102030103-ES0018-R02

SPALLATION NEUTRON SOURCE FINAL SAFETY ASSESSMENT DOCUMENT FOR PROTON FACILITIES

December 2010

A U.S. Department of Energy Multilaboratory Project

SPALLATION NEUTRON SOURCE

Argonne National Laboratory • Brookhaven National Laboratory • Thomas Jefferson National Accelerator Facility • Lawrence Berkeley National Laboratory • Los Alamos National Laboratory • Oak Ridge National Laboratory

SNS

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December 2010

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DOCUMENT APPROVAL RECORD

Spallation Neutron Source Final Safety Assessment Document
For Proton Facilities, SNS Document Number 102030103-ES0018-R02

This document describes the SNS Proton Facilities, identifies and analyzes associated hazards, and identifies appropriate controls to mitigate hazards in accordance with DOE Order 420.2B. This document is an update to the previous version (SNS 102030103-ES0018-R01, April 2007) and is issued to ensure the document remains "current and consistent" per the requirements of DOE Order 420.2B. The SNS Final Safety Assessment Document for Neutron Facilities (FSAD-NF), which serves as a companion document, is also being updated and will be approved and issued separately.

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ac	alternating current
ACL	acceptance criteria listing
AE-CM	architect engineer-construction manager
ALARA	as low as reasonably achievable
ANL	Argonne National Laboratory
APS	Advanced Photon Source
ARR	Accelerator Readiness Review
ASE	accelerator safety envelope
BCT	beam current transformer
BLM	beam loss monitor
BNL	Brookhaven National Laboratory
BSS	beam shutdown stations
CAA	Clean Air Act
CASE	Commissioning Accelerator Safety Envelope
CCL	coupled cavity LINAC
CCTV	closed-circuit television
CD	Critical Decision
CEBAF	Continuous Electron Beam Accelerator Facility—
	(at Thomas Jefferson National Accelerator Laboratory—[TJNAF] [JLAB])
CFCC	Conventional Facilities Central Control
CFD	computational fluid dynamics
CHL	Central Helium Liquefier
CLO	Central Laboratory and Office
CUB	Central Utility Building
CWA	Clean Water Act
dc	direct current
DI	deionized
DOE	Department of Energy

ACRONYMS AND ABBREVIATIONS

DTL	drift tube LINAC
EPA	Environmental Protection Agency
EPICS	Experimental Physics and Industrial Control System
ES&H	environment, safety, and health
ETTP	East Tennessee Technology Park (also known as the K-25 site)
FELK	Front End, LINAC, and Klystron
FHA	fire hazards analysis
FNAL	Fermi National Accelerator Laboratory
FODO	focus drift defocus drift
FSAD	final safety assessment document
FSAR	final safety analysis report
ft	foot/feet
FY	fiscal year
g/s	grams per second
GeV	giga electron volts (10^9 eV)
h	hour
H^-	hydrogen ions
HAZCOM	hazard communication
He	helium
HEBT	High Energy Beam Transport
HEPA	high efficiency particulate air
Hg	mercury
HOG	hot off-gas
HVAC	heating, ventilation, and air conditioning
Hz	hertz (cycles per second)
I/O	input(s)/output(s)
ICS	integrated control system
in.	inch(es)

ACRONYMS AND ABBREVIATIONS

JLAB	Thomas Jefferson National Accelerator Facility (TJNAF)
JHA	job hazard analysis
kW	kilowatt
LANL	Los Alamos National Laboratory
LBNL	Lawrence Berkeley National Laboratory
lbs	pounds
LEBT	Low Energy Beam Transport
LHe	liquid helium
LINAC	linear accelerator
LLLW	liquid low-level waste
LO/TO	lockout/tagout
m	meter(s)
M&O	management and operations
MAP	Mitigation Action Plan
MEBT	Medium Energy Beam Transport
MeV	million electron volts
min.	minute
mm	millimeter
MOA	Memorandum of Agreement
MPFL	maximum possible fire loss
mph	miles per hour
MPS	Machine Protection System
mrem	millirem
ms	millisecond
MSDS	material safety data sheet
MW	megawatt (million watts)
NEC	National Electric Code
NESHAP	National Emission Standards for Hazardous Air Pollution

ACRONYMS AND ABBREVIATIONS

NFDD	Neutron Facilities Development Division
NFPA	National Fire Protection Association
nm	neutron mirror
NPDES	National Pollutant Discharge Elimination System
NSSD	Neutron Scattering Science Division
ODH	oxygen deficiency hazard
ORNL	Oak Ridge National Laboratory, X-10
ORR	Oak Ridge Reservation
OSHA	Occupational Safety and Health Administration
P2	pollution prevention
P2DA	P2 Design Assessment
PC	performance category
PCE	primary confinement exhaust
PEP	Project Execution Plan
PFN	pulse forming network
PLC	programmable logic controller
PPE	personal protective equipment
PPS	Personnel Protection System
PSAR	Preliminary Safety Analysis Report
psi	pounds per square inch
psig	pounds per square inch gauge
QA	quality assurance
QC	quality control
R	roentgen
RAD	Research Accelerator Division
rad	radiation absorbed dose
RCRA	Resource Conservation and Recovery Act
RCT	Radiological Control Technician
rem	unit of radiation dose (roentgen equivalent man)

ACRONYMS AND ABBREVIATIONS

RF	radio frequency
RFQ	radio frequency quadrupole
RHIC	Relativistic Heavy Ion Collider
RSS	Research Safety Summary
RTBT	Ring-to-Target Beam Transport
RWP	Radiological Work Permit
SAD	Safety Assessment Document
SAR	Safety Analysis Report
SBMS	Standards-Based Management System
SBC	Standard Building Code
SCADA	supervisory control and data acquisition
SCL	superconducting LINAC
SIL	safety integrity levels
SIS	safety-instrumented system
SNS	Spallation Neutron Source
SOP	standard operating procedure
SPCC	Spill Prevention Control and Countermeasures
SSD	ORNL Safety Services Division
sq	square
TC	tray cable
TDEC	Tennessee Department of Environment and Conservation
TJNAF	Thomas Jefferson National Accelerator Facility (JLAB)
TLDs	thermoluminescent dosimeters
TPC	Total Project Cost
TPS	Target Protection System
TSR	technical safety requirement
TVA	Tennessee Valley Authority

UL	Underwriters Laboratories Inc.

ACRONYMS AND ABBREVIATIONS

μs	microseconds
UT	University of Tennessee
V	volt
WSS	work smart standards
y	year

1.0 INTRODUCTION

1.1 BACKGROUND

The Spallation Neutron Source (SNS) is one of the world's foremost neutron scattering facilities. The facility provides important scientific capabilities for basic research in many fields including material science, life sciences, chemistry, solid state and nuclear physics, earth and environmental sciences, and engineering sciences. The process begins with the generation of a pulsed beam of negatively charged hydrogen ions (H^-) accelerated to an energy of one billion electron volts (1 GeV) using a linear accelerator (LINAC). The H^- beam is transported to an accumulator Ring where it is injected after stripping away the electrons to leave the desired protons. In the Ring, the protons are collected and bunched into short (under one microsecond) pulses which are directed onto the mercury target at a rate of 60 pulses per second. Neutrons are created through the spallation reaction as the high energy protons collide with mercury nuclei. Emerging neutrons are slowed, or moderated, and channeled through beam lines to instrumented experimental areas. Figure 1.1-1 shows a schematic view of the facility that illustrates the national laboratories that participated in the initial design and construction.

The SNS was designed and constructed as a multi-laboratory partnership, led by the SNS Project Office in Oak Ridge, Tennessee. The partner laboratories included Argonne National Laboratory (ANL), Brookhaven National Laboratory (BNL), Los Alamos National Laboratory (LANL), Lawrence Berkeley National Laboratory (LBNL), Thomas Jefferson National Accelerator Facility (TJNAF [aka JLAB]), and Oak Ridge National Laboratory (ORNL). The collaborative approach took advantage of the best expertise available in different technical areas and made efficient use of resources. A commercial architect engineer-construction manager (AE-CM) team (Knight-Jacobs) handled design and construction management of the conventional facilities under a task order contract.

The *Final Environmental Impact Statement*[1-2] for the SNS was issued in April 1999, and on June 18, 1999, the Secretary of Energy signed the Record of Decision to proceed with construction. A *Mitigation Action Plan* (MAP)[1-3] was issued that identified actions to avoid or to minimize environmental harm in building and operating the facility.

The SNS conceptual design was evaluated by a DOE review committee in June 1997. At the same time, a DOE independent cost estimate was performed. In response to recommendations from these reviews, the project schedule was extended from six to seven years, and other adjustments were made that increased the Total Project Cost (TPC) from $1,226 million to $1,411 million (as spent).

The Secretary of Energy approved Critical Decision (CD) 1, "Approval of Mission Need," and CD-2, "Approval of Level 0 Project Baseline," for the SNS in August 1996 and December 1997, respectively. The SNS PEP,[1-1] which governed how the project was managed, was initially approved by the Secretary of Energy at the time of CD-2, and a subsequent revision was approved in November 1999. The Level 0 cost and schedule baselines set at CD-2 comprised a TPC of $1411.7 million and a seven-year design/construction schedule, with facility commissioning to occur in FY 2006. The project carried out advanced conceptual design and further research and development activities in anticipation of starting Title I design in FY 1999.

The project was formally complete after the CD-4 completion stage was achieved by demonstrating integrated operation of the accelerator to produce neutrons that meet defined specifications. CD-4 was achieved in April 2006 as SNS transitioned into an operating facility that is managed for the DOE by Oak Ridge National Laboratory.

This revision (Revision 2) incorporates changes and updates that have occurred since the last revision (April 2007) and includes relevant material from Unreviewed Safety Issue Determinations as well as miscellaneous updates and editorial improvements.

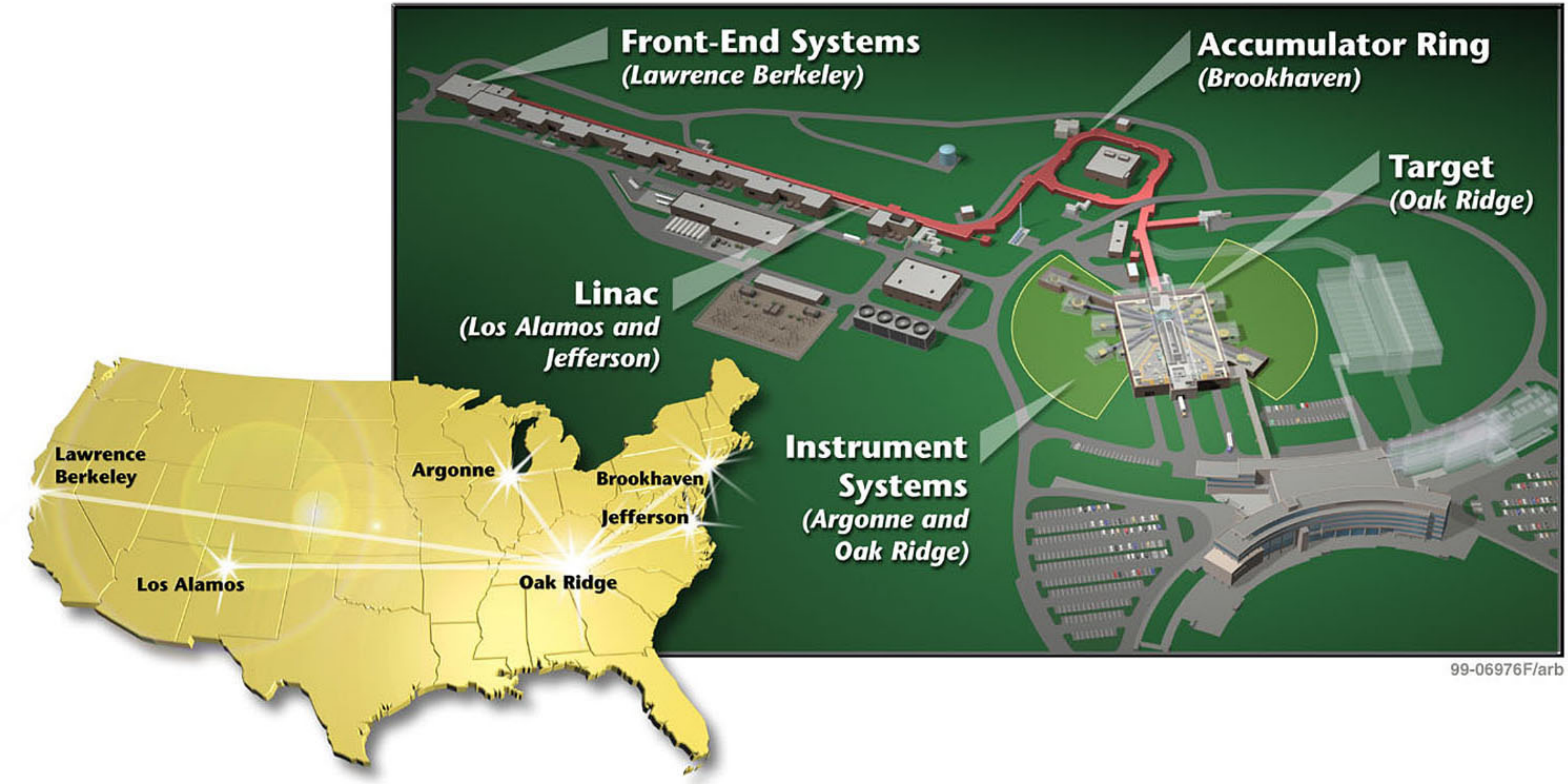

Figure 1.1-1 Schematic View of the SNS Facility and the Responsibilities of the Partner Laboratories

1.2 SNS APPROACH TO SAFETY

As an operating facility, SNS has fully integrated into the ORNL management systems. The ORNL institutional safety programs as promulgated through the Standards Based Management System (SBMS) provides protection from common industrial and laboratory hazards. The "SNS Integrated Safety Management (ISM) Plan," included in the *Spallation Neutron Source Environment, Safety, and Health Plan*,[1-5] documents the overall approach to the environment, safety, and health (ES&H) of the project. The ISM Plan[1-5] and annual updates have been submitted to DOE, and independent assessments of the program have been conducted. These reviews found the approach to, and implementation of, ES&H requirements throughout the project to be appropriate for an effort of this magnitude, risk, and visibility. Commitment to excellence in ES&H is a constant goal at all levels of the SNS, and improvements are sought on a continual basis. ISM is implemented through the ORNL Standards Based Management System (SBMS).

The SNS management team is committed to ensuring a safe facility. Systems to protect personnel and the environment were identified early in the project and were integrated into the project design. Projected radiation exposures from routine operations and the full spectrum of credible non-routine events have been carefully analyzed, and controls are in place to ensure compliance with the requirements of 10 CFR 835.[1-7]

In accordance with the principles of ISM, the SNS line management is responsible for safety at the SNS facilities. The SNS line organization includes an Operations Manager and ES&H staff to provide direction and support to the line management. A system of internal review committees provides opportunity and process for multidisciplinary peer review of safety questions in the design and operation of the facility.

The SNS is designed and built in accordance with the SNS standards for design and construction.[1-8] These standards reflect the University of Tennessee (UT)-Battelle's commitments to the DOE as well as the AE-CM contractual obligations to UT-Battelle. The standards were developed primarily to ensure the SNS would be safely designed, constructed, and operated. The SNS standards for design and construction incorporated the work smart standards (WSS) for engineering design developed at ORNL.[1-9]

1.3 SCOPE

The *FSAD for Proton Facilities (FSAD-PF)* addresses accelerator specific hazards associated Proton Facilities as well as SNS site-wide accelerator specific hazards associated with the entire site. Hazards associated with the Neutron Facilities portion of SNS are addressed in a companion document entitled *SNS Final Safety Assessment Document for Neutron Facilities (FSAD-NF).*[1-10] Together, the FSAD-NF and FSAD-PF provide a comprehensive safety assessment for hazards associated with the SNS as required by Order 420.2B[2]. Accelerator specific safety related controls identified in the FSAD documents combined with other applicable safety related ORNL institutional controls and management systems serve to ensure safety for all SNS activities.

Key components of the Proton Facilities include the Front End, LINAC, Klystron Gallery, LINAC Beam Dump, High Energy Beam Transport (HEBT), Ring Injection Dump, Ring, Ring Extraction Dump, RTBT, and support facilities such as the HEBT, RTBT, and Ring Support Buildings, the Central Helium Liquefier (CHL) Building, the Central Utilities Building (CUB), and the Central Laboratory and Office (CLO) Building. The Neutron Facilities are housed in the Target Building (Building 8700) and satellite buildings for instruments (e.g., Buildings 8702, 8705, 8707, 8711, 8713, 8714B) and include the target systems, neutron instrument systems and associated support facilities. The interface between the Proton and Neutron Facilities is detailed in Chapter 6.0.

It is expected that activities at the SNS site will continue to evolve and expand and that additional structures and facilities will be planned and erected to support the science mission of the facility. It is expected that the majority of such activities will involve standard industrial and laboratory hazards that will be managed under the ORNL institutional safety programs (SBMS, including RSS). Should future activities involve accelerator specific hazards, such hazards would be evaluated as part of the USID process and managed as part of the safety basis under DOE Order 420.2B.

1.4 REFERENCES

1-1 The *Spallation Neutron Source Project Execution Plan*, U.S. Department of Energy, Spallation Neutron Source, Oak Ridge, TN, Revision 3, November 2002.

1-2 "Construction and Operation of the Spallation Neutron Source Facility," *Final Environmental Impact Statement,* DOE/EIS-0247, Office of Science, U.S. Department of Energy, April 1999.

1-3 *Mitigation Action Plan for the Spallation Neutron Source*, U.S. Department of Energy, DOE-0247-MAP-R0, October 1999.

1-4 *Memorandum of Agreement between the Spallation Neutron Source and Argonne National Laboratory, Brookhaven National Laboratory, Lawrence Berkeley National Laboratory, Los Alamos National Laboratory, Oak Ridge National Laboratory, and Thomas Jefferson National Accelerator Facility*, Revision 4, May 22, 2001.

1-5 *Spallation Neutron Source Environment, Safety, and Health Plan*, 102030000-ES0001-R03, Spallation Neutron Source, Oak Ridge, TN, March 2006.

1-6 *Safety of Accelerator Facilities*, DOE Order 420.2B, Office of Science, U.S. Department of Energy, July 2004.

1-7 Title 10, *Energy*, Part 835, "Occupational Radiation Protection," 10 CFR 835, U.S. Department of Energy, Washington, DC.

1-8 *Spallation Neutron Source Standards for Design and Construction,* 108030000-ST0001-R00, Spallation Neutron Source, Oak Ridge, TN, September 1999.

1-9 *ORNL Necessary and Sufficient Standards for Environment, Safety and Health: ORNL Report of the Identification Team for Engineering Design of Standard Industrial, Radiological, Non-Reactor Category 2 and 3 Nuclear, and Accelerator Facilities,* Lockheed Martin Energy Research Corp., Oak Ridge, Tennessee, March 1998.

1-10 *Spallation Neutron Source Final Safety Assessment Document for Neutron Facilities, SNS 102030102-ES0016-R03.*

2.0 SUMMARY AND CONCLUSIONS

The major conclusion of this safety assessment is that the risk associated with the SNS Proton Facilities are low or extremely low for on-site impacts and are negligible for off-site impacts. This favorable outcome is the result of the following:

- The SNS Project formed partnerships for design, construction and installation with national laboratories selected for proven expertise in specific areas.
- The SNS has adopted the principles of integrated safety management (ISM). The SNS has implemented the ORNL Standards Based Management system that implements and promulgates codes and standards that the laboratory has agreed to follow through the Work Smart Standards process and best management practices adopted by the laboratory.
- The SNS applied a standards-based approach for construction and fabrication of buildings, structures, systems, and components to ensure common industrial hazards are well controlled.
- The SNS design has provisions for unique hazards (i.e., those not considered common industrial hazards) and design features that are at least the equivalent of those provided at other major DOE accelerators.

The SNS facilities and safety systems are described in Chapter 3 of this document. The SNS design is oriented toward safety of the worker, the environment, and the public.

The safety analyses of Chapter 4 identify accelerator specific hazards and appropriate controls. The analyses demonstrate the effectiveness of multiple layers of protection against an actual injury or death and identify instances where Credited Engineered Controls (CEC) are required to mitigate prompt radiation and oxygen deficiency hazards.

Chapter 5, "Basis for the Accelerator Safety Envelope," addresses the safety function requirements for CECs and summarizes the basis for the accelerator safety envelope. The interface between the Proton Facilities and Neutron Facilities is discussed in Chapter 6 to highlight essential features and requirements. Quality Assurance is addressed in Chapter 7.

3.0 SITE, FACILITY, AND OPERATIONS DESCRIPTION

This chapter describes the SNS site, facility, and operations for SNS except for those associated with the Neutron Facilities portion of the site. The Neutron Facilities, housed in the Target Building (Building 8700), satellite buildings for instruments (e.g., Buildings 8702, 8705, 8707, 8711, 8713, 8714B) and ancillary support facilities, are described in the FSAD-NF[3-25] companion document.

It is expected that activities at the SNS site will continue to evolve and expand and that additional structures and facilities will be planned and erected to support the science mission of the facility. It is expected that the majority of such activities will involve standard industrial and laboratory hazards which will be managed under the ORNL SBMS institutional safety programs. Should future activities involve accelerator specific hazards, such hazards would be evaluated through the USID process and managed as part of the SNS safety basis under DOE Order 420.2B.

3.1 SITE DESCRIPTION

The SNS site is located atop Chestnut Ridge, approximately 1.75 miles (2.8 km) northeast from the center of ORNL and is accessible by Chestnut Ridge Road across from the 7000 Area at ORNL. The SNS footprint extends on a long, wide, and gently sloping ridge top with a broad saddle area at its eastern end. The major buildings needed for the SNS LINAC, transport line, and Ring tunnels are notched into the south side of the ridge using cut-and-fill techniques, providing economical construction and effective shielding.

