limit the risk of a personnel to these products. A suggested set of words is given below.]*

When Flourinert is exposed to radiation, decomposition can produce small amounts of [enter gas 1] and [enter gas 2]. These gases have a regulatory breathing air concentration limit of [X] and [Y] respectively. A proprietary filter provided by the Flourinert vendor is installed in the system to capture these hazardous gases. The filter requires regular servicing. This filter and its servicing requirements are deemed essential for controlling these gases and preventing their release when the system is opened or if a leak occurs. Therefore, the filter is considered a credited control.

In addition to the preventive measure of the filter, work planning and control for opening the system includes requirements for monitoring for release of the hazardous constituents. [Fermilab may have to establish this requirement as it may not exist presently.]

**5.4 Passive Credited Controls** *[In this section, the Requirement and Basis/Context of the Passive Credited Controls will be clearly, unambiguously, and explicitly stated.]*

**5.4.1 Shielding**

*[State the Requirement and the Basis/Context for the Shielding Credited Control. Wording from the Tandem ASE is below**. The wording in the current version of the ASE can be used, but be sure it is clear and unambiguous.* *These words will essentially be lifted verbatim and put in the ASE.]*

Requirement:

During [state the condition under which the shielding must be installed [e.g., beam operations or beam operations is possible], shielding must be installed in its proper configuration. Shielding consists of steel, concrete walls, concrete plug doors, concrete blocks, and berm per [state what describes the shielding requirements so it is ambiguous whether a current condition meets the shielding requirements or not].

Basis/Context:

This control protects personnel from radiation resulting from beam operation and fault conditions. Elevated radiation may occur when [describe accident conditions]. Beam containment elements include [describe elements of the shielding package, e.g., beam shielding, adjacent shielding, berms]. Shielding elements at the facility are managed under Fermilab’s Configuration Management Program to ensure that shielding elements are properly placed and that changes to the configuration of these elements must undergo USI evaluation, review, and approval by the Radiation Safety Committee [or appropriate organization at Fermilab] before they can be implemented. The configuration of shielding elements is documented with pictures or drawings and the appropriate inspection procedure to validate the configuration of each element.

**5.4.2 Fencing**

*[State the Requirement and the Basis/Context for the Fencing Credited Control. Suggested wording is below. The wording in the current version of the ASE can be used, but be sure it is clear and unambiguous. These words will essentially be lifted verbatim and put in the ASE. ]*

Requirement:

During [state the condition under which the fencing must be intact, e.g., beam operations or beam operations is possible] fencing must be installed in its proper configuration. Fencing consists of [describe the fencing requirements [state what describes the fencing requirements so it is ambiguous whether a current condition meets the fencing requirements or not].

Basis/Context:

This control protects personnel from radiation resulting from beam operation and fault conditions. Elevated radiation may occur when [describe accident conditions]. The fencing prevents personnel from accessing areas that may have elevated radiation levels. Fencing at the facility is managed under Fermilab’s Configuration Management Program to ensure that fencing is placed and that changes to the fencing must undergo USI evaluation, review, and approval by the Radiation Safety Committee [or appropriate organization at Fermilab] before they can be implemented. The configuration of fencing is documented with pictures or drawings and the appropriate inspection procedure to validate the configuration of the fencing.

* 1. **Active Engineered Credited Controls**

*[In this section, the Requirement and Basis/Context of the Active Engineered Credited Controls will be clearly, unambiguously, and explicitly stated.]*

**5.5.1 RSIS and Associated Detectors**

*[State the Requirement and the Basis/Context for the RSIS and Associated Detectors Credited Control. Suggested wording is below. The wording in the current version of the ASE can be used, but be sure it is clear and unambiguous. These words will essentially be lifted verbatim and put in the ASE.]*

Requirement:

During [state the condition under which the RSIS must be functioning e.g., beam operations or beam operations is possible], the RSIS must prevent entry to the [describe the areas isolated by the RSIS]. [If there are different areas that must be isolated under different operating conditions, give each one a separate paragraph. For example, first paragraph, During X, the RSIS must prevent entry to Y; second paragraph, During Z, the RSIS must prevent entry to W; third paragraph, During V, the RSIS must prevent entry to U.]

During [state the condition under which the associated detectors must be functioning e.g., beam operations or beam operations is possible], radiation detectors as specified in [state the document that lists the detectors that must be operating, or list the detectors here. The objective is that it is unambiguous what the detector status has to be (which have to be operable and what their setpoints are) to be in compliance with the ASE.]