The majority of the information for this section is a summary of more detailed information contained in the *Final Environmental Impact Statement:* "Construction and Operation of the Spallation Neutron Source Facility,"[3-1] in the ORNL/ENG/TM-19, *Oak Ridge National Laboratory Site Data for Safety Analysis Reports*,[3-2] and in ORNL-5870, *Environmental Analysis of the Operation of the Oak Ridge National Laboratory*.[3-3] The information taken from the reports has been reviewed and updated, as necessary, to reflect present conditions.

3.1.1 GEOGRAPHY

The SNS is located in Roane County, Tennessee, on the DOE Oak Ridge Reservation (ORR). The ORR lies within the Tennessee Valley between the Cumberland and Southern Appalachian mountain ranges in the eastern portion of the state of Tennessee and is within the corporate limits of the city of Oak Ridge. A road map of the Oak Ridge area is shown on Figure 3.1.1-1. The ORR consists of about 34,500 acres with three major industrial complexes located in separate but adjacent valleys: the East Tennessee Technology Park (ETTP [also known as the K-25 site]), the ORNL site, and the Y-12 site. The SNS is about midway between the ORNL and Y-12 sites. The SNS site is about four miles southwest of the commercial and population center of the city of Oak Ridge and about 22 miles west of the center (downtown) of the city of Knoxville.

A map of the ORR is shown on Figure 3.1.1-2. The closest ORR boundary to the SNS site is about 7,500 ft to the northwest on the south side of East Fork Ridge. The public road closest to the SNS site is Bethel Valley Road, which runs in an east-west direction approximately one mile to the south. Figure 3.1.1-3 is an aerial photograph of the area surrounding the SNS site (Note: Bethel Valley Road is closed to the public thoroughfare by manned gates located several miles to the east and west of the SNS site.).

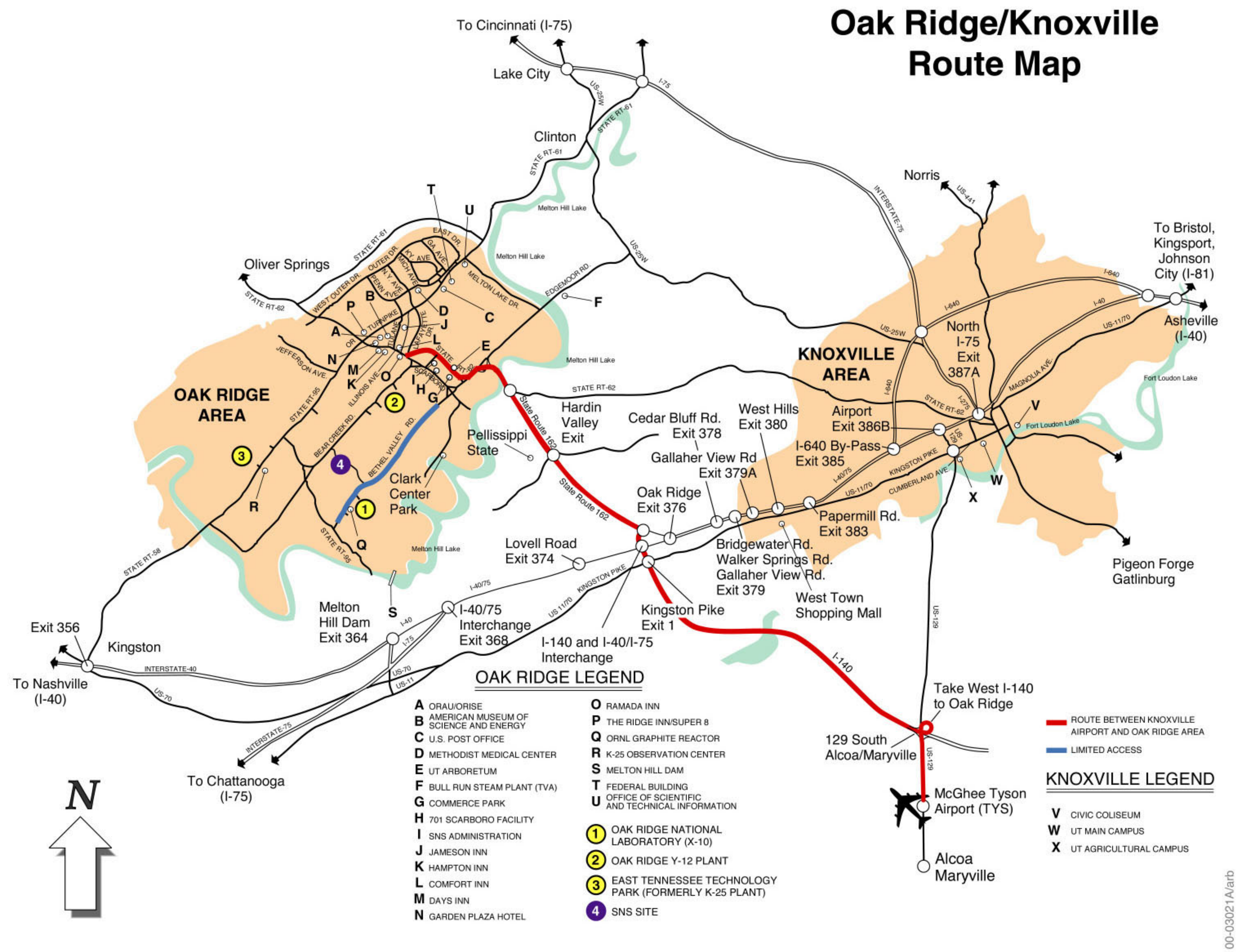

Figure 3.1.1-1 Oak Ridge/Knoxville Route Map

Map of the Oak Ridge Reservation

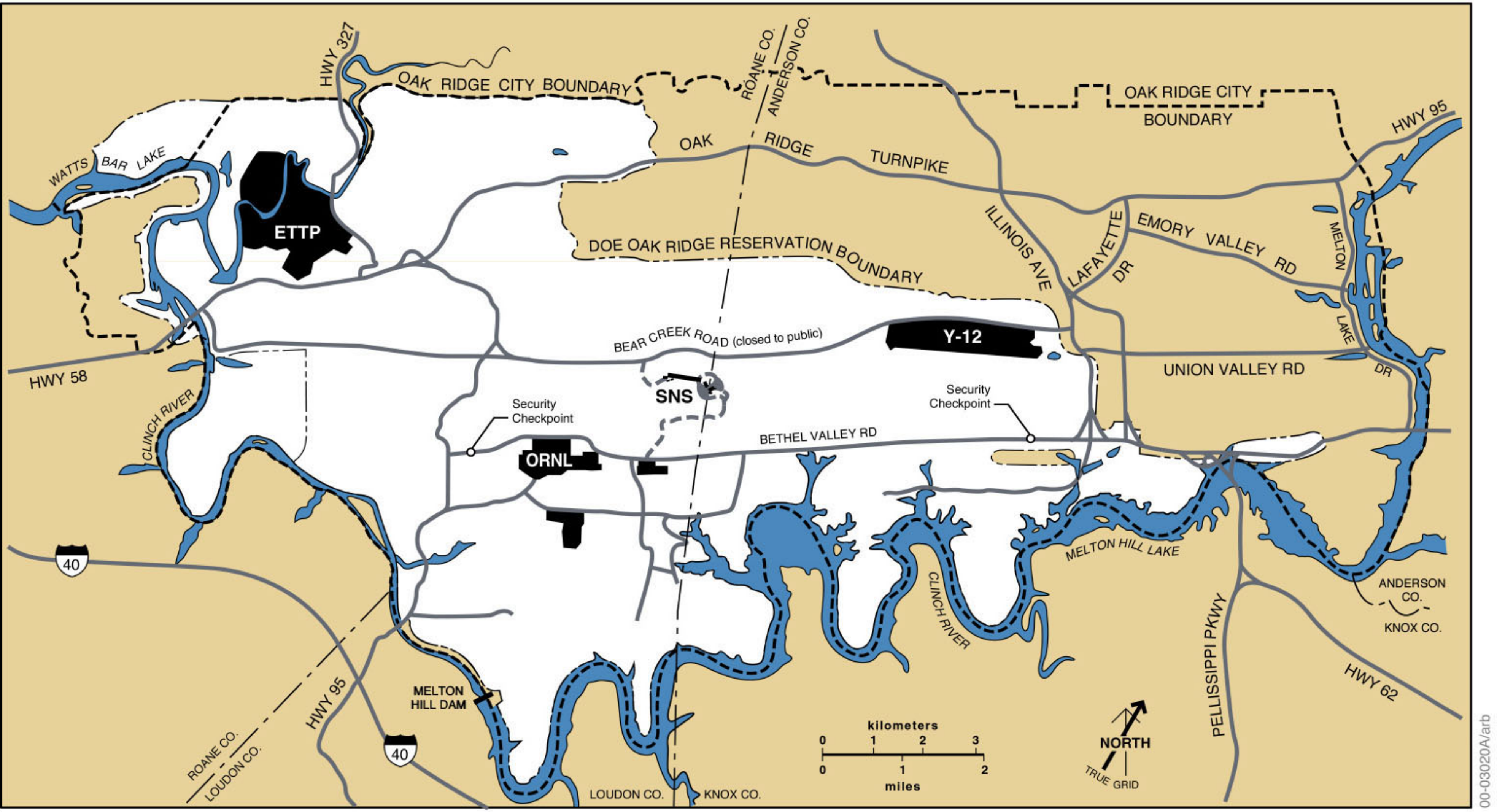

Figure 3.1.1-2 Map of the Oak Ridge Reservation

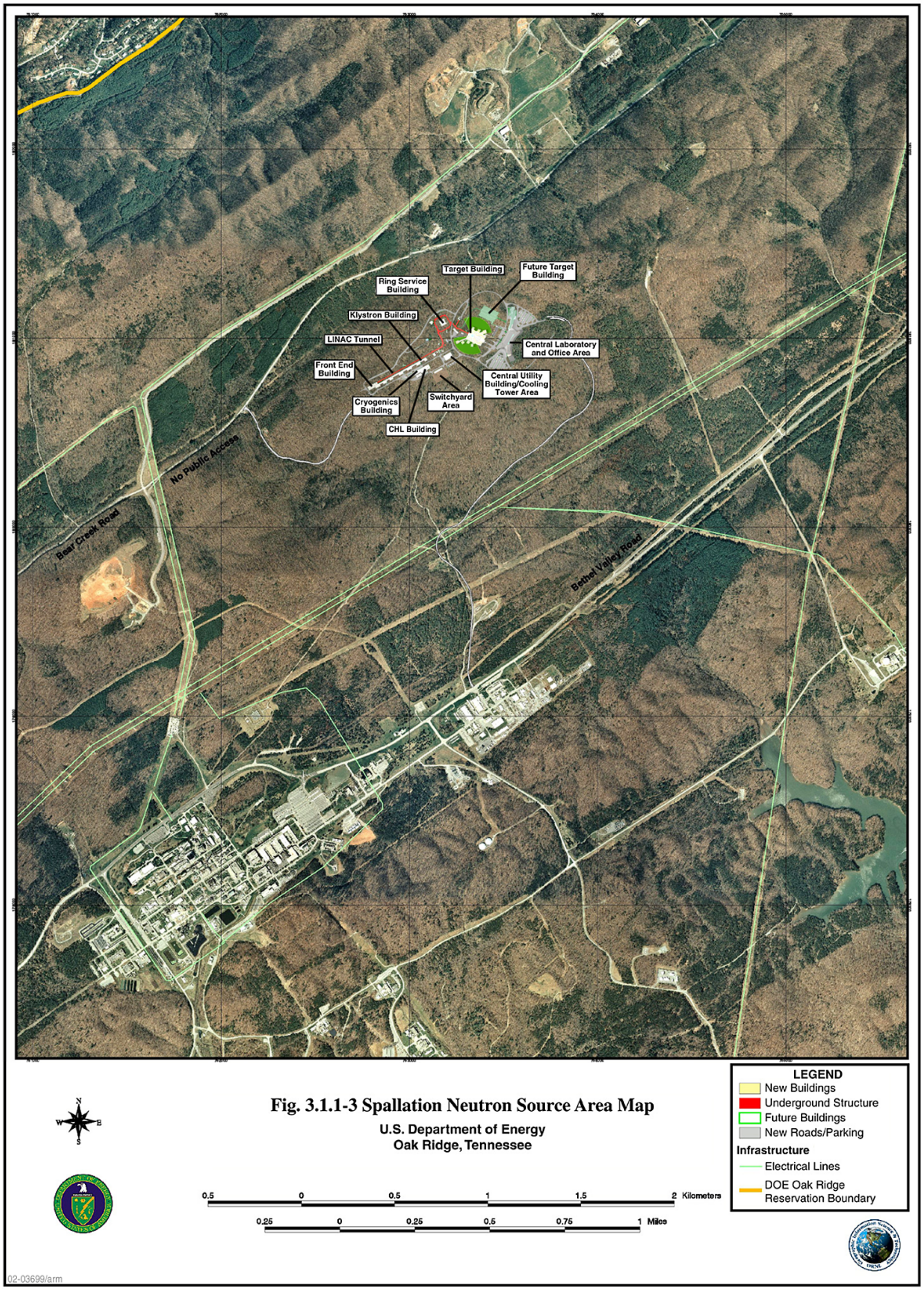

Figure 3.1.1-3 Spallation Neutron Source Area Map

Access to ORNL is from Bethel Valley Road to the south and Tennessee State Highway 95, which runs in a north-south direction west of ORNL. All access roads onto the ORNL site from Bethel Valley Road and from Tennessee State Highway 95 are posted and closed to the general public. The SNS buildings are sited on Chestnut Ridge about 1,030 to 1,050 ft above sea level. The overall SNS site development includes improved and re-routed Chestnut Ridge access roads that are closed to the general public. ORNL controls access on Bethel Valley Road, as necessary, to limit vehicles to those having official business and also has the authority to control access on Tennessee State Highway 95 in the event of an emergency.

3.1.2 DEMOGRAPHY

The ORR lies within the corporate limits of the city of Oak Ridge; however, there are no private residences within the ORR. With the exception of the city of Oak Ridge, the major portion of the land adjoining the ORR is predominantly rural and is used largely for residences, small farms, and pastures. The city of Oak Ridge had a 1996 population estimate of about 28,000.[3-4] The Knoxville metropolitan area (which includes the city of Oak Ridge) had a 1996 population estimate of about 650,000.[3-5] The demography of the area is not expected to change significantly.

3.1.3 ENVIRONMENTAL DESCRIPTION

3.1.3.1 Meteorology and Climatology

The reader is referred to References 3 and 6 of this chapter for a description of Oak Ridge meteorology, including regional climatology and local meteorology.

Damaging winds are relatively uncommon, and peak gusts recorded in the Tennessee Valley are generally in the 60–70 miles-per-hour (mph) range for the months of January through July and less during the other months. The Tennessee Valley is infrequently subjected to tornadoes and tropical storms (the remnants of hurricanes). The Oak Ridge-Clinch River area has one of the lowest probabilities of tornado occurrence in the state of Tennessee.[3-6]

3.1.3.2 Hydrology

3.1.3.2.1 Surface Water

Surface water at the Chestnut Ridge SNS site consists of a small perennial stream that acts as headwater to White Oak Creek. This unnamed tributary flows southeast from the valley below the footprint on Chestnut Ridge into the ORNL main plant area. Two additional drainages northeast and southwest of the site dissect the scarp face of Chestnut Ridge and flow northwesterly into Bear Creek. While these drainages may receive runoff from the footprint area, the site footprint does not overlay the actual stream channels. Site development provides a basin to retard runoff from the graded areas around the SNS site.

3.1.3.2.2 Subsurface Hydrology

Groundwater at the Chestnut Ridge site is observed at a depth of greater than 60 ft (18 m). Temporary water levels were recorded in open borings by Law Engineering at the site at 67 and 94 ft (20 and 29 m). Also, two groundwater monitoring wells located about 3,000 ft (914 m) east of the site (Oak Ridge Administrative Coordinates N27800, E44500) have water levels at depths of greater than 75 ft (23 m). It should be noted that groundwater levels vary significantly depending on height above the valley floor and seasonal and climatic conditions.

The hydrology of the ORR is described by Moore.[3-7] Groundwater flow on the ORR parallels closely the contours of the surface topography, and the water emerges to contribute to local stream flow. Recharge is derived primarily from precipitation and groundwater discharge through evapotranspiration, springs, and streams. The surface streams ultimately augment the water supply of the Clinch River, which is the hydraulic sink for the region. The riverbed lies at the base level of the zone of saturation, and all groundwater from both sides of the channel enters the river. Because the riverbed is a major topographic feature set down in bedrock, it is unlikely any groundwater can flow beneath the Clinch River.

3.1.3.3 Geology

The ORNL site is located within the folded and faulted Valley and Ridge Physiographic Province of the Appalachians. Several major ridges, formed from resistant strata, dominate the topography of the ORR. Moving from southeast to northwest, prominent ridges are named Copper Ridge, Haw Ridge (south of the ORNL main plant), Chestnut Ridge (separating the ORNL and Y-12 Plant sites), and Pine Ridge (between the Y-12 Plant and the city of Oak Ridge).

Law Engineering has completed soil borings at the SNS site on Chestnut Ridge to test subsurface conditions. Testing consisted of boreholes that obtained undisturbed samples at various horizons and continuous measurement of the penetration rate (as an indicator of soil strength, density, consolidation, etc.). The borings were taken to depths of approximately 150 ft (46 m) and encountered bedrock at several locations. A rotary drill hole was subsequently installed to determine actual depth to solid bedrock; details are documented in a series of reports. Initial conclusions are that a highly irregular and weathered bedrock surface exists at the site and that large slabs and fragments of chert may occur within the soil mass. Selected soil samples were analyzed for standard engineering characteristics such as grain size, consolidation rates, specific gravity, moisture content, and Atterberg limits. The soils tested ranged from clayey, sandy silt with gravel-sized chert[3-8] to highly plastic, clayey silt. Soil samples yielded unconfined compressive strengths between about 3.6 and 2.1 kg/ft² (8 and 4.7 pounds [lbs]/ft²). These soils are typical of the ORR and are not susceptible to liquefaction or mass movement.

Historic seismic activity within 200 miles of the ORNL site has primarily occurred in the Valley and Ridge Physiographic Province with some minor historical activity in the Appalachian Plateau province to the west and the Blue Ridge province to the east. The maximum historical ground accelerations at the ORNL site have resulted from earthquakes with epicenters located outside of the Valley and Ridge Physiographic Province, the Appalachian Plateau Province, the Blue Ridge Province, and further than 200 miles from the ORNL site.

3.1.4 NATURAL PHENOMENA HAZARDS

The SNS facilities are categorized as Performance Category (PC)-2 or PC-1 as shown by Table 3.1.4-1 and are evaluated for all applicable natural phenomena threats in accordance with DOE-STD-1020-94, *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities*.[3-9]DOE-STD-1020-94[3-9] requires the evaluation of flooding, high winds and tornadoes, and earthquakes. Categorization of structures is governed by DOE-STD-1021-93.[3-11]

3.1.4.1 Flooding

The site is atop Chestnut Ridge and thus not within a floodplain. Widespread flooding is not likely for a ridge-top site location several hundred feet above the valley floor.

3.1.4.2 Local Precipitation

In accordance with the applicable PC designation (see Table 3.1.4-1), each structure's roof and building drainage are required to endure design basis precipitation. The SNS site is graded to prevent undesired water accumulation and a site retention basin provided to control rainwater drainage from the SNS site.

DOE-STD-1020-94[3-09] specifies the evaluation of snow loads in accordance with applicable building codes and standards. Therefore, snow loads on the SNS roofs are evaluated in accordance with American Society of Civil Engineers (ASCE) 7-95, *Minimum Design Loads for Buildings and Other Structures*,[3-12] using an importance factor of 1.2. For the SNS site, the ground snow load from ASCE 7-95 is ten pounds (lbs)/ft^2, which is not limiting compared to other design loads.

Table 3.1.4-1

Classification of Structures

Building/Feature	Performance Category[a]	Code of Record[e,f]
Front End Building	PC-2	Standard Building Code (SBC)[3-10]
LINAC Tunnel	PC-2[b]	SBC
Klystron Building	PC-2	SBC
HEBT Tunnel	PC-2	SBC
Ring Tunnel	PC-2	SBC
RTBT Tunnel	PC-2	SBC
Target Building	PC-2	SBC
Ring Service Building	PC-1[c]	SBC
RTBT Service Building	PC-1	SBC
Beam Dumps	PC-2	SBC
Central Helium (He) Liquefier Building	PC-1	SBC
RF Cavity Reconditioning and Test Buildings	PC-1	SBC
Central Utilities Building	PC-1	SBC
Central Laboratory and Office (CLO) Building	PC-1	SBC
Site[d]	PC-1	SBC

[a]PC designation based on requirements of DOE-STD-1021-93,[3-11] et al.
[b]PC-2 is based on cost and mission considerations; Importance Factor = 1.25. Peer review of design is required.
[c]PC-1 is essentially life safety; Importance Factor = 1.0.
[d]Site included miscellaneous foundations (e.g., switchyards) and structures (e.g., conduit banks and piping tunnels).
[e]Wind loads defined per ASCE 7-95.[3-12]
[f]Seismic accelerations determined per UBC-97.[3-13]

3.1.4.3 Winds

Wind design and evaluation criteria for DOE facilities are specified in DOE-STD-1020-94[3-09] and ASCE 7-95.[3-12] The minimum wind design criteria for SNS is given in Table 3.1.4.3-1 (see Table 3.1.4-1 for building PC designations).

Table 3.1.4.3-1		
Wind Design Criteria for SNS		
Performance Category (PC)	1	2
Hazard Annual Probability of Exceedance	2×10^{-2}	2×10^{-2}
Peak mph Wind Speed at 10 m Height	90	90
Importance Factor	1.0	1.07
Atmospheric Pressure Change	NA	NA
Missile Criteria	NA	NA

3.1.4.4 Seismic Activity

Seismic design and evaluation criteria for DOE facilities are specified in DOE-STD-1020-94.[3-09] The seismic hazard levels and amplified response spectra have been determined for the SNS site in accordance with DOE-STD-1022-94, *Natural Phenomena Hazards Site Characterization Criteria*.[3-14]

3.1.5 EXTERNAL MANMADE THREATS

There are no nearby industrial facilities or other manmade hazards that present hazard to the SNS site. The Center for Nanophase Material Sciences facility is located adjacent to the SNS central laboratory and office building but it does not involve energetic processes or hazards that could threaten the SNS facilities. Major airports are more than 10 miles distant from the SNS site; for example, McGee Tyson Airport, the only major airport in the area, is located about 18 miles to the southeast, in Blount County, Tennessee.

3.1.6 NEARBY FACILITIES

As mentioned above (see Section 3.1.1) and as illustrated by Figures 3.1.1-2 and 3.1.1-3, three major installations are located within several miles of the SNS: ETTP (K-25), Y-12, and ORNL.

3.1.7 WILDFIRES

Due to the location of the SNS site in a forested area, a fire analysis was done, consistent with the requirements and guidelines of National Fire Protection Association (NFPA) 299,[3-15] to determine the wildfire risk to the SNS site. The risk assessment, conducted in accordance with the guidelines of Table A-3-2 (a) of NFPA 299,[3-15] indicates that the risk from a wildfire is a low hazard. The site fire hazards analysis (FHA) (see Appendix E) contains the detailed analysis. The analysis assumes that administrative controls are in place and implemented in accordance with NFPA 299[3-15] to maintain a minimum 30-ft defensible space to protect all SNS buildings and equipment from the effects of a wildfire. The results indicate that no additional physical fire protection features beyond those required by this analysis (and those specified in each SNS building FHA) are needed to maintain a low hazard rating.

3.1.8 ENVIRONMENTAL ANALYSES

The environmental impact analyses for the SNS are documented in the Final Environmental Impact Statement[3-1]. A supplemental analysis was filed to describe potential impacts of the project change to a superconducting LINAC (SCL) early in calendar year 2000.

3.2 ACCELERATOR AND SUPPORT SYSTEMS

This section describes accelerator related facilities on site except for those associated with the Neutron Facilities, which are addressed in the FSAD-NF.[3-25] Figure 3.2-1 shows the SNS site with buildings labeled and is a representative depiction of key SNS facilities with the exception that some of the soil has been removed to allow a more complete view of below-grade accelerator structures, such as the tunnels. In Figure 3.2-1, the existing CNMS facility is ghosted-in at right of the SNS Central Lab and Office Building and the possible second target building ghosted-in to right of present Target Building.

3.2.1 ACCELERATOR SYSTEMS

Figures 3.2.1-1 through 7 show plan, isometric, and cross-sectional views of the accelerator facilities. These are schematic illustrations of the facilities discussed below (i.e., not “as built” drawings).

3.2.1.1 Front End Systems

The SNS Front End consists of a Cesium-enhanced, volume RF-discharge Ion Source with a nominal –65 kV potential to ground. H^- ions produced in the ion source are extracted by the –65 kV potential difference. The short Low Energy Beam Transport (LEBT) section contains two electrostatic lenses that focus the beam into the Radio Frequency Quadrupole (RFQ). The second lens is split in 4 segments that pre-chop the beam. The 402.5 MHz RFQ bunches the H^- beam and accelerates the beam to about 2.5 MeV, while periodically refocusing it in both transverse planes.

To match the transverse emittance properties of the beam exiting from the RFQ to the first accelerating tank of the drift tube LINAC (DTL), there is a Medium Energy Beam Transport (MEBT) between these two structures. The MEBT not only includes the magnetic focusing elements but also RF bunching cavities to maintain the 402.5 MHz longitudinal beam structure. It also contains a traveling-wave beam chopper to match the nominal beam and synchronous gap at the Ring RF rotation frequency of ~1 MHz. Scrapers are used to remove the beam halo.

During routine operation, the Front End feeds H^- beam to the LINAC for acceleration. By contrast, when operating in the “Front-End-Only” mode, the beam ends in the PPS-controlled MEBT beam stop. This mode enables coordinated operation of the Front End while allowing safe worker access to the LINAC. The MEBT beam stop is a carbon block with reentrant shape that does not require active cooling at the intended beam power (about 45 W). The PPS does not allow the Front-End-Only mode unless the MEBT beam stop is in place.

Figure 3.2-1 **Spallation Neutron Source Site Facilities**

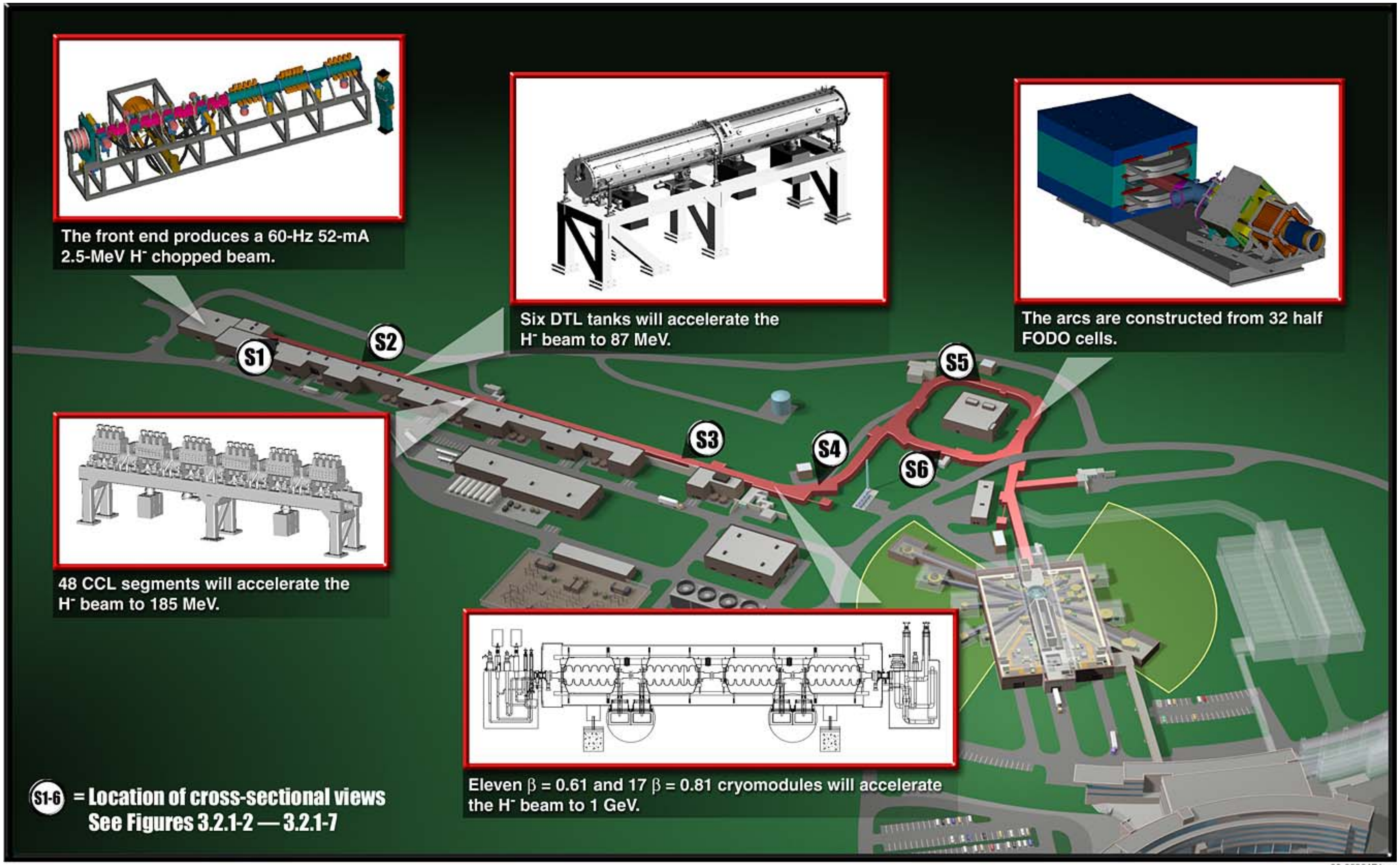

Figure 3.2.1-1 Illustration of Accelerator Systems Technical Equipment

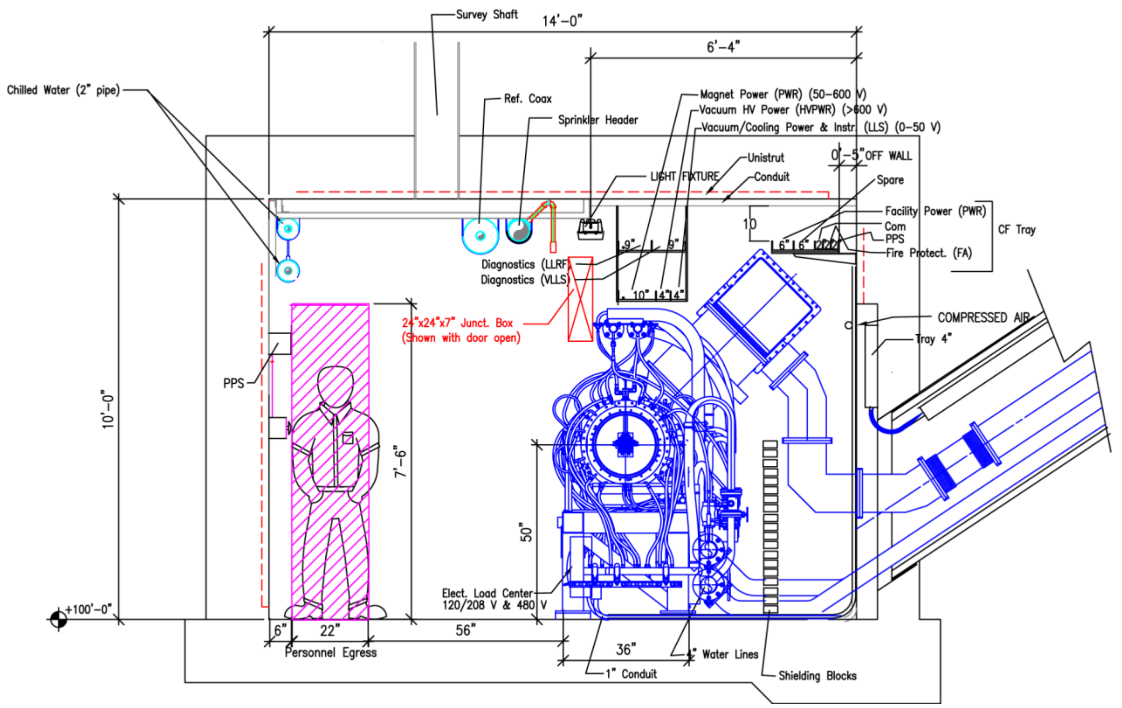

Figure 3.2.1-2 DTL Tunnel Cross Section (Schematic Illustration)

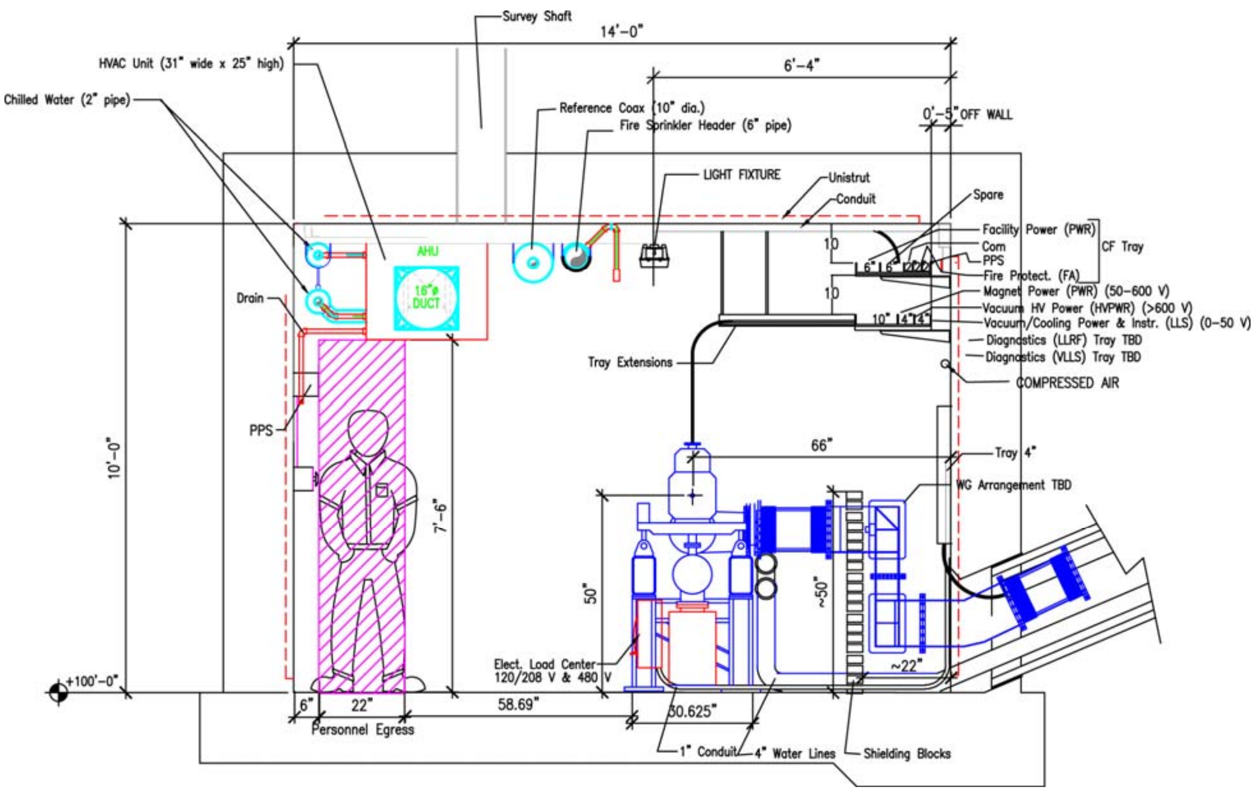

Figure 3.2.1-3 CCL Tunnel Cross Section (Schematic Illustration)

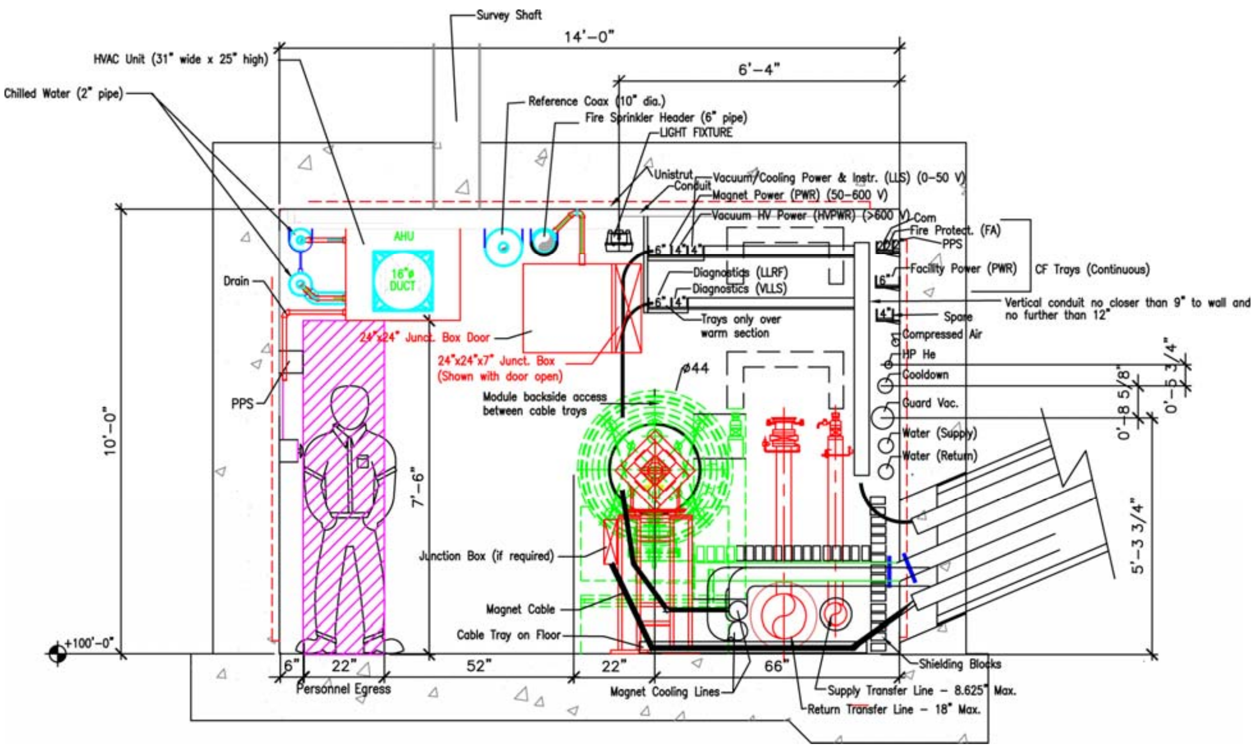

Figure 3.2.1-4 Superconducting Tunnel Cross Section (Schematic Illustration)

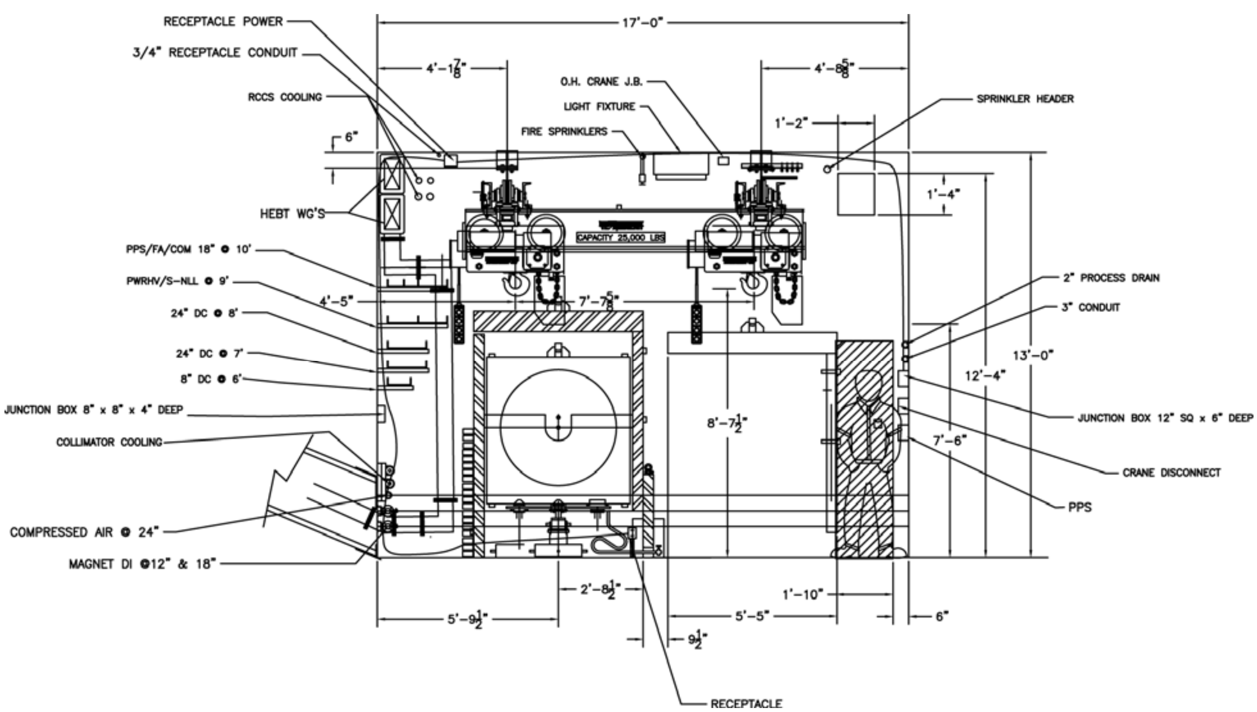

Figure 3.2.1-5 HEBT Tunnel Cross Section (Schematic Illustration)