Basis/Context:

The safety analysis identifies the use of radiation monitors to provide indication that radiation levels are higher than expected. The settings of these detectors have been established based on analysis to alarm if abnormal conditions occur.

**5.5.2 Fluorinert Filter**

*[State the Requirement and the Basis/Context for the Fluorinert Filter Credited Control. Suggested wording is below. These words will essentially be lifted verbatim and put in the ASE.]*

Requirement:

Whenever Fluorinert that has been exposed to radiation is in the system and the Fluorinert is being circulated, the vendor provided filter for collection of Fluorinert decomposition products shall be in the system and shall not be expended as indicated by the filter life indicator. [These are possible words. Fermilab should confirm this is the appropriate requirement for this filter.]

Basis/Context:

When Flourinert is exposed to radiation, decomposition can produce small amounts of [enter gas 1] and [enter gas 2]. These gases have a regulatory breathing air concentration limit of [X] and [Y] respectively. A proprietary filter provided by the Flourinert vendor is installed in the system to capture these hazardous gases. This filter must be functioning any time Fluorinert that has been exposed to radiation is in the system and being circulated.

**5.6 Administrative Credited Controls** *[In this section, the Requirement and Basis/Context of the Active Engineered Credited Controls will be clearly, unambiguously, and explicitly stated. These words will essentially be lifted verbatim and put in the ASE.]*

**5.6.1 Authorization Operating Document**

Requirement:

During beam operations [can this be made more definitive? When something is energized, when some measurement reads X or higher? When beam operations are not inhibited by any controls?] to the Linac segment of the Fermilab Main Accelerator, an approved Linac Beam Permit & Running Condition shall have been issued prior to Linac beam operations. The Beam Permit & Running Condition document shall be approved by [list the positions required to approve this document.

Basis/Context:

To summarize the bounding conditions for safe operation of the Linac, and to provide explicit approval for operations of the Linac. The limitations specified in this authorizing document ensure that assumptions used in the analysis to ensure safe operations are valid.

**5.6.2 Staffing**

Requirement:

During beam operations [same comment as above] to the Linac segment of the Fermilab Main Accelerator, the following staffing shall be in place during applicable beam operation:

* At least one member of the AD Operations Department who has achieved the rank of Operator II or higher shall be on shift.
* At least one member of the AD Operations Department shall be present in the Main Control Room (MCR).

Basis/Context:

To ensure operations within bounding conditions specified in Operation Authorization Document, and to disable beam operation to the Linac and initiate an immediate response in the event of a determined ASE violation.

**5.6.3 Bounding Parameters**

Requirement:

During beam operations [same comment as above] to the Linac segment of the Fermilab Main Accelerator, The Linac segment will be operated within the following parameters:

| Mode | Intensity | Energy |
| --- | --- | --- |
| Full Operation | 1.77e19 protons/hr | 400 MeV |

These parameters are further specified in the Operation Authorization Document.

Linac intensity is monitored via: L:RF3INT

Basis/Context:

Linac lower level penetrations up to NTF are interlocked to 50 mrem outside the beamline enclosure with Chipmunks by the transmission lines for tanks 1-5. Using scaling criteria 1, the Chipmunk trip point scaled to a 500 mrem accident condition results in a factor of 10. The current operating limit is 6.7 x 1017 protons/hour. Scaling up by 10 sets the Linac ASE to 6.7 x 1018 protons/hour up to NTF.

Linac upper level downstream waveguide penetration limit is 10 mrem/hour for 3.54 x 1017 protons/hour. The Chipmunks at the lower level penetrations for the transmission lines for tanks 6-9 were adjusted down to trip at 10 mrem. The calculated dose at the upper level penetrations is similar to the dose at the lower level penetrations allowing the lower level penetration Chipmunks to also protect the upper level waveguide penetrations. Using scaling criteria 1, the Chipmunk trip point scaled to a 500 mrem accident condition results in a factor of 50. The current operating limit is 3.54 x 1017 protons/hour. Scaling up by 50 sets the Linac ASE to 1.77 x 1019 protons/hour after NTF.

**5.7 Configuration Management for Credited Controls**

To ensure the integrity of the Credited Controls during accelerator operation, several methods of Configuration Management are in place.