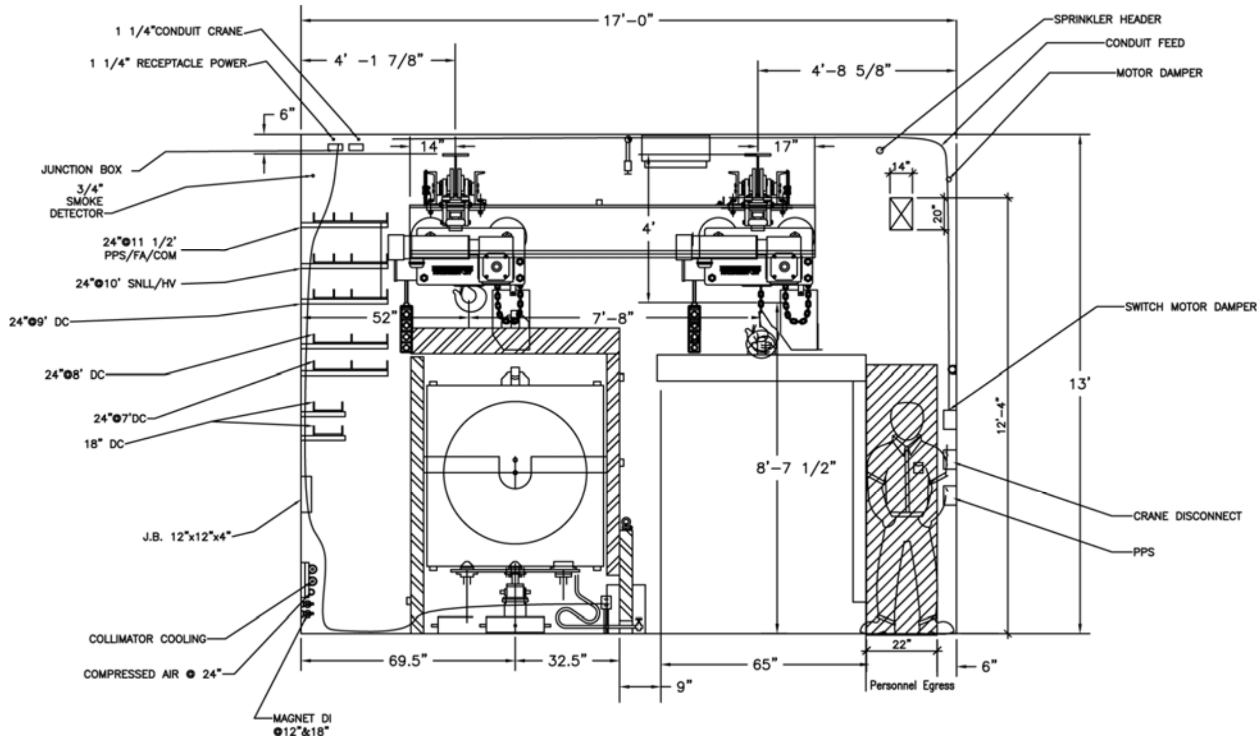

Figure 3.2.1-6 North Ring Tunnel Cross Section (Schematic Illustration)

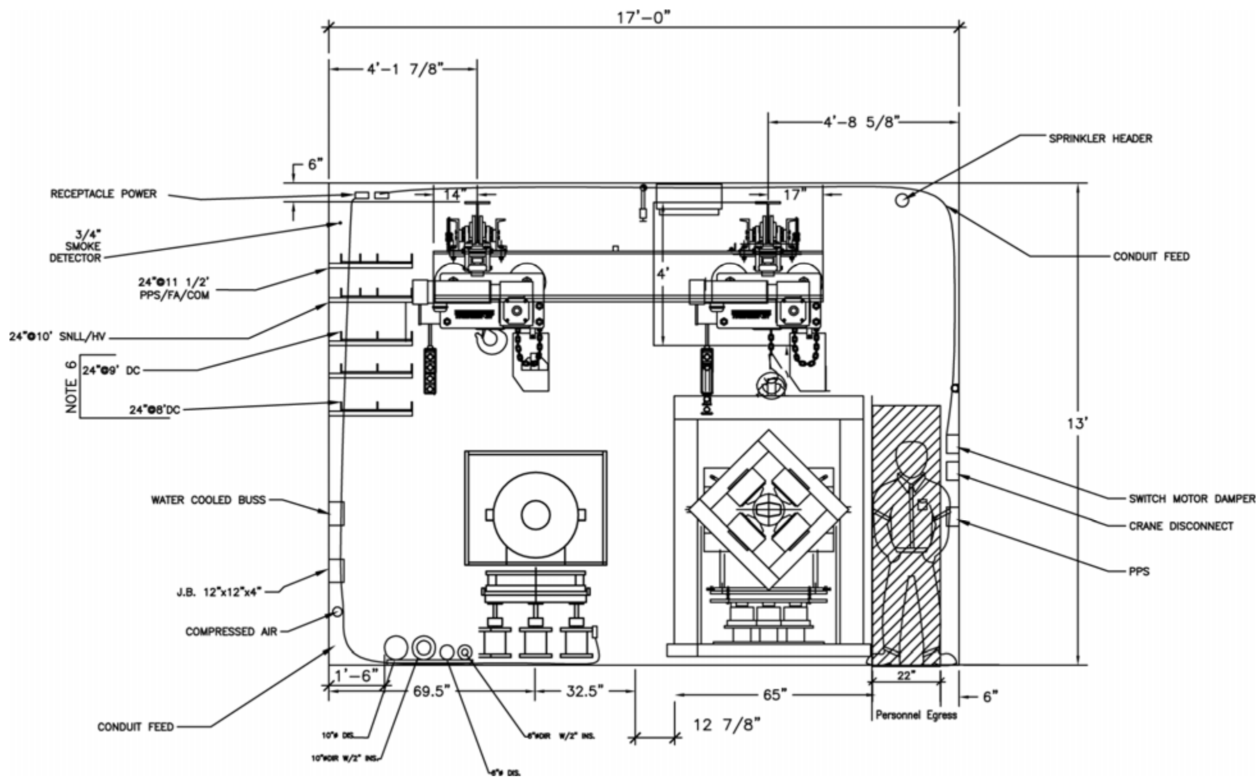

Figure 3.2.1-7 South Ring Tunnel Cross Section (Schematic Illustration)

The Front End facility includes space for two ion source test stands. So far, one test stand has been built and used to study design variations for ion source design improvement. The ion source test stand operates as a stand-alone entity (not connected to the LINAC) when in use. The test stand currently in use includes an ion source and a LEBT, and an RFQ may be added in the future.

3.2.1.2 LINAC Systems (includes klystrons)

As described below, the SNS LINAC includes three separate accelerating technologies (DTL, CCL, and SCL) in four distinct sections—two “room temperature” and two superconducting. The superconducting LINAC (SCL) consists of 3-cavity, medium-beta and 4-cavity, high-beta cryomodules. See Figure 3.2.1-1. The H^- nominal beam in the LINAC is a 1-millisecond (ms) pulse every 16.67 ms (60 Hz).

1. The DTL accelerates the beam received from MEBT from ~2.5 MeV to ~86 MeV and is operated at the same frequency as the RFQ MEBT (402.5 MHz) and receives power from 2.5 MW klystrons. The beam is also transversely focused in the DTL by the use of permanent magnet quadrupoles (PMQs) located within the cavity drift tubes.
2. The coupled cavity LINAC (CCL) then accelerates the H^- beam from ~86 MeV to ~187 MeV. It receives power from the 5 MW klystrons. As the H^- beam makes the transition into the CCL, it is captured by the CCL RF accelerating buckets (805 MHz), which is twice the DTL frequency.
3. Following the CCL, the beam is injected into the SCL. The first section has a relative phase velocity beta of 0.61. The second SCL section has a beta of 0.81. These cavities receive their power from 550 kW (kilowatt) klystrons with the transverse focusing provided in room temperature straight sections between cryomodules.
4. The 335-m long klystron gallery contains 92 klystrons. See Figure 3.2.1.2-1 for a view of the superconducting klystron gallery starting with the klystrons for cryomodule 18 (of 23) and looking west (upstream) toward the normal conducting section. This figure shows typical SCL klystrons and modulator sets as viewed from the maintenance aisle. High Voltage Converter Modulators (HVCMs) power these klystrons. Each HVCM provides 10 MW of peak power (1 MW average) at voltages ranging from 69 kV to 136 kV. Four water pump rooms (adjacent and to the south from the main klystron gallery) provide cooling water flows for klystron cooling and normally-conducting LINAC cavity cooling (cavity resonance is sensitive to temperature). Controls and communications racks, magnet power supplies and cavity field control (LLRF) are also housed in the klystron gallery.

Figure 3.2.1.2-1 Klystron Gallery (from within the superconducting section, looking west)

3.2.1.3 Ring and Transfer Line Systems

The ring and transfer lines form three distinct areas, two of which are single-pass beam lines and the last being a ~248 m circumference ring into which nominally 1000 turns of proton beam are injected and then extracted to the Target Station.

The HEBT is the beam line in which the ~1 GeV H^- beam is transported from the LINAC to the Ring. The H^- nominal beam that exists in the HEBT is a 1-ms pulse every 16.67 ms (60 Hz). In two locations in the HEBT, collimator systems serve as controlled loss points for beam halo that may develop and, therefore, control the effective transverse beam emittance of HEBT to be within the acceptance of the Ring Injection System. Additionally, a similarly constructed, water-cooled, beam-stop structure in the HEBT is provided to remove off-energy particles. It is designed to operate at 5 kW or less. This off-energy beam stop accepts the portion of the beam whose energy is outside the desired Ring acceptance criterion. The HEBT also has several quadrupoles in a focus drift defocus drift (FODO) configuration to define the required Twiss parameters at the injection foil. The HEBT beam line includes an arc of 90° to align the H^- beam as it approaches the Ring.

An alternate destination for the HEBT beam is the LINAC beam dump located at zero degrees from the LINAC. The LINAC beam dump is intended for use only for low-power beam commissioning and accelerator studies. The LINAC beam dump is a passive dump and is designed to accommodate approximately 7.5 kW of average beam power. A shield wall and PPS gate are provided shortly after the HEBT arc to allow work activities to occur in the Ring during LINAC studies and commissioning.

The Ring is actually more of a "square" with gradual bends of the four arcs and a circumference of ~248 m. Several unique features/elements are within the Ring:

- Injection is accomplished using direct current (dc) septum magnets and a stripping foil to remove the two electrons from the H^- and yield protons to circulate in the Ring. This stripping process should be nominally about 95% efficient (ranging from 90 to 98% depending on the stripping foil material and thickness). The H^- particles that escape stripping end up in the injection dump, described in 3.2.1.5.2. In the Ring injection region, there are eight pulsed/programmable kickers (four per plane) that permit the circulating proton beam to be preferentially placed at specific locations in phase space as a function of turn number. This process is necessary to form the desired beam profile (density distribution) of the ultimate accumulated beam to be delivered to the Target.
- The Ring is designed using a "hybrid lattice," which means simply that the arcs are composed of dipole magnets and quadrupoles in a FODO configuration; while the lattice functions in the straight sections are defined by quadrupole Focus Defocus (FD) doublet elements. This allows for more efficient use of the straight section space for other necessary equipment.
- A series of collimators are located in the north Ring straight section (after injection) and provide a localized area for controlled beam loss during accumulation. These devices are water-cooled and are expected to operate at 2 kW or less.
- The south straight section is occupied primarily by the Ring RF System. This consists of three RF cavities at ~1 MHz (fundamental) to provide the primary bunching of the beam and one cavity operating at the second harmonic to control the bunch shape.
- In the east straight section, the circulating beam is extracted from the Ring to the RTBT beam line using a fast-rise ferrite kicker system (14 modules) and a magnetic septum. Extraction is accomplished by discharging a series of capacitor banks into their corresponding pulse forming

networks for the kickers (this provides the proper field). These kickers then rise from zero to full field within the rotating beam bunch separation (between the tail and head) and extract the beam in one turn (<1 μs). If dipole magnet DH13 is energized, the beam is deflected toward the Target. If dipole DH13 is not energized, the beam is deflected to the Ring Extraction Dump.

At the exit of the Ring is the RTBT beam line. The nominal beam pulse length in the RTBT is ~700 ns as it is transported from the Ring to the Target Station. Another set of collimators is included in this beam line to further control/localize any beam loss to one specific area. Transverse focusing of this proton beam is provided by a FODO lattice up to the end of RTBT where two quadrupole doublets are located to allow final shaping of the beam profile.

Beam diagnostics are used to quantify beam properties and to provide the operations staff with sufficient information to first define and to then maintain the desired beam properties throughout the SNS Accelerator Facility.

3.2.1.4 Support Facilities: CHL and RF Test Facility

CHL Building. The central helium liquifier (CHL) houses equipment that liquefies and circulates helium through the SCL. It contains compressors, pumps, cold boxes, vacuum equipment, oil removal equipment, and the controls and diagnostics necessary to allow smooth operation of the cryogenic systems. There are gas and liquid storage areas outside the building, as well as areas for tank and tube trucks to enter and make deliveries. Underground cryogenic transfer lines transport supercritical helium from the CHL to the LINAC tunnel. Electrical power is essential for routine operations of the CHL equipment. An emergency diesel generator (not credited for safety purposes) is provided to minimize the probability that an extended AC power loss could lead to safe, but financially costly, venting of helium inventory to the outdoor air. A system of oxygen deficiency alarms is maintained to warn workers in the CHL in the event of a potentially inadvertent hazardous release of inert gas (see Sections 3.2.3.11 and 5.2.2).

The CHL is divided into two major rooms: (1) the compressor room on the west side houses the compressors, and (2) the cold box room on the east side holds the cold box and associated equipment. The building has a mezzanine that contains the CHL Control Room. The outside walls have sound suppressing vents. The helium compressors operate continuously and lose considerable heat to the air of the compressor room, so the room is provided with ventilation features that help maintain habitable temperatures. Side vent panels with area in excess of about 300 ft^2 are built into the compressor room north and south walls to allow relatively cool outdoor air to enter the building. Ceiling vents (free area about 40 ft^2) provide a passive path to exhaust warm air to the outdoors. The ceiling vents are equipped with fans to increase flow rate as desired. The passive side and ceiling vents are credited with minimizing oxygen deficiency hazard (ODH) in the event of inadvertent release of non-cryogenic helium into the compressor room (see also Section 5.2.4).

Figure 3.2.1.4-1 provides a block diagram of the cryogenic system that supports cryogenic operation of the SCL. This system comprises eight major subsystems: gas storage, compressor system, main cold box, 2.1 K cold box, purification system, 7000 L Liquid Helium (LHe) dewar, LINAC distribution system, and the cryomodules. It spans from just outside the CHL Building through the CHL and into the tunnel. The gas storage system has eight 30,000-gallon vessels that can store helium at approximately 250 psig. Helium gas flows from these tanks to/from the compressor system and to/from the purification system. The compressor system (located in the compressor room of the CHL Building) consists of three dual stage compressors with two in constant operation and the third as a standby. The compressed helium flows to the main cold box (cold box room on the east side of the CHL Building) where it is pre-cooled with liquid nitrogen. It is further cooled to 4.5 K within the cold box through a series of turbo expanders and countercurrent flow heat exchangers. The main cold box supplies the LHe dewar and the tunnel distribution system. The cold boxes are confined spaces that are not routinely occupied. They may, however, be entered under carefully defined conditions that may require a confined space permit as defined per the ORNL SBMS.

The LHe dewar was designed to support the commissioning of the refrigeration system prior to the commissioning of the transfer lines and of the cryomodules. During normal operation the LHe dewar is used to manage the refrigeration system capacity. The tunnel distribution system utilizes approximately 950 ft of both supply and return transfer line. These lines connect the refrigeration system to the cryomodules. The cryomodules are the last part of the cryogenic system. It is within these components that the cryogenic and accelerator systems are intertwined. Helium is liquefied across a Joule-Thompson valve in the cryomodule. The 2.1 K cold box pumps on the liquid inventories in all the cryomodules thereby lowering the temperature of the liquid to 2.1 K. This 2.1 K liquid (super fluid) provides cooling to the superconducting cavities that propel the proton beam.

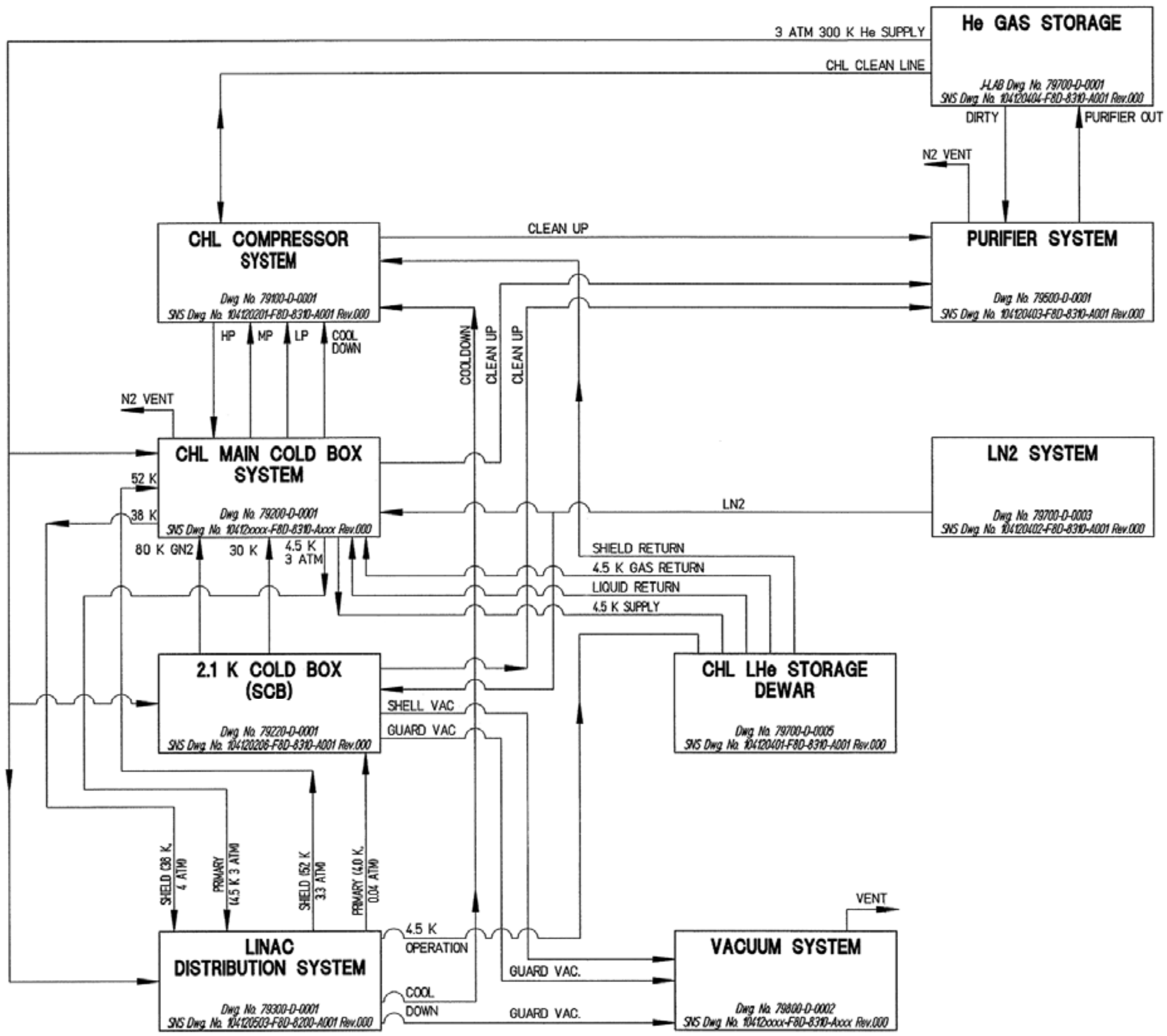

Figure 3.2.1.4-1 Cryogenic System Block Diagram

<u>RF Test Facility.</u> The high-power RF stations that provide RF power at 402.5 and 805 MHz to all RF test stations are located in the adjacent RF Building, along with a small area to store spare klystrons. RF power at 805 MHz is transported by means of waveguides to the superconducting cavity shielded test cave in the RF Test Building. Liquid helium is provided to the test cave by transfer lines connected to the CHL distribution system. RF power at 402.5 MHz is also available to test RFQ and DTL modules in the RF Test Building (Section 3.2.4.1.5 provides additional descriptive information regarding the RF Test Facility building).

3.2.1.5 Beam Dumps

The SNS has three beam dumps located outside the tunnels—one at zero degrees to the LINAC near the HEBT (LINAC dump), another downstream of the Ring injection region adjacent to the Ring (injection dump), and the third near the RTBT beam line (extraction dump). Each beam dump is located below grade, a short distance from the tunnel. The LINAC and extraction beam dumps are passive dumps designed for an average power of ≤7.5 kW. The passive dumps are intended for infrequent use (e.g., low-power commissioning and beam studies). The injection beam dump, however, is designed for continuous use and accepts any portion of the HEBT beam not fully stripped at the foil (nominally 2-10% of the injected beam). This beam dump is designed for an average power of ≤150 kW.

Table 3.2.1.5-1 gives selected representative values for major design parameters. The location of these dump facilities, relative to the remainder of the accelerator, is shown on Figure 3.2-1.

Section 3.2.1.3 describes two sets of collimators and one beam stop (the off-momentum beam stop) located inside the Accelerator Ring and HEBT. The expected thermal power level for each is smaller than the three beam dumps discussed in this section.

Table 3.2.1.5-1

Beam Dump Design Parameters

Beam Characteristics at the Beam Dumps (Representative Values)

Parameter	LINAC	Injection	Extraction
Maximum Average Power (kW)	7.5	150	7.5
Beam Energy (GeV)	1.0	1.0	1.0
Pulse Length (ms)	~ 1.0	~ 1.0	~ 0.0006
Nominal Pulse Energy (kJ/pulse)	33	3.33	33
Frequency (Hz)	1	60	1
Duty Cycle (%)[a]	10	100	10

[a]Note: Duty cycle is defined as the operating time in a one-year period divided by 5000 h.

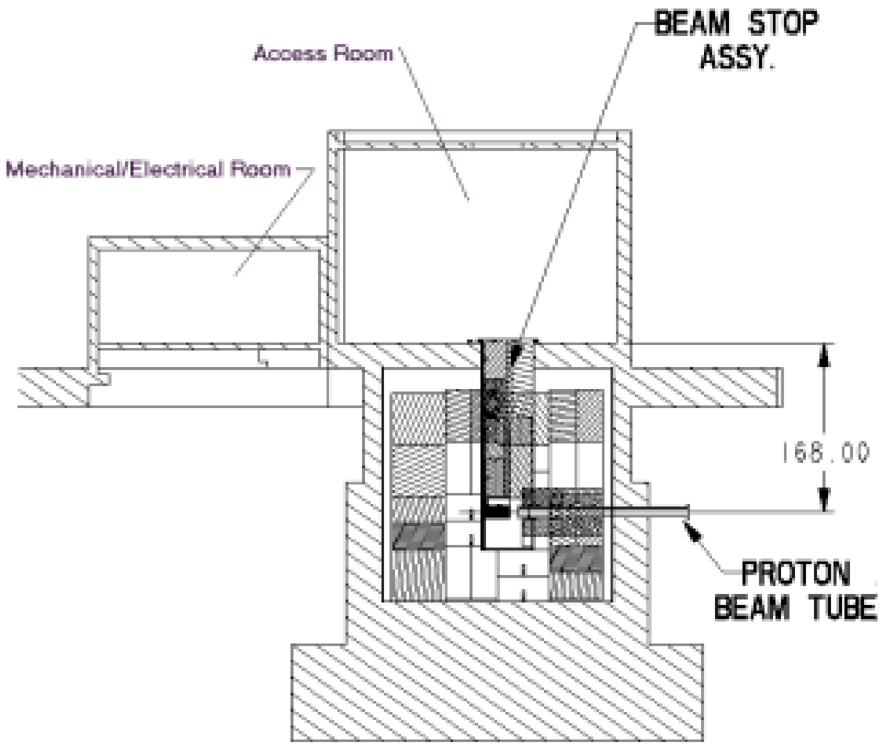

Figure 3.2.1.5-1 Vertical Section of Dump Facility—Typical of Ring Injection Dump (LINAC and Ring Extraction Dumps do not have mechanical/electrical or access rooms.)

The general arrangement concept for the dumps provides a branch of the evacuated proton beam flight tube that extends horizontally through the berm and enters the beam dump shielded vault. The beam dump vault is filled with an array of multi-ton shielding blocks with sufficient thickness to minimize soil activation and reduce personnel radiation exposure consistent with 10 CFR 835[3-16] (Note: Soil berm around the beam dumps has the same water control features described in Section 3.2.4.1.3 for the accelerator tunnels.).

The flight tube for the Ring Injection Dump is capped with a water cooled vacuum window immediately on the inside of the beam stop enclosure. Criteria for periodic replacement of this vacuum window include applicable personnel radiation exposure considerations, including as low as reasonably achievable (ALARA) goals. Failure of the window is an operational concern due to the potential for window failure to degrade accelerator vacuum or to spread contamination to the interior of the accelerator proton beam tube. The beam stop enclosure contains the beam stop assembly and miscellaneous shielding slabs.

The primary windows for the flight tubes leading to the LINAC and extraction dumps are located in the HEBT and RTBT sectors of the beam tunnel. There is no planned access to the LINAC or extraction beam dump vaults, nor do these two dumps have aboveground buildings.

3.2.1.5.1 LINAC and Ring Extraction Dump Description

The LINAC and Ring extraction dumps are very similar in design, and both dissipate the beam-induced heat passively.

For these two 7.5 kW passive dumps the beam stop is a stack of carbon steel plates with variably thin center sections in the beam interaction region. The plates are firmly grouted and anchored at the bottom edges so the heat is conducted through this connection to the surrounding shielding and eventually to the soil. Approximately 80% of the particle beam thermal energy equivalent is deposited directly in the stop, with the remainder deposited in the surrounding array of multi-ton shielding blocks. The soil is the ultimate heat sink for these dumps.

3.2.1.5.2 Ring Injection Dump Description

The injection dump is needed to accept non- and partially-stripped H^- ions produced in the injection process from the HEBT to the Ring. It is limited to an average power of 150 kW. Normal operating losses are less than the rated average power limit. The injection dump is used for HEBT tuning. An H^- intensity monitor after the injection foil is part of the injection system and is used to monitor the foil condition.

The beam stop for this dump is more sophisticated than that for the two 7.5 kW dumps. It is based on the successful beam stop at the LANSCE facility. The SNS adaptation is shown pictorially in Figure 3.2.1.5.2-1. The beam stop is assembled into a beam stop enclosure similar to the other dumps and is shown in vertical section on Figure 3.2.1.5.2-2.

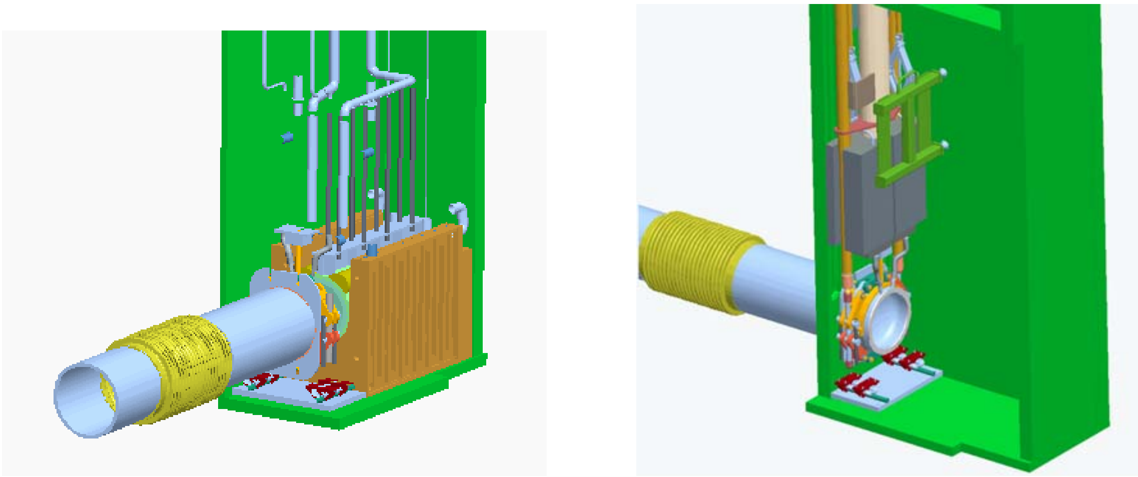

Figure 3.2.1.5.2-1 Injection Beam Stop

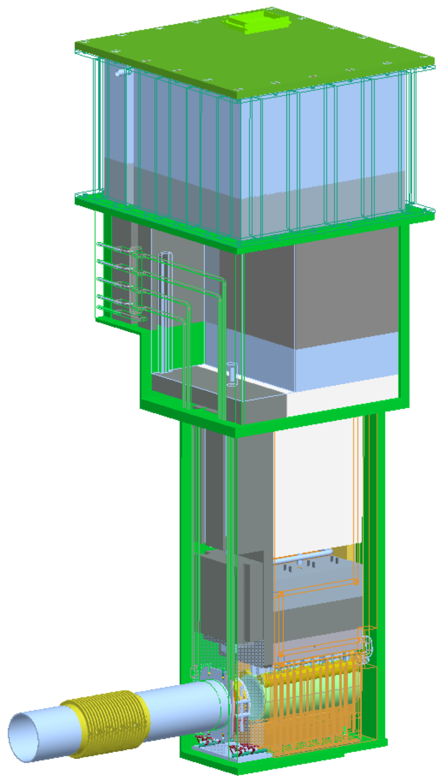

Figure 3.2.1.5.2-2 Vertical Section of the Injection Beam Stop and Supporting/Shielding Structure

This beam stop uses water-cooled copper disks enclosed in a stainless steel vessel to absorb the proton beam energy and dissipate the energy to the water. The copper disks are sized (i.e., thickness increasing with beam penetration) to absorb about 5 kW watts in each disk, and a water flow path is machined into each disk. Heat exchanger, pumps, and ion-exchange units are located in the shielded utilities vault. The injection dump heat load is ultimately rejected to the SNS cooling tower through an intermediate cooling water loop. No direct connections are provided between tower water and radioactive beam dump water. Design features are provided to minimize the probability of heat exchanger leaks causing inadvertent cross contamination. The primary heat exchanger is an all welded plate and frame construction with the secondary closed loop DI water system at higher pressure than the primary. The secondary system is cooled through another plate and frame heat exchanger that interfaces with the site wide cooling tower water system.

3.2.1.5.3 Operations and Maintenance

Since the LINAC dump and Ring extraction beam dump have no structures or buildings (other than the vault enclosing their shielding stack), there are no operations and maintenance activities associated with these dumps.

Maintenance activities at the Ring Injection Beam Dump occur in the three rooms above the beam stop vault. These rooms are the mechanical/electrical equipment room, the utility services vault, and the beam stop access room and are depicted in Figure 3.2.1.5.3-1. The PPS controls access to the utility services room. Access to the mechanical/electrical equipment room is anticipated on a frequent basis. The equipment racks and non-activated utility equipment are located in this room. When a beam dump operation sequence is planned, it is expected that personnel may enter this room to turn on the pumps and prepare the dump for operation.

The beam stop access room has very little equipment that requires routine personnel attention. It is primarily used when the beam stop is being removed through the hatch in the roof. Since there is potential for increased radiation doses in this area this room is access controlled.

The utility services vault houses the water pumps, the heat exchangers and the ion exchange columns used for injection dump cooling. This area has elevated radiation levels during operation and is equipped with 40-inch (in.) concrete walls and labyrinth opening. Some of the equipment contains activated material (especially the ion-exchange columns), which requires personnel-controlled access even when the facility is not operating. Access to this area is controlled, and a PPS interlock is installed on the door so that the beam is tripped when unauthorized access is attempted.

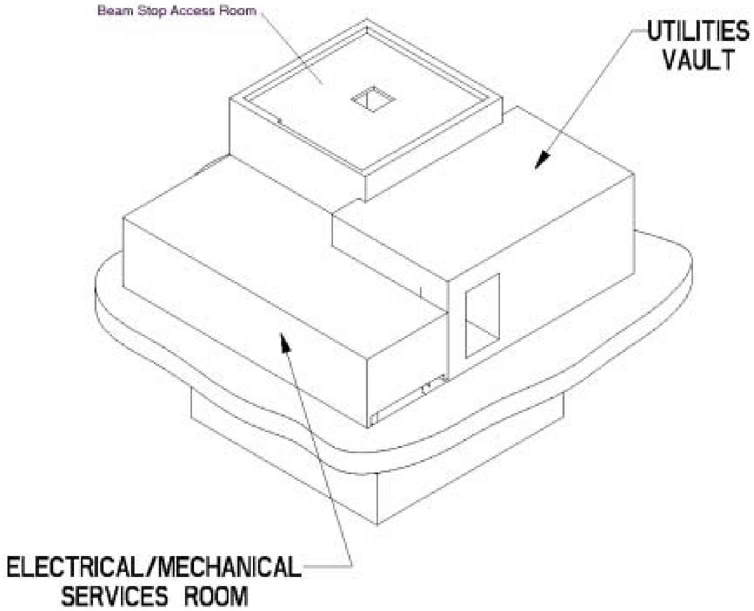

Figure 3.2.1.5.3-1 Isometric View of Ring Injection Beam Dump Facility

3.2.2 INTEGRATED CONTROL SYSTEM

3.2.2.1 Introduction

The integrated control system (ICS) provides both high and low level machine control and cutoff functions and includes both the Machine Protection System (MPS) and the Personnel Protection System (PPS). An approved security plan[3-24] is implemented to protect the controls network from intrusion. Operator console access is controlled by passwords. Other means are used, as appropriate, to minimize the probability of unauthorized actions.

The ICS provides:

- supervisory control and data acquisition (SCADA) for accelerator, conventional, and Target subsystems;
- the "machine protection system" (MPS) for protecting equipment from beam-related damage;
- the timing system for synchronization of accelerator subsystems; and
- the PPS for protecting workers against prompt radiation.

SNS supervisory controls are implemented using the Experimental Physics and Industrial Control System (EPICS) software tools. EPICS follows the “standard model” for a distributed control system. The architecture of this model is characterized by distributed controllers, operator interface workstations, and file servers, all of which are linked via an Ethernet TCP/IP local area network. EPICS is in use at several major accelerator facilities, including the Advanced Photon Source (APS) at ANL and the Continuous Electron Beam Accelerator Facility (CEBAF) at the JLAB. All SNS technical systems (Front End, LINAC, Ring, Target, and cryogenic helium liquefier, as well as the Conventional Facilities) are controlled via EPICS-based supervisory controls.

Proper operation of SNS requires synchronization of equipment for generation, acceleration, transport, storage, and extraction of beam. For example, beam chopping in the Front End must be timed to maintain the gap in the beam circulating in the Ring. The ICS includes a timing and synchronization system to fulfill this function. This system is modeled after a system in use at the Relativistic Heavy Ion Collider (RHIC) at BNL. For this purpose, it utilizes two dedicated fiber communication links: a “real-time data link” and an “event link” for synchronization.

The ICS includes the MPS for the protection of SNS equipment from beam-related damage. This system inhibits beam when equipment is not configured to accept it, whether due to equipment failure or operational error. Examples of events that prevent beam include: (1) detection of significant beam loss; (2) magnet failures; and (3) Target system not configured to receive beam. Configuration of the MPS is dependent on the operational mode of the SNS facility, which is distributed redundantly by the timing and synchronization system links. Figure 3.2.2.1-1 shows a schematic of these major ICS subsystems and their interfaces with other systems and subsystems. The elements of the distributed control system are shown in yellow. The Personnel Protection System (PPS) is in rose; the Machine Protection System (MPS) is in blue; the Timing System is in olive; and the various systems being controlled are shown in green. The entire network is isolated from the SNS public network (office computers, etc) by a commercial firewall and the SNS network is in turn isolated from the ORNL enterprise network by another commercial firewall layer. This security is regularly probed for vulnerabilities by the ORNL computer security group.

3.2.2.2 ICS Layered Protection

ICS subsystems are structured in a manner that provides layered protection (defense-in-depth) against threats to both equipment and personnel. Figure 3.2.2.1-2 shows this layering of subsystems schematically. The PPS ensures protection of workers against prompt radiation but, as discussed below, other controls provide layers of protection against potential operational problems before they require PPS actuation.

The supervisory control system provides the first layer of defense by enforcing system configuration rules, annunciating abnormal conditions, and responding when conditions approach unacceptable boundaries. While the supervisory control system acts to prevent challenges to other ICS systems, it is not considered to be either a safety system or a protection system.

The MPS provides the second layer of safety, responding to out-of-bound operating conditions by shutting off the beam. The MPS is a high reliability system but is not a safety system. However, it does contribute to layered protection by preventing challenges to the PPS radiation monitoring function by cutting off beam quickly when beam losses occur.

Thus, both the EPICS-based supervisory control system and the MPS contribute to overall assurance of safety by limiting challenges to the PPS, which is described below in Section 3.2.3. Control, protection, and safety functions are layered so that as the consequences of a failure increase so, too, does the quality level of the responsible system.

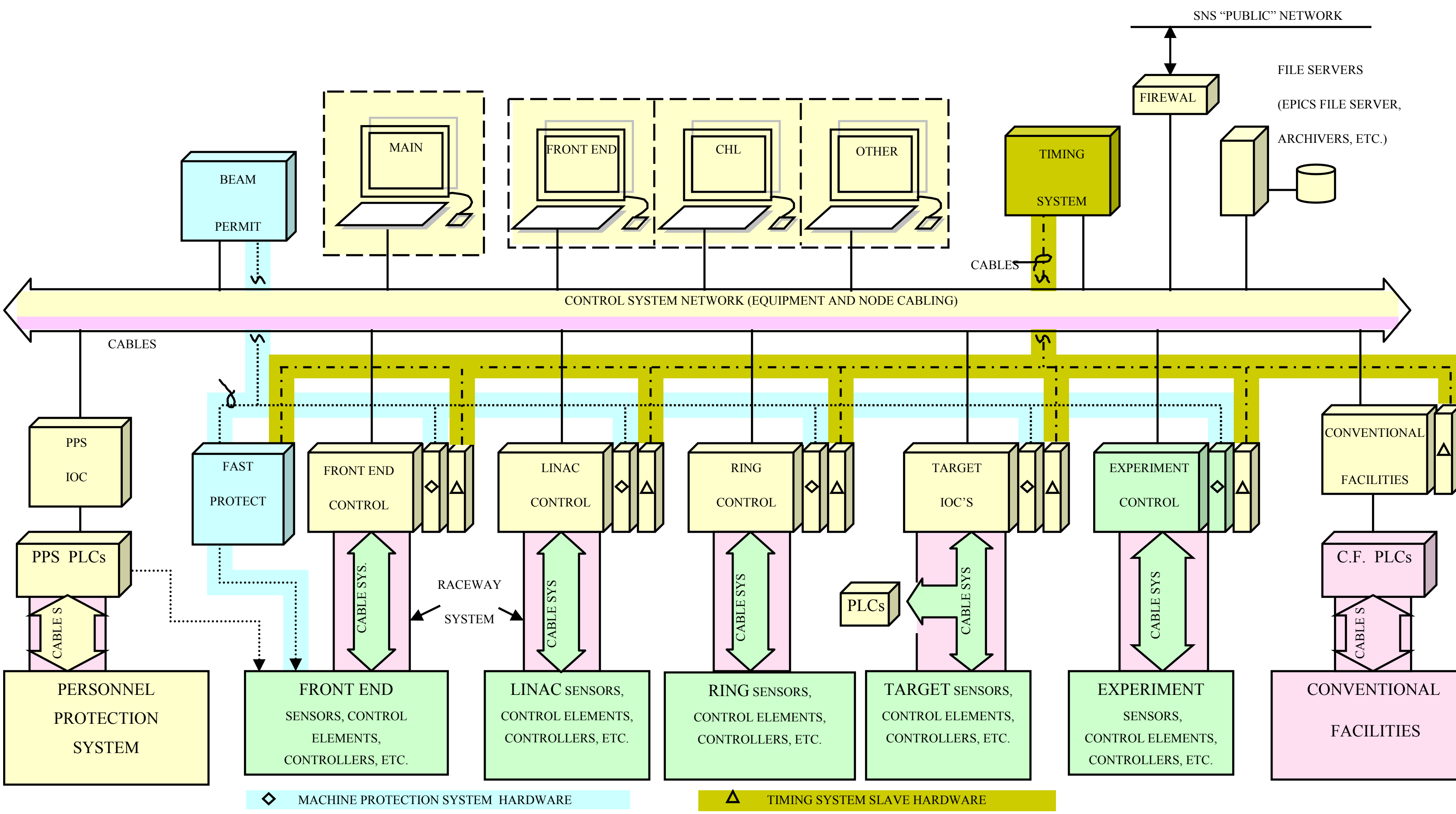

Figure 3.2.2.1-1 Integrated Control System Block Diagram

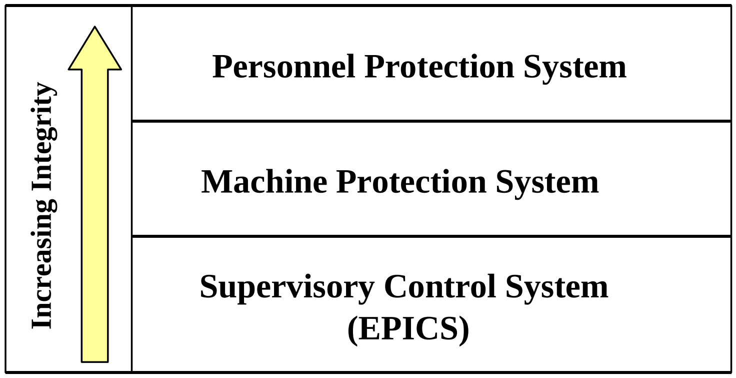

Figure 3.2.2.1-2 Integrated Control System "Layers of Defense"

3.2.2.3 Machine Protection System

The MPS is used to shut off beam if equipment malfunctions are detected that could result in equipment damage. It is made up of the following three subsystems listed in decreasing order of criticality and QA requirements:

1. A "Fast Protect—Auto Reset" Subsystem that terminates the beam pulse creation rapidly (20 μs response design goal) on detection of an anomalous beam-related condition (e.g., high losses) but allows the next pulse to be accelerated. This is a hardware system with an independent fiber link to the Front End for beam turnoff. It has an important ALARA impact by minimizing activation of structures.
2. A "Fast Protect—Latched" Subsystem that terminates the beam pulse creation rapidly (20 μs response design goal) on detection of an anomalous equipment status (e.g., power supply trip) and that requires operator intervention to reset. This is a hardware system with an independent fiber link to the Front End for beam turnoff.
3. A "Beam Permit" System verifies that selected aspects of the facility are configured so as to conform to the requirements of the operator-selected (or the program-selected) mode before allowing beam. This system is implemented in software to indicate to the operator the status of equipment, including the two fast-protect systems and the PPS, and to flag when equipment is not configured correctly.

These subsystems collectively provide the following functions:

- Protect SNS equipment from beam-induced damage. If a mis-steered beam (e.g., due to a magnet failure) is not quickly terminated, then equipment damage may result. Similarly, if the target or the ring injection dump is not ready to receive beam (e.g., due to a cooling system failure) then the beam must be terminated, or damage may result. The MPS monitors beam-related equipment and beam parameters and terminates beam if failures are detected.
- Reduce radioactivation of equipment by cutting off the beam when beam loss is detected. The MPS is designed to terminate beam in tens of microseconds when excessive beam loss is detected. This action also serves to reduce prompt radiation levels.
- Facilitate beam tuning by regulating the beam pulse duration when the beam tuning is less than ideal. After a beam loss is detected and the beam pulse is terminated, the system automatically resets so the next pulse can occur. This “pulse width modulation” automatically minimizes the impact of the beam loss while allowing tuning to continue.
- Guard against equipment configuration errors. When an operator requests a new operating mode, the MPS allows the mode change only if related equipment is configured properly. The operator is informed of any conditions that are preventing the mode change.

The MPS protects against some events that could otherwise result in a significant loss of capital and/or operating time. Those portions of the MPS for which a failure could result in a significant loss are assigned a Quality Level 2; the remainder of the system is Quality Level 2 or 3. MPS trip features may be bypassed, e.g., during maintenance or testing activities, but only in accordance with specified SNS operations procedures.

Due to the potential impact of the MPS on the availability of SNS, steps are taken to ensure its reliability. The steps include the following:

- Design the system to operate reliably.
- Design the system to “fail safe” (e.g., A power outage, open circuit, or out-of-range signal should cause SNS to revert to the protected state.).
- Design the system to facilitate fast and efficient periodic testing (e.g., by automated configuration testing and verification).
- Apply configuration control commensurate with the consequences of a failure.