* Excavation within the “Excavation Waiver Prohibited Zone” around the accelerator are required to go through the JULIE process. Part of the JULIE process includes ES&H Division Radiation Safety personnel review to determine if required shielding may be impacted.
* Required movable and penetration shielding is posted and/or locked and/or bolted in place where applicable.
* Components that are part of the Radiation Safety Interlock System (RSIS) are labeled.
* Surveillance is performed, as specified in Section 8.

~~If shielding or fencing is planned to be removed, the assigned Radiation Safety Officer (RSO) is responsible for ensuring the affected segment of the Fermilab Main Accelerator is locked off in a safe state, using RSO Configuration Control locks.~~ [This probably should be deleted. Any deviation from the ASE requirements should be approved via the USI process.]

~~If any Credited Control is not in place, either planned or discovered, the assigned RSO is responsible for ensuring the affected segment of the Fermilab Main Accelerator is locked off in a safe state, using RSO Configuration Control locks.~~ [This probably should be deleted. Any deviation from the ASE requirements should be approved via the USI process.]

Removal of Credited Controls (i.e., rescinding Operation Authorization Documents, removing shielding or fencing, etc.) during maintenance periods is common, and the assigned RSO is responsible for ensuring the affected segment of the Fermilab Main Accelerator is locked off in a safe state, using RSO Configuration Control locks.

The ES&H Division Radiation Physics Operations and Accelerator Safety Departments utilize a Configuration Control Log to track instances of placing affected segment of the Fermilab Main Accelerator in a Configuration Controlled off state. This Log keeps track of reasons why the affected segment of the Fermilab Main Accelerator was locked off, what must be done prior to resuming operations, and confirmation that conditions are back in place and confirmed before operations are permitted to resume.

**5.8 Required Calibration, Testing, Maintenance, and Inspection Schedules for Credited Controls**

**5.8.1** Operation of all RSIS components shall be tested at an interval annually not to exceed 12 months.

**5.8.2** Area radiation monitors must be functionally tested and calibrated as an interval, not to exceed 12 months.

**5.8.3** Operation of all ODH monitoring and alarming components shall be functionally tested at an interval annually, not to exceed 12 months.

**5.8.4** All shielding shall be inspected at an interval not to exceed 12 months.

**5.8.5** All Fluorinert Filters shall be inspected at an interval not to exceed XX months.

**5.8.6** All fencing shall be inspected at an interval not to exceed 12 months.

**6 Quality Management Programs** *[See Tandem SAD for content and example wording]*

**6.1 Fermilab Quality Assurance Program** *[See Tandem SAD for content and example wording]*

**6.2 DOE Order 414.1D Quality assurance** *[See Tandem SAD for content and example wording]*

**6.3 Personnel Training and Qualifications** *[See Tandem SAD for content and example wording]*

**6.4 Quality Improvement** *[See Tandem SAD for content and example wording]*

**6.5 Documents and Records** *[See Tandem SAD for content and example wording]*

**6.6 Work Process** *[See Tandem SAD for content and example wording]*

**6.7 Design** *[See Tandem SAD for content and example wording]*

**6.7.1 Configuration Management (CM)**

**6.7.2 Configuration Managed SSCs and Documents**

**6.7.3 Change Control** *[See Tandem SAD for content and example wording]*

**6.8 Procurement** *[See Tandem SAD for content and example wording]*

**6.9 Inspection and Acceptance Testing** *[See Tandem SAD for content and example wording]*

**6.10 Management Assessment** *[See Tandem SAD for content and example wording]*

**6.11 Independent Assessment** *[See Tandem SAD for content and example wording]*

**6.12 Accelerator Safety Software** *[See Tandem SAD for content and example wording]*

**7 Accelerator Facility Post Operations: Stabilization, Deactivation and Decommissioning Plans.** *[See Tandem SAD for content and example wording****]***

**7.1 Introduction** *[See Tandem SAD for content and example wording]*

**7.2 Baseline Conditions** *[See Tandem SAD for content and example wording]*

**7.3 End-Point Goals** *[See Tandem SAD for content and example wording]*

**7.4 Regulatory Requirements** *[See Tandem SAD for content and example wording]*

**7.5 Decommissioning Methods** *[See Tandem SAD for content and example wording]*

**7.6 Waste Streams** *[See Tandem SAD for content and example wording]*

**References**

**Appendix A – Risk Matrices**