3.2.3 ACCELERATOR SAFETY SYSTEM

Three essential safety systems are used to protect workers from significant hazards associated with the Proton Facilities: (1) the PPS, (2) the ODH monitoring and alarm system, and (3) the ODH system initiation of the tunnel Emergency Ventilation System. These systems protect workers from accelerator-specific hazards—namely prompt radiation associated with the H^- or proton beam and inert gases associated with the superconducting LINAC—that could cause worker injury. These systems are maintained in accordance with rigorous standards and procedures to provide a high level of system performance. Essential parts of the PPS and ODH system are designated Quality Level 1 and are configuration controlled in accordance with SNS procedures.

3.2.3.1 Overall Scope of PPS and ODH System

Figure 3.2.3.1-1 illustrates the scope of the PPS and the major facility segments it serves. The primary function of the PPS is to protect workers from potentially injurious prompt radiation produced by accelerator operations. A secondary (non-credited) function is to help protect workers from exposed electrical conductors associated with beam line magnets. The PPS is patterned after other successful radiation protection systems at the CEBAF and the APS. The PPS controls access to hazardous areas (beam line tunnels, equipment rooms and instrument enclosures) during accelerator operation. If the potential exists for personnel to access a hazardous area during operation, the accelerator is not allowed to operate or is shut down to prevent injury. The PPS supports administrative actions to clear hazardous areas of personnel prior to operation (sweep). For example the PPS provides audible and visual alarms to alert personnel to clear hazardous areas prior to allowing accelerator operation. The PPS divides Proton Facilities beam enclosures into four separate segments from Front End through RTBT. A system of double-entrance doors to beam line tunnels allows the control room operator to rigorously control access to these large areas without requiring the area to be re-swept. Each PPS segment is independent of the other segments such that modifications or repairs to one segment do not affect the other segments.

The ODH system is a separate safety monitoring and alarm system that is not connected to the PPS. Cryogenic systems are used in the LINAC and CHL to support the SCL cavities. These systems circulate helium in the LINAC and helium and nitrogen in the CHL Building. A system composed of oxygen transmitters and warning lights and horns is installed to protect workers in the event of a release of inert gas. ODH warning horns are designed to make a different sound from the PPS warning horns, so that workers know which hazard they are being warned about. The ODH system initiates forced venting via the Emergency Ventilation System (EVS) fans on detection of low oxygen levels in the LINAC tunnel.

Figure 3.2.3.1-1 Overall Scope of the PPS

The PPS and ODH systems are designed to operate independently from each other and are maintained as separate systems. This allows one system to be taken out of service without affecting the performance of the other system.

3.2.3.2 Safety Life Cycle

The PPS and ODH systems are implemented in accordance with a safety life cycle. This safety life cycle contains all of the elements required to ensure their proper performance throughout the life of the facility. The safety-life cycle for the PPS and ODH systems uses, as guidance, the requirements outlined in ISA-S84.01-1996, *Application of Safety Instrumented Systems for the Process Industries.*[3-17]

The safety life cycle begins with a hazard analysis to determine the hazards presented by the system and determines the appropriate methods to mitigate these hazards. The analysis includes a determination of the safety functions, as well as the required performance level for each safety function. The performance level, defined in the standard[3-17] as the Safety Integrity Level (SIL), defines the minimum reliability requirements commensurate with risk documented in hazard evaluations.

The PPS and ODH system are developed in accordance with the requirements for Quality Level 1 equipment in accordance with the *Spallation Neutron Source Quality Manual*.[3-18] These requirements include activities such as the following: (1) independent design reviews; (2) thorough documentation; (3) vendor qualifications; (4) configuration control; (5) formally trained operations and maintenance workers, and; (6) formal testing and certifications. The SNS Radiation Safety Committee provides independent review of proposed substantive changes to the PPS as appropriate.

3.2.3.3 Functional Design of the PPS

3.2.3.3.1 Segmentation

The design of the PPS segments the facility for ease of monitoring and operational organization. The facility is divided into five basic segments as follows (see Figure 3.2.3.1-1 above). These segments are:

1. LINAC—Includes the Front End and LINAC areas
2. HEBT—The HEBT Tunnel
3. Ring—Includes the Ring and Injection Dump
4. RTBT—The RTBT Tunnel
5. Target Building —Includes the Target utility areas and the neutron instrument enclosures

A redundant pair of programmable logic controllers (PLCs) serves each segment. Using this architecture, testing or maintenance can be conducted on the PPS equipment in one segment without affecting the PPS equipment in other segments.

3.2.3.3.2 Operating Modes

The PPS is designed to allow each of the accelerator tunnel segments to be in one of six modes. The PPS requires an orderly progression from one mode to the next before the accelerator can be operated. The operating modes are listed in Table 3.2.3.3.2-1.

Acting within the administrative controls of the Spallation Neutron Source Operations Procedures Manual (OPM),[3-19] the operator selects the appropriate mode for each segment using key switches located in the control room. The operator may not select the Controlled Access Mode or higher until a correct sweep of the tunnel has been performed. The PPS does not go into the Controlled Access-Magnets Energized Mode unless the Power Permit Mode has been reached (ensures no one is in the tunnel when the controlled access-magnets-on mode is selected).

Table 3.2.3.3.2-1	
PPS Operating Modes	
Mode	**Features**
Restricted Access	Personnel access to segment controlled by operator, ORNL prox card, or both. Access limited to trained or escorted personnel. Hazardous operations in segment not permitted.[a]
Sweep	Personnel access to segment controlled by operator and ORNL prox card. Only search personnel allowed in segment. Personnel required to carry an exchange key while in the segment. Hazardous operations in segment not permitted.
Controlled Access	Personnel access to segment controlled by operator and ORNL prox card. Access limited to specially trained personnel only (no escorting). Personnel required to carry an exchange key while in the segment. Hazardous operations in segment not permitted.
Power Permit	No personnel access permitted. RF klystron operation; energized exposed conductors allowed. No beam operation in segment.
Controlled Access—Magnets Energized (engagable only after reaching Power Permit)	Personnel access to segment controlled by operator. Access limited to specially trained personnel only. Personnel are required to carry an exchange key while in the segment. Exposed conductors may be energized.[b] RF or beam operations in segment not permitted.
Beam Permit	No personnel access permitted. Full operation allowed.

[a]Hazardous operation includes RF klystron operation, energized exposed conductors, or beam acceleration.
[b]Although the magnets' exposed conductors may be energized, this access does not constitute working "on or near." Actual work on the energized magnets would require an additional on-or-near work permit.

3.2.3.3.3 Safety Functions

The PPS is responsible for the following primary safety functions:

- Prevent beam operation in segments not cleared of personnel (beam containment).
- Shut off beam if personnel enter an operating segment.
- Shut off beam if the Target carriage is not in position to receive beam.
- Shut off beam if equipment faults cause radiation levels to increase over acceptable levels in potentially occupied monitored areas.
- Support administrative actions to clear personnel from segments before beam operation; drop the sweep if personnel enter a cleared segment.
- Prevent RF klystron operation in segments not cleared of personnel.

The PPS also performs for the following secondary functions to help enforce safety:

- Prevent energizing of exposed electrical conductors in segments not cleared of personnel except in controlled circumstances.
- Shut off RF klystrons and de-energize exposed electrical conductors if personnel enter an operating segment.
- Warn personnel located in segments before beam operations.

3.2.3.4 System Architecture

3.2.3.4.1 PLC Hardware

The logic functions for the PPS are performed by SNS standard PLCs. The PLCs are applied redundantly to increase the system reliability. The PLCs are applied in a one-out-of-two architecture or equivalent for the SIL-2 safety functions. SIL-1 safety functions are in some cases performed by a single designated channel. In one-out-of-two architecture, if either PLC detects the designated potential hazard under the predetermined condition(s), the source of the hazard (such as beam production) is eliminated. Inputs and outputs (I/O) to the PLCs are scattered throughout the facility. For this reason, the remote PLC I/O modules are connected to the PLC processor via SNS standard industrial control networks. The PPS PLCs have the following features:

- All I/O circuits are designed to be fail-safe. In the event of a power loss, broken wire, or out-of-range signal, the equipment goes to a safe condition (beam production stopped, klystrons shut down, exposed conductors de-energized).
- Each redundant PLC in a one-out-of-two configuration is maintained as a separate system to minimize common mode failures.
- PLC network and I/O cable are routed separately from other facility cabling.
- Equipment that interfaces to the PPS, not under the control of the PPS group, is isolated from the PPS. Isolation of external equipment prevents damage to the PPS in the event of a fault in the external equipment (i.e., short circuit, over-voltage, etc.).

3.2.3.4.2 PLC Software

The PLC logic programming is based on a rigorously prepared and reviewed logic specification. Separate programmers develop the PLC programming independently for each redundant PLC. The programs are never temporarily modified to bypass an input or force an output from the PLC. PLC programs are copied to removable media (such as CD-R or DVD disk) prior to certification. These disks are maintained in accordance with procedure by the PPS system engineer and the protection systems team leader as the official copies of the programs. During operation the PLC programming computer is removed from the control room and the network connection is disconnected inside the PPS rack. Installation and use of the programming computer during troubleshooting is controlled by procedure. Only authorized personnel are allowed to modify the PLC programs in accordance with the configuration control procedure.

3.2.3.4.3 PPS Computer Displays

PPS PLCs are connected to EPICS workstations in the Central Control Room. These workstations are used to display the status of the PPS. The workstations allow the operator to rapidly obtain information on the status of each segment in terms of operating mode and status of critical devices. Most of the inputs monitored by the PPS are logged by the main archive engine. This allows EPICS workstations to display historical data, such as radiation levels recorded by the radiation detectors. The PPS PLCs are connected to the PPS input-output controller (IOC**)** using a private network system separate from the network used for accelerator controls. The PPS IOC has two network connections, one for the PPS private network and one for the controls network. The PPS IOC has a specially modified operating system that prevents transmission of information from the controls network to the private network. This feature, along with the firewall installed between the controls network and the external laboratory networks precludes the possibility that someone can access the PPS PLC equipment from a remote location. The EPICS workstations are provided as operator aids. The proper execution of safety functions by the PPS is not dependent on the operation of the workstations.

3.2.3.5 Critical Devices

Designated critical devices (see Table 3.2.3.5-1) are used to stop beam production at the front end or prevent beam transport from an operating segment to an occupied segment. Critical devices are selected for reliability, certainty, and verifiability of the desired beam control state. PPS control of critical devices is implemented in accordance with fail-safe principles such that credible failure modes, such as loss of PPS power or continuity, result in removal of power to the device such that the device returns or remains in the desired safe state.

3.2.3.5.1 Beam Cutoff

The primary method the PPS uses to eliminate radiation hazards associated with the accelerator operation is to shut off the beam at the Front End. Three critical devices are normally used to stop beam production: (1) the –65 kV extraction power supply associated with the ion source; (2) the RF supply to the RFQ, and (3) RF power supply for the ion source plasma antenna. Elimination of any one of these 3 energy sources completely terminates beam production by the Front End system. The PPS is

Table 3.2.3.5-1				
Beam Containment Modes				
Operating Mode	**Operating Equipment**	**Critical Devices**	**No Access Allowed Areas**	**Access Allowed Areas**
Ion Source Conditioning	Ion Source	RF to RFQ and –65 KV power supply or RF power to ion source antenna	None	All
Front-End-Only	Front End (RF plasma, –65 kV, RF to RFQ)	MEBT beam stop[d] DTL 1, DTL 2 mode specific shorting plates[e]	None	All
LINAC Tuning	Front End, LINAC, and HEBT straight section	First Dipole Magnet in HEBT Second through Eighth Dipole Magnets in HEBT	LINAC HEBT	Ring, RTBT, Injection Beam Dump, Target Equipment Areas, Instrument Enclosures
Ring Tuning	Front End, LINAC, HEBT, Ring, RTBT, Injection Dump	RTBT Dipole Magnet[a] (RTBT.DH13) Extraction Septum[b] Dipole Magnet	LINAC HEBT Injection beam dump Ring RTBT	Target Equipment Areas, Instrument Beam Line Enclosures
Full Operation	Front End, LINAC, HEBT, Ring, RTBT, Injection and Extraction Dump, Target and Beam Lines	Mercury Target[a]	LINAC HEBT Injection beam dump Ring RTBT Target Equipment Areas	Instrument Beam Line Enclosure[c]

[a]Described in FSAD-NF (Reference 3-25).
[b]When target plug assembly not in position, the extraction septum is disabled along with RTBT.DH13. In this case, beam cannot be extracted from the Ring.
[c]When primary and/or secondary shutter closed.
[d]PPS detects MEBT beam stop position and monitors for burn-through, tripping the beam if either indicate a fault.
[e]Shorting plate with PPS trap key prevents RF transmission to DTLs in Front-End-Only mode.

operable if any 2 of the 3 are operable; thus, the PPS logic allows the power supply for the ion source plasma antenna to be used instead of the –65 KV power supply prior to beam operation (to allow conditioning of the high voltage section of the front end). In the event the PPS detects a fault condition with either of the first two beam production critical devices, the plasma RF is automatically shut off.

3.2.3.5.2 Beam Containment (Downstream Access Mode)

The PPS uses several methods to contain beam to portions of the accelerator to allow limited accelerator operation while downstream sections are occupied.

Table 3.2.3.5-1 lists the various beam containment modes and containment methods.

3.2.3.5.3 Control of Critical Devices

Front End Power Supplies. The –65 kV, RF, and plasma generating power supplies used for beam cutoff are controlled by redundant PPS ac contactors that remove power from the power supply. Each redundant contactor is controlled by both PLCs for the LINAC segment. During the high voltage conditioning phase of pre-beam startup preparations, the PPS does not control use of the –65kV (see Table 3.2.3.5-1).

RF to RFQ. The PPS controls the output of the RF to the RFQ using two diverse methods:

1. The PPS controls the 2100 V alternating current (ac) power supply to the high voltage modulator using the input line contactor contained in the SCR controller cabinet. The control signal to the contactor is routed through interposing relays controlled by the PPS. When the PPS removes power from the interposing relays, the control signal is removed and the contactor drops out, removing high voltage from the klystron tube and thereby stopping RF production.
2. The PPS controls the ac power to the RF drive amplifier using interposing relays controlling the ac power to the amplifier. When the PPS removes power from the power relays, ac power is removed from the RF drive amplifier, stopping RF production.

MEBT Beam Stop. The MEBT beam stop is a moveable beam instrumentation device installed in the MEBT. When the beam stop is in the inserted position, beam from the front end can be tuned into the beam stop. When in the Front-End-Only operating mode, the PPS allows operation of the front end (–65 kV power supply, Plasma RF and RF to RFQ) with the LINAC or HEBT tunnels accessible. The

PPS monitors the status of the MEBT beam stop when the PPS is in the MEBT beam stop mode. In order for the PPS to enter or remain in the Front-End-Only mode, the following conditions must be met:

- MEBT beam stop fully inserted into the beam path
- MEBT beam stop intact
- MEBT beam stop locked in position
- DTL 1 and DTL 2 waveguides blanked off with shorting plates

The PPS monitors the MEBT beam stop position when the Front-End-Only mode is active to ensure that the beam stop is fully inserted in the beam path. The beam stop has a pressurized cavity. The pressure is monitored by the PPS to ensure that the beam stop is intact (beam has not burned through beam stop). Motor power to the beam stop drive motor is controlled by the PPS. When in the Front-End-Only mode power to the motor is disabled to prevent retraction of the beam stop. Operation of the RFQ RF requires that the RF to DTL 1 and DTL 2 be enabled. Because the LINAC tunnel can be accessed during Front-End-Only mode, no RF can be transmitted to the DTL cavities. Prior to operation, waveguide blanks (also known as “shorting” plates) are installed in the DTL 1 and DTL 2 waveguides. These blanks are monitored by the PPS to ensure they are installed before Front-End-Only mode is enabled. Disabling the beam stop motor power and installation of the waveguide blanks is also enforced via trapped keys. A key exchange unit in the front end releases the Front-End-Only mode operating key used in the front end only after the waveguide blanks have been installed and the beam stop motor power has been disabled.

HEBT Dipole Power Supplies. When LINAC tuning is performed by running the beam to the LINAC dump and personnel access to the Ring or RTBT is desired, de-energizing the power supplies for the HEBT arc dipoles prevents beam transport out of the HEBT. Two power supplies feed the eight dipole magnets (one for the first magnet and one for the remaining seven). Either critical device sufficiently mitigates any prompt radiation hazard in the Ring.

These power supplies are controlled by the PPS using two devices. A dedicated PPS ac contactor is used to remove power from the power supply. This contactor is controlled by both PLCs for the HEBT segment. Both PLCs also control the power supply via the standard PPS interface (see Section 3.2.3.7.1.3).

Extraction Septum Magnet Power Supply. If beam were to be transported to the Target Building without the Target plug assembly in place, this could lead to extremely high radiation levels in occupied areas. For this reason, a second critical device is used (in addition to the RTBT dipole magnet) to ensure the beam cannot be transported to the Target Building when the Target plug is not in place. This second device, the Extraction Septum magnet, is interlocked, preventing extraction of beam from the Ring. When the Target plug assembly is not in position, the PPS interlocks power to the Extraction Septum power supply. This action, in conjunction with the RTBT dipole magnet, prevents beam transport to the Target Building while allowing beam operation in the LINAC, HEBT, and Ring.

The Extraction Septum power supply is controlled by the PPS using two devices. A dedicated PPS ac contactor is used to remove power from the power supply. This contactor is controlled by both PLCs for the Ring segment. Both PLCs also control the power supply via the standard PPS interface (see Section 3.2.3.7.1.3).

RTBT Dipole Magnet. The RTBT dipole magnet (RTBT.DH13) is used by the PPS and TPS to prevent beam transport to the Target. Equipment provided by the TPS controls both the ac power (ac contactor) to the RTBT.DH13 magnet power supply and the dc power (dc disconnect) to the magnet. These devices are controlled by the PPS and monitored by the PPS and TPS. When power is removed from this magnet, beam is contained to the RTBT (steered to the ring extraction dump).

The dc power to the RTBT.DH13 dipole is controlled by the PPS using three devices. The RTBT segment PLCs supply a control signal to the TPS ac contactor. Both PPS PLCs also control the dipole’s power supply via the standard PPS interface (see Section 3.2.3.7.1.3). The PPS actuates the DC disconnect, but only after the ac power has been shut off and the stored energy in the magnetic field has been dissipated.

3.2.3.6 Interface with Machine Protection System

PPS interfaces with external systems, e.g. the MPS, are designed to ensure that a malfunction of the external system would not affect the ability of the PPS to perform its safety functions. A minimum number of connections have been provided between the PPS and the MPS to enhance the mission reliability of each.

The PPS provides a status signal from the A and B PLCs for each segment to inform the MPS PLC when beam is allowed in the segment (both the A and B PLCs must be in beam permit to before the MPS allows beam operation in that segment). When the machine mode key switch requests beam for a machine section, MPS disables beam if the PPS indicates the required segments are not in beam permit. The PPS inputs are provided to the MPS PLC system and are not maskable by the MPS system except through a hardwired jumper or software change to the MPS PLC program. If the PPS detects an internal fault of one of the chipmunk radiation sensors, it sends a signal to the MPS calling for beam cut-off.

If the MPS detects a beam shut off fault (MPS attempts to shut off beam, but the beam does not shut down), the MPS provides an input signal to the PPS. When the PPS receives this signal, the PPS shuts down the beam using the PPS critical devices described above.

3.2.3.7 Other PPS Controlled Devices

The PPS controls additional devices associated with the accelerator to protect workers from non-beam related hazards or from X-rays that could be generated by RF during access to the tunnel. These devices include RF power supplies that provide RF to accelerating cavities located in the LINAC tunnel and magnet power supplies that may have exposed leads. Although PPS control of these other devices is beneficial to worker safety, they are not defined as critical devices because either (1) they concern non-radiation hazards or (2) the X-rays are not prompt radiation and are at a lower radiation level than prompt radiation (i.e., radiation associated with the accelerated beam).

The PPS shuts off the RF supplies for the normal and superconducting cavities in the LINAC whenever access is allowed to the LINAC or HEBT segments or when there has been an access violation in either segment.

The PPS also controls the RF to the MEBT rebuncher cavities because these cavities can create ionizing radiation in occupied areas. A Chipmunk is located near the MEBT rebuncher cavities at the front end. Excessive radiation from these cavities shuts off the MEBT RF, as well as the -65 kV power supply and the RF to the RFQ.

3.2.3.7.1 RF Sources

As specified above, the PPS controls the RF power supplies coupled to accelerator cavities. Two types of supplies are controlled: (1) the RF klystrons and (2) the RF supplies for the MEBT rebuncher cavities. The RF source to the RFQ is controlled to prevent beam production (see Section 3.2.3.4.2). The other RF supplies (except for the RF supply in the Ring) are controlled by the PPS because the RF produced by these supplies can cause accelerating cavities in the LINAC to generate X-rays.

3.2.3.7.1.1 *RF Supplies for Accelerating Cavities*

These RF supplies are controlled in the same manner as the RF to the RFQ. Each channel of the PPS controls both the 2100 V power supply to the high voltage modulator and the power to the RF amplifier.

3.2.3.7.1.2 *RF Supplies for the MEBT Rebuncher Cavities*

The PPS controls the output of the RF amplifiers using two diverse methods:

1. PPS Channel A controls a mechanical RF relay that is installed in each RF supply. The input drive signal is routed through this relay. When the PPS removes the enable signal from this relay, the RF drive signal to the amplifier is shut off, stopping RF production.
2. Each RF supply has an external connector to allow remote control of the power supply. Control signals from the Front End control system are routed to this connector to allow control of the power supply from an EPICS workstation. The remote on/off signal for each supply is routed though interposing relays controlled by the PPS. When the PPS Channel B of the PPS removes power from the interposing relays, the control signal is removed and the power supply is shut off, stopping RF production.

3.2.3.7.1.3 *Magnet Power Supplies*

Magnets located throughout the accelerator have exposed electrical connections. To protect workers from the hazards associated with the exposed conductors, the PPS disables power supply operation when the tunnels are accessible (except during “Controlled Access-Magnets On” Mode). Normal lockout/tagout (LO/TO) methods are used to protect workers required to perform “on or near” maintenance on electrical equipment.

Small power supplies for corrector magnets are controlled using a PPS device (small power supply controller) that contains an ac contactor. This contactor is controlled by the PPS and provides a readback signal to indicate when the contactor is open or closed. This contactor controls power to a rack containing several individual power supplies.

Medium and large power supplies are controlled using a standard PPS interface. The PPS interfaces with each power supply via a dedicated unique electrical connector. The PPS provides a control signal that enables or disables power supply operation. Two readbacks contact are provided from the power contactor(s) in the power supply to indicate the contactor status (open/closed).

3.2.3.8 Access Control Features of the PPS

3.2.3.8.1 Double-Entrance Doors to Tunnel

Normal personnel entrances to beam line tunnels have a small alcove with two doors—an inner and outer door in series. The doors are locked with electric locks controlled by the PPS. These locks are controlled differently depending on the operating mode of the segment being entered.

When the segment being entered is in the Restricted Access Mode, the outer door is unlocked. The locked inner door controls access. Entry into the beam line tunnel is controlled by the PPS and the ORNL prox card reader. Trained personnel can use their ORNL prox card to access the tunnel. The operator can monitor the door remotely via network based video camera and can place the PPS in a mode where both operator action and the prox card reader are required to open the door.

During a sweep, both the inner and outer doors are locked and must be opened by the control room operator to allow sweep teams to enter the beam line tunnel. Personnel entering during this mode use a separate prox card reader to verify that each person has special training. Each person on the sweep team must take an exchange key when entering the tunnel.

When the sweep is complete and the segment is placed in controlled access, both the inner and outer doors are locked. The control room operator controls both doors. To prevent piggybacking (where unauthorized persons attempt entry with authorized persons), only one door can be opened at a time. If both doors open at the same time, the sweep is dropped and must be repeated to get back to Controlled Access Mode. To gain entry, a worker contacts the control room. The operator unlocks the outer door, the worker enters the alcove, and the outer door locks (provisions are made for emergency exit from each personnel door). The operator supervises the entry procedure via network video camera. Prior to entry, each worker going into the beam line tunnel must take an exchange key. These keys are trapped in a key release box located in the alcove. To release the keys, a master key must be removed from an interlock switch and be inserted into the key exchange box (this master key is released by the control room operator). The master key is electrically interlocked to the PPS, such that when the key is removed, hazardous operations are not allowed in the segment (except during “Controlled Access-Magnets Energized” when the magnet power supplies are allow to operate). Personnel entering during this mode use a separate prox card reader to verify that each person has special training. The operator opens the inner door and the workers can proceed into the beam line tunnel. Upon exiting the beam line tunnel, the workers replace the exchange keys.

A warning light and status display are mounted at the outer door. These devices are used to inform workers of the operating mode of the beam line.

Double-entrance doors have a provision for emergency entry. A device located at the outer door is available to unlock both doors in an emergency. This device requires deliberate action to operate (i.e., break the glass). This action also disables hazardous operation in the segment (segment drops to Restricted Access Mode).

3.2.3.8.2 Single-Entrance Doors to Injection Dump Room

A single-entrance door is used to control access to the utilities vault associated with the injection beam dump. This area does not have a controlled access mode (a search is performed after each entry) and, therefore, does not require a second door. The method to control access is similar to that used for a double door. Warning and status devices located at the door inform workers of the status of the room. Provisions are made for emergency entry.

3.2.3.8.3 Tunnel Equipment and Emergency Exit Doors

Equipment and emergency exit doors are monitored but not remotely unlocked by the PPS. The emergency exit doors have standard emergency door features that allow crash-bar opening from the inside but prevent opening from the outside. Equipment doors include the truck doors adjacent to the double door personnel access ways at the RTBT and HEBT. The equipment doors are locked using conventional locks; the keys to these locks are controlled administratively by Operations. A warning device is located at each door to alert workers to hazardous conditions inside the beam line tunnel.

3.2.3.8.4 Beam Line Tunnel Gates

Gates located inside the beam line tunnel separate adjacent tunnel segments using a wire mesh structure except for the HEBT/Ring interface which has a fire door installed in the shielding labyrinth at that location. These gates are monitored and controlled by the PPS. PPS gates are used to separate one segment from another. These gates are locked using magnetic locks controlled by the PPS. PPS PLCs for both the upstream and the downstream segment monitor the gate position. Warning devices are located on both sides of the gate to alert personnel of potentially hazardous operations on the other side of the gate. Pushbuttons are located on both sides of the gate to allow personnel to unlock the gate in the event of an emergency.

Wire mesh gates are prefabricated double swing-type doors (except for the HEBT-ring door). One side of the gate is locked with a conventional lock; the other side is locked using a magnetic lock controlled by the PPS. Both doors are monitored by the PPS. The doors swing open toward the closest tunnel exit. A wire mesh fence is installed across the tunnel at each gate to prevent personnel entry past the gate when the gate is locked. The HEBT/Ring gate is a fire-rated personnel door located in the shield wall installed at this location. The door is locked with a magnetic lock and has the same features (warning devices and pushbottons, etc.) as described in this subsection for all segmentation gates.

3.2.3.8.5 Front End Plug Door

The Front End plug door is a moveable shield between the Front End and the LINAC. Although the plug door is on wheels, it is too heavy to be moved by a worker of normal strength. When in the rolled-back position it provides a potential unauthorized bypass path around the nearby double door tunnel access way. The PPS ensures the plug door is in the inserted position during beam operation by using a trap key arrangement that does not allow the sweep to begin until the plug door is returned to the inserted position and stops the beam if it is unlocked.

3.2.3.8.6 Target and Instrument PPS Access Control Areas

The Target PPS and the Instrument PPS for each instrument facility are segments/modules of the PPS that are described in the Final Safety Assessment Document for Neutron Facilities[3-25]. Whenever any of these segments sense a need for beam cut-off, the PPS cuts off the beam at the Front End.

3.2.3.9 Chipmunk Radiation Monitors

Radiation monitors (Fermilab-style “Chipmunks” or approved equivalent) are provided to detect radiation levels. Chipmunks are generally located in occupied areas adjacent to beam areas. For example, Chipmunks are installed around the accelerator and Target Building in areas where higher than expected prompt radiation levels may occur (due to beam loss, insufficient shielding and/or tunnel penetrations). This function is preventive in nature and distinct from personal dosimetry. Chipmunks are used to automatically shut off the beam if significantly elevated radiation levels inconsistent with the area classification are detected. Chipmunks used for beam cutoff are part of the PPS and, therefore, subject to the strict configuration control and other administrative procedures that govern the implementation and maintenance of the PPS.

A single detector simplifies calibration and failure checks. As used in this document, the term “Chipmunk” refers to devices that have been shown through design reviews and testing to have radiation detection and fail-safe capabilities equivalent to Fermi Chipmunks.

The primary remote output of the Chipmunk consists nominally of one pulse for each 0.0025 mrem detected. These pulses form the principal input from this instrument to the PPS. Since there is only one detector for both gammas and neutrons, the quality factor of the instrument is adjusted for neutron energy, gamma/neutron dose ratio, pulse width and timing, and field magnitude, as needed, to ensure that the intended degree of protection is provided. The Radiation Safety Officer is responsible for specifying the location and number of Chipmunks (see Section 4.2.2.2).

Chipmunks produce several outputs that are used by the PPS. Dose rates are indicated by a pulsed output (e.g., Chipmunks are typically set to produce one pulse for each approximately each 2.5 μrem). The PPS totalizes the number of pulses over time to determine dose rate. Adjustable dose rate limits are used to activate area alarms and stop beam production. These limits are based on a rolling average to prevent spurious trips (e.g., activate an area alarm if the average dose over a 15-minute (min.) period exceeds 10 mrem/h, and stop beam production if the average dose rate over a 15-min. period exceeds 20 mrem/h). Chipmunks have a keep-alive gamma source that causes an output pulse to be generated periodically regardless of radiation level. The PPS monitors the pulse output and stops beam production if no pulses are detected after a time delay (i.e. from 120 seconds for a QF=1 to 20 seconds for QF=10).

The radiation monitors produce two digital outputs used by the PPS. A 100 mrem/h fixed alarm output is used to stop beam production immediately by a PPS trip signal. Chipmunk internal diagnostics monitor for a lack of pulse outputs and out of tolerance critical parameters (such as ionization chamber high voltage). If these diagnostics detect an internal failure of the Chipmunk, a digital output is produced that stops beam production by a PPS trip if it persists continuously for more than a nominal 30 s. The same internal failure signal is sent to the MPS for immediate beam suspension via the Fast Protect—Auto Reset feature of the MPS.

The radiation levels are recorded by the main archive engine to allow personnel to trend radiation levels in monitored areas and retrieve historical data.

3.2.3.10 Auxiliary Safety Assurance Features of the PPS

3.2.3.10.1 Warning Lights and Horns

Various types of warning devices are used to alert workers prior to hazardous operations inside the beam line tunnels. Warning lights are installed at each entry point to the beam line (personnel, emergency exit, or equipment door). These lights are on any time hazardous operations are permitted inside the tunnel. Each beam shutdown station (BSS) inside the tunnel, equipment room or instrument enclosure has a warning light and horn to alert workers located inside the area prior to allowing hazardous operations. Accelerator tunnel lighting is automatically dimmed prior to hazardous operations.

3.2.3.10.2 Beam Shutdown Stations

BSSs are located throughout the beam line tunnels and inside PPS interlocked radiation areas such as vaults and instrument enclosures. These devices perform multiple functions:

- Inform workers of the status of the beam line tunnel
- Provide an emergency stop capability
- Provide a visual and audible warning prior to permitting hazardous operations
- Support the search function

Stations located in tunnels are installed such that they are visible from anywhere in the tunnel to workers located in the normal personnel walkway. A person located anywhere in the tunnel, walking at a normal pace, can reach a BSS within 30 seconds. There is a minimum 60 second delay between the time that an operator requests power permit or beam permit mode and the time when the PPS controlled equipment is enabled to allow workers in the tunnel time to exit the tunnel or press the emergency stop button on the nearest BSS.

3.2.3.10.3 Gamma Blockers

Components inside the injection dump and the target become activated during normal operation. Gamma radiation from these activated components can shine back down the flight tube when the accelerator is shut down. To minimize gamma dose rates for workers in the applicable tunnel segments, gamma blockers have been installed as an ALARA measure in the vacuum pipe near the injection dump in the Ring tunnel and at the end of the RTBT.

Each gamma blocker consists of a vacuum chamber containing a metal cylinder that is rolled in and out of the beam path via pneumatic cylinders. These actuators are controlled by the PPS. When the tunnel is accessible, the respective gamma blocker is rolled into the beam path. When personnel are excluded from the tunnel, the PPS rolls the gamma blocker out of the way, allowing beam operation. The design of the gamma blocker results in a “fail-as-is” design. On loss of air or power, the gamma blocker stays in the last position.

The inserted and retracted position of the gamma blocker is monitored by the PPS and MPS using redundant position switches. If the gamma blocker remains in the beam path when commanded to open, both the MPS and PPS would prevent beam operation. If the gamma blocker fails to close when the tunnel is accessible, the PPS requires operator intervention to open the PPS access doors to the tunnel (personnel cannot enter via the badge reader only mode). The position of each gamma blocker is indicated in the central control room via status lights and also on the EPICS displays.

3.2.3.11 Oxygen Deficiency Hazard (ODH) Alarm System

A release of cryogenic gases can displace air in an enclosed space, creating an oxygen deficiency. To protect workers from these hazards, the ODH alarm system is installed to alert personnel when the oxygen level drops below an acceptable level. These systems are installed in all areas where they are required per the SNS cryogenic safety policy (see *Safety for Cryogenic Operations at SNS,* Appendix D).

Separate ODH systems are installed in the SCL section of the LINAC tunnel and the CHL. Oxygen sensors are mounted on the ceiling of the SCL section of the tunnel. Flashing lights and warning horns are installed in the LINAC and HEBT tunnels to warn personnel of low oxygen levels; flashing lights are also installed at each entry point to the SCL section of the LINAC tunnel. The oxygen sensors are connected to electronic transmitters that provide digital and analog outputs to a PLC-based system located in the CHL control room. Flashing lights and warning horns are installed in the warm compressor area and cold box section of the CHL to warn personnel of low oxygen levels; flashing lights are also installed at each entry point to the CHL.

CHL ODH System. The CHL is divided into three zones; the warm compressor area, the cold box area and the CHL control room. The ODH system monitors the oxygen level in each zone and can independently provide audible and visual evacuation alarms in each zone. Oxygen sensors are installed in each zone and tied to a central system installed in the control room. These detectors continuously monitor the oxygen levels and initiate an evacuation alarm whenever the detected oxygen level drops to 19.5% or less. Warning beacons are installed at each entry door to the CHL to alert personnel of an ODH condition prior to entering the building. An alert is provided in the CHL control room when the oxygen levels are abnormal (either high or low). These alert alarms are adjustable. A graphical display is provided in the CHL control room to indicate the oxygen levels at each detector location and the status of each zone (normal, alert or evacuation). The ODH system monitors faults from the oxygen transmitters and alerts the operator if a fault condition is detected. The oxygen levels are recorded by the main archiver. In the warm compressor area, oxygen sensors are placed in an elevated location to detect warm gas helium leaks. Passive venting in the warm compressor area of the CHL (air intake louvers built into the CHL north wall and ceiling vents) mitigates the impact of helium releases in that area. The control room has one sensor located near the ceiling. The cold box area has sensors in elevated locations to detect helium leaks and near the equipment floor to detect nitrogen leaks and cryogenic helium releases.

Independent ODH systems are installed in the CHL cold box area (one system at each entry door to the cold box area) to provide redundancy for the main ODH system for the CHL. These stand-alone systems have of an oxygen sensor/transmitter, warning beacon and electronic horn that function independently of the main system. The output of oxygen transmitters are fed to the main ODH system and activate the main system's warning lights and horns if oxygen levels 19.5% or less are detected.

LINAC ODH System. The LINAC ODH system is installed in the SCL section of the LINAC tunnel. Cryogenic helium is supplied to the cryomodules via transfer lines running the length of the SCL. Each cryomodule maintains an inventory of liquid helium during operation. The ODH system is intended to protect workers from a leak of gaseous helium from the transfer lines or the release of the liquid inventory inside a cryomodule. The LINAC ODH system initiates the LINAC EVS (see Sections 3.2.4.1.3 and 5.2.3) that exhausts accidentally released helium directly from the LINAC to the outdoor air, protecting workers in the front end (and/or HEBT and ring if the beam if not on) by confining the helium release to the LINAC. Passive partial barriers, 2.5-ft-deep lintels projecting downward from the ceiling at each end of the SCL, help channel the relatively buoyant helium from an inadvertent release into the ceiling vents that lead to the EVS.

Oxygen sensors are located on the ceiling of the tunnel from the end of the CCL section to the end of the LINAC tunnel. These detectors continuously monitor the oxygen levels and initiate an evacuation alarm whenever the detected oxygen level drops to 19.5% or less.

An alert is provided in the CCR when the oxygen levels are abnormal (either high or low). These alert alarms are adjustable. A graphical display is provided in the CCR to indicate the oxygen levels at each detector location and the status of the tunnel (normal, alert or evacuation). The ODH system monitors faults from the oxygen transmitters and alerts the operator if a fault condition is detected. The oxygen levels are recorded by the main and backup archivers. The area is treated as a single zone by the ODH system. Warning lights and horns are installed throughout the length of the LINAC tunnel, the north LINAC fire escape tunnel and the HEBT tunnel. Warning beacons are installed at each possible entrance to the SCL LINAC to alert personnel of an ODH condition prior to entering the LINAC tunnel. The LINAC ODH system actuates regardless of the beam-on or beam-off status.

3.2.4 STRUCTURES AND SUPPORT FACILITIES

3.2.4.1 General Description of Structures

Unless otherwise noted, buildings at or above grade are steel frame structures. The exterior skins of the above-grade buildings are made of insulated metal panels consistent with the overall site design. The roofs are made of composite built-up roofing. Personnel access doors are provided as required by code. Air conditioning is typically provided by central air handling units using water from the chilled water system and the hot water heating system. Support buildings and other facilities with no significant potential for airborne contamination typically run at a slight positive pressure or a neutral pressure. Facilities with potential for airborne contamination (e.g., injection beam dump vault) are maintained at a slight negative pressure with respect to ambient.

3.2.4.1.1 Building 8100—Front End Building

The Front End Building houses the accelerator ion source, the RFQ, the LEBT line, the MEBT line, the ion source test stand(s), the first 30 ft of the DTL, and related support equipment. The ground floor elevation is at the same level as the LINAC tunnel with the beam centerline elevation at 50 in. above the floor. There is a Mezzanine Level in the Front End Building. One point of personnel access to the LINAC tunnel is through the Front End Building via a door in the labyrinth that separates the two spaces. As with all tunnel access points, this is a PPS-controlled/interlocked entrance (see Section 3.2.3.8, “Access Control Features of the PPS”). The building has two independent chilled water systems for the RFQ. The following systems support operation of the Front End Building: DTL DI water, compressed air, chilled water, building heating water, potable water, sanitary waste, and process waste.

3.2.4.1.2 Building 8300—Klystron Building

The Klystron Building (also known as the Klystron Gallery or Hall) houses the power supplies, cooling systems, and controls supporting the LINAC. It is 18 ft 10 in. from the LINAC tunnel (interior wall to interior wall) and parallel to it. The rear (north) wall is designed as a concrete retaining wall to support the earth shielding which surrounds the LINAC tunnel. The building has an interior clear height of approximately 26 ft. Utility chases for routing mechanical system piping, electrical cabling, and the RF wave guides are provided between the Klystron Building and LINAC tunnel. The Klystron Building floor elevation is nine feet above the floor elevation of the Front End Building and LINAC tunnel.

Air conditioning is provided throughout the building except for the DI water equipment rooms. The building has four DI water systems, a glycol water system that supports the RF equipment in the gallery, and 11 smaller DI systems for cooling LINAC equipment in the tunnel. It is serviced by the following systems: tower water, chilled water, compressed air, the potable water, the sanitary waste, and the process waste.

3.2.4.1.3 Building 8200—Accelerator Tunnels

Unless otherwise noted, the below-grade tunnels are constructed of reinforced concrete. Tunnel floors are flat and have a gutter along the aisle way wall to help clean up any water leakage from beam line equipment. Necessary utilities and other equipment are routed overhead or along the wall. Consistent with the need to prevent worker access to the tunnel during beam operations, the entrance ways are controlled and/or monitored by the PPS (see Section 3.2.3.8).

Shielding for the tunnels and access passageways are provided by an earthen berm. The berm is nominally 17-ft thick around the tunnels and, when combined with the concrete walls and roofs of the tunnels, sufficient to protect the surrounding buildings and their occupants. The berm is vegetated with grasses to prevent erosion of the berm without requiring frequent cutting. A waterproof membrane is provided over the tunnels to further mitigate water intrusion from the earth shielding. A system of perforated drain line is provided along the tunnel foundation along the klystron side to allow monitoring of water that does exit the berm. A typical cross section of the LINAC tunnel showing the berm, the membrane, and the groundwater interceptor drain is shown in Figure 3.2.4.1.3-1. This membrane runs

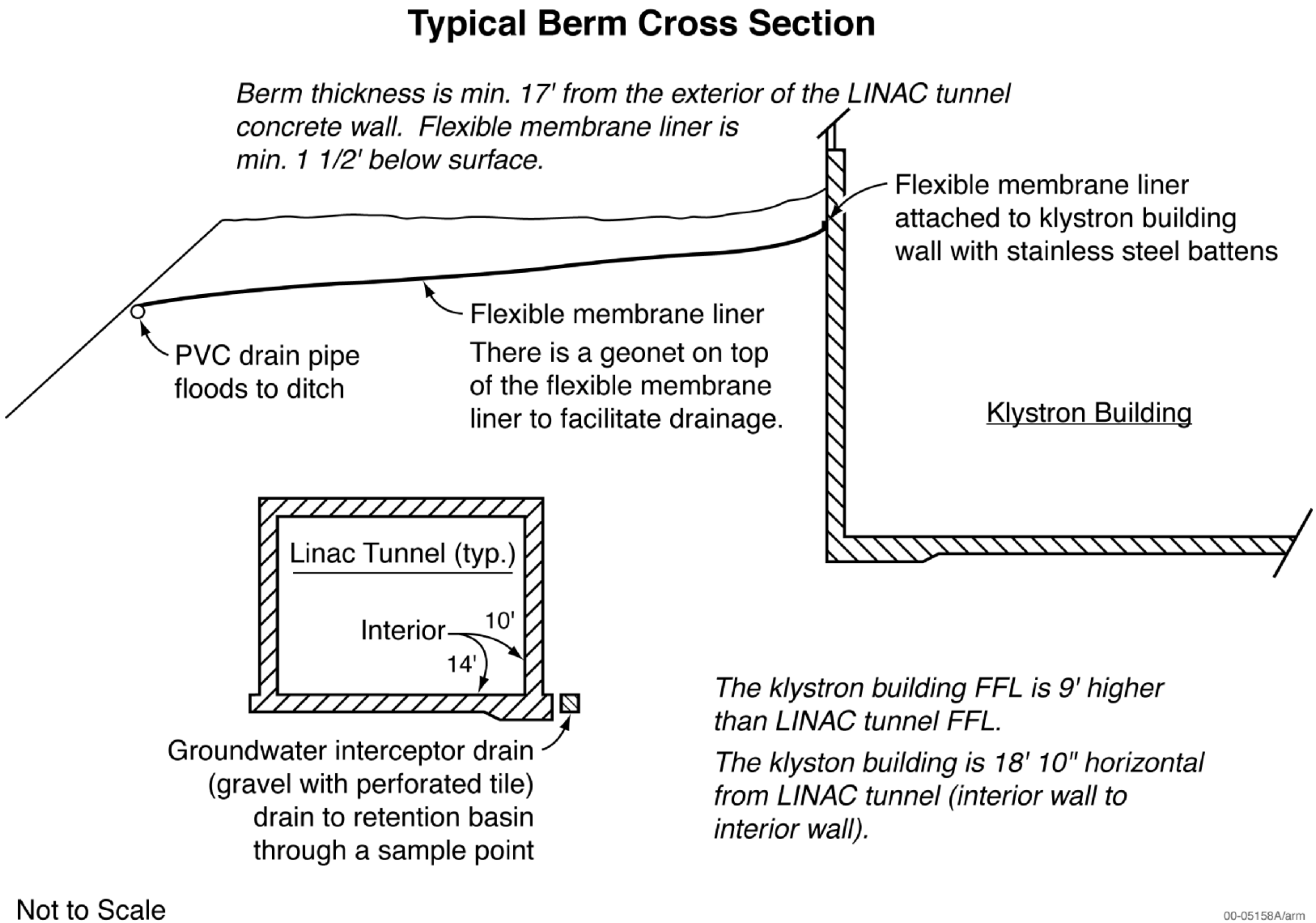

Figure 3.2.4.1.3-1 Typical Berm Cross Section

along the LINAC, HEBT, Ring, and RTBT tunnel segments as well as out to the beam dumps (i.e., above the proton beam tubes that extend to the dumps).

Air conditioning in the LINAC tunnels is provided by four ceiling-mounted air conditioning units positioned at intervals along the length of the tunnel. These units provide local air recirculation. Air conditioning in the HEBT, Ring and RTBT tunnels is provided by two surface HVAC units with supply distribution ducts in the tunnel and common wall returns in the injection and extraction areas of the Ring. Cooling is accomplished using water from the chilled water system. Heat is provided by duct-mounted electric coils in the LINAC and by the building hot water system for the Ring units. A separate smoke removal system utilizing grade-mounted exhaust fans is also provided. The ducts of the smoke removal system have bubble-tight dampers that remain closed when the tunnel is closed for normal beam operation. The ducts associated with the smoke removal system are also used to reduce the ODH in the LINAC tunnel. The automatically actuating part of the smoke removal system that has the ODH related mission is referred to as the LINAC EVS.

Tunnel ventilation is described in Section 3.2.4.2.2.2. During normal accelerator operation with beam, the tunnel is not occupied and bulk supply and exhaust flows are not provided. Positive ventilation (including fresh air intake) may be provided anytime workers are present in the tunnel. The Front End, Klystron, and Ring Service buildings have connection paths to the tunnel. These connections to the tunnel can be adequately flow-restricted if needed to prevent significant occupational exposure in the adjoining building(s) due to leakage of tunnel air to their potentially occupied spaces (i.e., during beam operation when tunnel air can become activated). Air in the potentially occupied spaces connected to the tunnel is periodically monitored to ensure that radioactive air does not exceed allowable levels where workers may be present or contribute unnecessarily to worker exposure.

Potable water is not supplied to the tunnel. Cooling water supplied to the tunnel may become activated by normal beam loss. Design features are provided to prevent this water from cross contaminating non-radioactive streams and to ensure its proper routing for disposal. Closed-loop piping with higher pressure on the non-radioactive side of the heat exchanger is the typical design approach. Heating, ventilation, and air conditioning (HVAC) condensate from the tunnel is potentially activated, so it is collected for sampling and disposal. Its disposal is based on water quality measurements per the ORNL SBMS (also see Section 3.2.4.2.4, “Waste Systems”).

3.2.4.1.3.1 *Building 8200—LINAC Tunnel*

The LINAC Tunnel houses the majority of the LINAC components. These components consist of the DTL, the CCL, and the SCL (low and high beta cryomodules). The tunnel floor elevation is the same as the Front End Building.

Access to the tunnel for both personnel and heavy equipment is through the Front End Building on the west and a large equipment plug and nearby personnel door located to the east of the HEBT Service Building. The tunnel is serviced by the chilled water system, the compressed air system, and the process waste system. Structures and magnets in the LINAC tunnel are cooled by gallery mounted, closed loop DI water systems that are, in turn, cooled by chilled water. The cryogenic section of the tunnel has design features to facilitate helium venting in response to an ODH evacuation alarm (see Section 3.2.3.11). This function is provided by automatic initiation of the smoke exhaust fans upon detection of low oxygen. Lintels are placed across the top 2.5 ft of the tunnel near either end of the superconducting section to channel helium releases to the vents and minimize propagation to the non-superconducting areas of the tunnel.

3.2.4.1.3.2 *Building 8200—HEBT Tunnel*

The HEBT tunnel houses the HEBT equipment, including the proton beam tube, magnets, RF debuncher, and collimators, used to transport the proton beam from the LINAC to either the Ring or the LINAC dump. Included in the equipment is an overhead crane to be used throughout the ring tunnels to maintain and remove equipment. The crane has remote controls to minimize exposure to the workers.

Access to the tunnel is through the LINAC tunnel, the Ring tunnel, a large equipment plug door, and personnel access ways. The tunnel is serviced by the instrument air system, the magnet DI water loop, two collimator cooling loops, and the process waste system.

3.2.4.1.3.3 *Building 8200—Ring Tunnel*

The Ring tunnel houses the proton beam tube, magnets, RF cavities, and collimators that accumulate beam pulses received from the LINAC via the HEBT, bunches them into intense short pulses, and delivers them to the Target or the Ring Injection Dump by way of the RTBT tunnel. The required beam height is approximately 50 in. above the floor. Included in the equipment are two overhead cranes to be used throughout the tunnel to maintain and remove equipment. The cranes have remote controls to minimize exposure to the workers.

Access to the ring tunnel is through the HEBT tunnel, the RTBT tunnel, and the south personnel access way. The tunnel is serviced by the chilled water system, the instrument air system, the magnet DI water loop, collimator cooling water system, the RF cooling loops, and the process waste system.

3.2.4.1.3.4 *Building 8200—RTBT Tunnel*

The RTBT tunnel houses the beam tube, magnets, and collimators that transport the short proton bursts from the Ring to the Target or the Ring Extraction Dump. The required beam height is approximately 41 in. above the floor. Included in the equipment is an overhead crane to be used throughout the tunnel to maintain and remove equipment. The crane has remote controls to minimize exposure to the workers.

Access to this section of the tunnel is through the Ring tunnel and a large equipment plug door. The tunnel is serviced by the instrument air system, the magnet DI cooling system, and the collimator cooling loops.

3.2.4.1.4 Building 8310—Central Helium Liquefier Facility

The Central Helium Liquefier (CHL) Facility Building is located across the street from the Klystron Gallery immediately adjacent to the RF Test Facility on the west side. Its intended use is to provide superfluid helium for use in the superconducting LINAC cryogenic systems (see Section 3.2.1.4 for details).

Outside and immediately adjacent to the building are eight (8) 30,000 gallon gaseous helium storage tanks with purifier systems, a 20,000 gallon liquid nitrogen dewar, and parking and unloading areas for helium and liquid nitrogen trailers.

A free standing expansion unit provides air conditioning only for the CHL Control Room and office area. The building has its own helium and nitrogen systems and is serviced by the following systems: DI water, compressed air, potable water, sanitary waste, and process waste.

3.2.4.1.5 Building 8330—RF Test Facility and RF Annex

The Radio Frequency (RF) Test Facility is located to the east of the CHL Facility. Its intended use is to test 402.5 MHz and 805 MHz klystrons, RF power components, and superconducting accelerating structures, and to repair cryomodules. Major modulator repair can be performed in this area along with low-level RF testing and development and conditioning of couplers. To accomplish this mission, the building has 805 MHz test areas, a 402.5 MHz test area, a RF test lab, a cleanroom, a cryomodule repair area, a shielded test cave, and a cave support equipment area. There is a transition area with a separate entrance where radiation confirmation surveys can be performed on components from the LINAC tunnel.

The building is serviced by the following systems: DI water, glycol water, tower water, chilled water, building heating water, the compressed air, potable water, sanitary waste and process waste. Liquid helium is supplied from the CHL. An annex added to 8330 houses RF equipment; envisioned activities include modulator testing.

3.2.4.1.6 Building 8340—HEBT Service Building

The HEBT Service Building is located east of the Klystron Building. It houses the power supplies, instrument racks, vacuum racks, and control cabinets for the HEBT technical equipment. The building contains electrical cabinets and the necessary equipment for a DI water cooling system for the power supplies. Air conditioning is provided throughout the building except for cooling the DI water equipment room. The building has a DI water system and is serviced by compressed air, potable water, sanitary waste, and the process waste systems.

The HEBT Service building contains a test stand for testing of modulator units. Hazards associated with the modulator test stand are safely managed under the provisions of the ORNL SBMS.

3.2.4.1.7 Building 8520—Ring Injection Dump; LINAC Dump and Ring Extraction Dump

The dumps house the beam stops, shielding vaults, and, for the Ring Injection Dump only, the associated electrical, control, cooling, waste, supply, and heating and ventilation systems in an appropriate, serviceable environment. The Ring injection dump service areas are located on grade level, adjacent to the below-grade dump. The passively cooled LINAC and Ring extraction dumps do not require active cooling, so they do not have associated service rooms. Additionally, the beam stops (internal beam arresting apparatus) are designed to last for the life of the facility without periodic changeout. Design features of the beam dump systems are described in Section 3.2.1.5.

The dumps are below-grade vaults constructed of reinforced cast-in-place concrete surrounding the metal shielding of the dump. The dumps extend approximately 21 ft below finished grade.

The injection dump utility vault, adjacent to the mechanical/electrical rooms, is enclosed with concrete shield walls. The concrete floor is covered with a stainless steel liner that turns up 8 in. onto the base of the wall. A 5-ft wide overhead service door provides access from the exterior of the dump vault. A deep tank sump with a stainless steel lining below the utility vault floor level is accessed through a hatch.

Injection dump building heating is provided by units using water from the hot water heating system. The building is serviced by the tower water, chilled water, compressed air, and potable water systems. The central ventilation system maintains the utility vault and the beam stop access room under a negative pressure and provides high efficiency particulate air (HEPA) filtering of the exhaust air from these two rooms. The only utility needed for the two passively cooled dumps is control of the vacuum atmosphere of the flight tube leading from the (H^-) beam tube to the beam stop. It is necessary for the beam to pass through vacuum on its way to the surface of the beam stop to minimize activation of air and also because passage through air would be conducive to the formation of corrosive nitrates.

3.2.4.1.8 Building 8540—Ring Service Building

The Ring Service Building houses the power supplies (including RF), electrical systems, cooling systems, vacuum control systems, and air systems to serve the Ring equipment.

The basement of the Ring Service Building contains the pumping and heat exchange equipment for the three separate cooling systems: Ring magnet, RF, and power supply cooling water loops. The basement walls, floor, and floor/ceiling assembly are concrete.

Air conditioning is provided throughout the building (except for cooling the pulse forming network (PFN) area and basement) by a roof mounted air conditioning unit. The building contains equipment for the DI water system(s) and is serviced by the compressed air, potable water, sanitary waste, and process waste systems.

3.2.4.1.9 Building 8550—RTBT Service Building

The RTBT Service Building houses the power supplies, instrument racks, vacuum racks, and control cabinets for the RTBT technical equipment. The building contains electrical cabinets and the necessary equipment for a DI water-cooling system for the power supplies.

Air conditioning is provided throughout the building except for cooling the DI water equipment room. The building contains a DI water system and is serviced by the compressed air system and the process waste system.

3.2.4.1.10 Building 8600—Central Laboratory and Office Building

The CLO building is a mixed-use facility providing the office, laboratory, conference, cafeteria, and shop space necessary to operate the SNS facility. The building combines a five-story, curved office "bar" connected to a four-story shop and lab "block." The CLO building is adjacent to the Center for Nanophase Materials Sciences, which is not part of the SNS complex.

The main CLO building entry plaza is on the west side, on Level 1. Other entrances are provided on all sides of Level G. The CLO service access, a triple bay truck dock, is located on Level G at the north side of the shop and lab block. A freight elevator links the dock area with the three lab floors and mechanical penthouse.

The accelerator control room located on Level 1 has direct access to a small service vehicle parking area. The control room features a mezzanine overlook at Level 2 for public tour viewing. User offices are located along the perimeter for access to the Target Building. All of the heavy-duty technical support shops and the material handling area, which require truck access, forklift use, and a minimum ceiling height of 12 ft are located on Level G, the ground floor, of the shop and lab portion of the building. Other building service spaces requiring ground level access such as the plant shop are located on Level B1. Space on the sub-basement, Level SB, provides space for electrical, mechanical, and telecommunications functions.

The large technical support labs are located primarily above the shops on Level 1. The CLO labs on Level 1 conduct small scale measurements, analyses and studies in support of the accelerator operation and development. For example, the foil research facility includes equipment such as the foil evaluation diagnostic scanner. Labs located on Level 2 are devoted to measurements, analyses and studies that support SNS development and science activities. For example, the x-ray lab is one of the labs located on the second floor. The activities conducted in the CLO labs are authorized through the research safety summary (RSS) system and are compliant with applicable ORNL SBMS safety requirements.

3.2.4.1.11 Building 8700—Target Building

The target building and activities conducted in it and its connected satellite buildings and ancillary support buildings are described in the FSAD for Neutron Facilities.

3.2.4.1.12 Activated Equipment Maintenance Shop

An activated equipment shop (hot shop) has been envisioned for eventual inclusion into the SNS facilities. Possible features may include facilities for handling/maintaining radiologically activated accelerator equipment, instrument choppers, and a Target equipment shop, including a waste staging area. The types of facilities could include a machine shop, a vacuum shop, an instrument repair shop, a magnet repair area, a negative air hood area, a storage area, and a receiving/packaging area. The building would be serviced by the compressed air system, the potable water system, the sanitary waste system, and the process waste system. Portions of the building would be maintained at a slight negative pressure relative to ambient if warranted by a potential for airborne contamination.

3.2.4.1.13 Building 8910—Central Utility Building

The Central Utility Building (CUB) houses the chilled water system, the tower water pumps, and the compressed air system serving the site. The building also has a boiler room containing two gas-fired, water tube boilers that provide hot water for heating the following buildings: 8910, Front End, Klystron, RF Test Facility and CHL building, HEBT, Ring and RTBT Service, Ring HVAC, Ring Injection Dump, and the Target.

The building has a multiple-zone, refrigerant monitor to detect refrigerant leakage from the chillers, with at least one zone per monitor or refrigerant storage vessel. The monitor has audible and visible alarms both inside and outside the building. The building also has an automatic refrigerant spill exhaust system designed with opposing intake(s) and exhaust outlet(s) to sweep air across the potential spill zone at floor level. The monitor automatically initiates operation of the refrigerant spill exhaust system and simultaneously deactivates other ventilation equipment in the event of a refrigerant spill. Hazards associated with the refrigerant are standard industrial type hazards and are safely managed under the provisions of the ORNL SBMS.

Air conditioning is provided in the offices and restrooms. The building is serviced by the potable water system and the sanitary waste system. Power is supplied from the site 13.8 kV distribution system, including transformers that provide 4.16 kV to the Chillers and 480 VAC to the motor control centers.

3.2.4.1.14 In-Process Storage of Activated Components

On-site areas are used, as-needed and authorized by management, for storage of accelerator related activated components and equipment items. For example, designated Sea-Land trailers, a fenced area, and a concrete pad (described below) to the west of the Front End Building have been designated as areas for storage of bulk accelerator related activated/contaminated items that may have a future mission with the SNS. Precautions and procedures followed with these materials are commensurate with potential hazard, in keeping with ORNL SBMS radiological safety requirements. For example, administrative control and surveillance is maintained, the objects are properly labeled and the areas properly posted.

An activated equipment storage building has been discussed for eventual inclusion into the SNS facilities to provide indoor storage of activated components such as magnets, cryomodules, shield blocks, and shutters. Potential hazards and controls will be addressed when and if plans are finalized for construction of this building. The following includes thinking on possible attributes of the facility. The building would be heated and ventilated. Heating would be provided by units using water from the hot water heating system. The building would be serviced by the potable water system and the process waste system. Equipment access would be from an adjacent parking apron through roll-up doors. Personnel access doors would be provided as required by code and sized sufficiently to accommodate the movement of equipment within the building. The initial stage of construction has been completed and consists of an approximately 13,000 sq ft concrete pad (designated as Building 8916); as mentioned in the previous paragraph, the pad is in use for storing activated items that do not require indoor storage.

3.2.4.2 Services and Utilities

Services and utilities include: (1) electrical site services; (2) HVAC site services; (3) mechanical/piping utility systems; (4) waste systems; (5) maintenance and general-purpose equipment; (6) fire protection system; and (7) conventional facilities instrumentation system.

3.2.4.2.1 Electrical Site Services

Electrical Site Services is a network with a nominal 50 MW capacity that includes: (1) the SNS primary substation; (2) the site electrical distribution system; (3) the telecommunications/alarm systems; and (4) the miscellaneous electrical utility systems.

3.2.4.2.1.1 *SNS Primary Substation*

The SNS Primary Substation receives electrical power from two offsite 161 kV supply sources through the primary plant service transformers and supplies 13.8 kV for onsite distribution. The substation has a SCADA subsystem that provides the capability of remote monitoring and control. It also has overhead passive lightning protection equipment for the primary substation and provides lightning and surge protection at the 161 kV level.

3.2.4.2.1.2 *Site Electrical Distribution System*

The site electrical distribution system routes electrical power via underground feeders from the SNS primary substation to the various facilities that constitute the SNS. It is divided into A and B systems to provide a degree of isolation between the large RF power supply loads and other loads. The system provides protective relaying and equipment to minimize equipment damage by isolating faults and is designed and coordinated so an electrical fault is isolated by the source side circuit protective device nearest the fault. The site electrical distribution system follows NEC criteria, e.g., by ensuring that conduits containing instrumentation, communication, and alarm circuits are isolated from conduits containing power circuits (i.e., circuits 120 V and higher). The site electrical distribution system includes the SNS site-grounding mat, which is buried beneath buildings.

3.2.4.2.1.3 *Telecommunications/Fire Alarm System*

The telecommunications/fire alarm system provides high-speed data communications systems, interplant data and voice communications, and the SCADA system to the various facilities that constitute the SNS. The system terminates offsite telecommunications and alarm services at a site main distribution frame and provides at least two redundant means of communication between the SNS and other ORNL facilities during normal and emergency plant operation. The system is integrated with the Oak Ridge Federal-Integrated Communications network, the ORNL intra-plant fiber optic network, the ORNL portable radio system, and various other ORNL communication services (fire alarm, security, etc.).

Fire alarm service is provided by a series of looped peer-to-peer fire alarm control panels strategically located throughout the SNS complex and at the ORNL Fire Department. Seven fire alarm control panels provide local service to the Accelerator Facilities and various support buildings, two fire alarm control panels provide global annunciation at the CLO Central Control Room, and a single fire alarm control panel at the ORNL Fire Department provides global annunciation and interface to the ORNL site-wide fire alarm system.

3.2.4.2.1.4 *Miscellaneous Electrical Utility Systems*

Miscellaneous electrical utility systems include the cathodic protection system and exterior area lighting. Exterior area lighting provides exterior lighting systems with sufficient illumination to accomplish operations and maintenance functions under normal operating conditions and provides areas requiring continuous lighting for safety or security reasons with an emergency power source for such lighting.

3.2.4.2.2 HVAC Site Services

HVAC Site Services includes: (1) aboveground and underground ductwork connecting to appropriate ductwork from individual buildings; (2) the centralized exhaust stack; (3) confinement exhaust systems located remotely from buildings and tying into the centralized exhaust stack; and (4) associated miscellaneous controls and accessory devices. These are shown schematically in Figure 3.2.4.2.2-1.

3.2.4.2.2.1 *Centralized Exhaust Stack*

Central Exhaust Building 8915, adjacent to the centralized exhaust stack, houses the blowers that discharge to the stack. Confinement exhaust systems located remotely from buildings and tying into the centralized exhaust stack include the tunnel exhaust system, confinement exhaust systems from the Target building, and Injection Dump building exhaust. The centralized exhaust stack is a prefabricated, free standing, all welded, steel construction with ladder and platform to provide access to isokinetic monitoring equipment mounted a minimum of five diameters above any duct connection. The platform is wide enough to provide room for personnel and adequate clearance for maintenance of monitoring equipment. The stack is sized to handle the maximum simultaneous exhaust airflow from the tunnel, injection dump building, and Target HOG and Target Building primary and secondary confinement systems up to a maximum discharge velocity of 4000 ft per min. The stack has a height of 80 ft and is located to minimize the length of duct runs and number of runs that have to traverse the berm.

3.2.4.2.2.2 *Tunnel Exhaust System*

The tunnel exhaust system conveys tunnel exhaust air underground to the centralized exhaust stack. The system is intended to function only after the beam has been cut off, but is generally not employed for short outages. Measurements of airborne radioactivity in the tunnel air have indicated that tunnel exhaust is not required for radiological protection of workers entering the tunnel when the beam is off. During beam operation, the makeup and exhaust ducts, as well as the smoke removal ducts, are closed off from the tunnel by isolation dampers. This prevents the discharge of potentially activated tunnel air during beam operation. The air within the tunnel is maintained under temperature and humidity control by local heating and cooling units inside the tunnel that utilize local recirculation and do not involve discharge of air outside the tunnel. The tunnel exhaust fans are located near the centralized exhaust stack. Exhaust fans and makeup air units are sized to ventilate the tunnel complex (i.e., when the beam is off) at a flow rate that provides acceptable air quality (nominal exhaust capacity is about one air-change per hour).

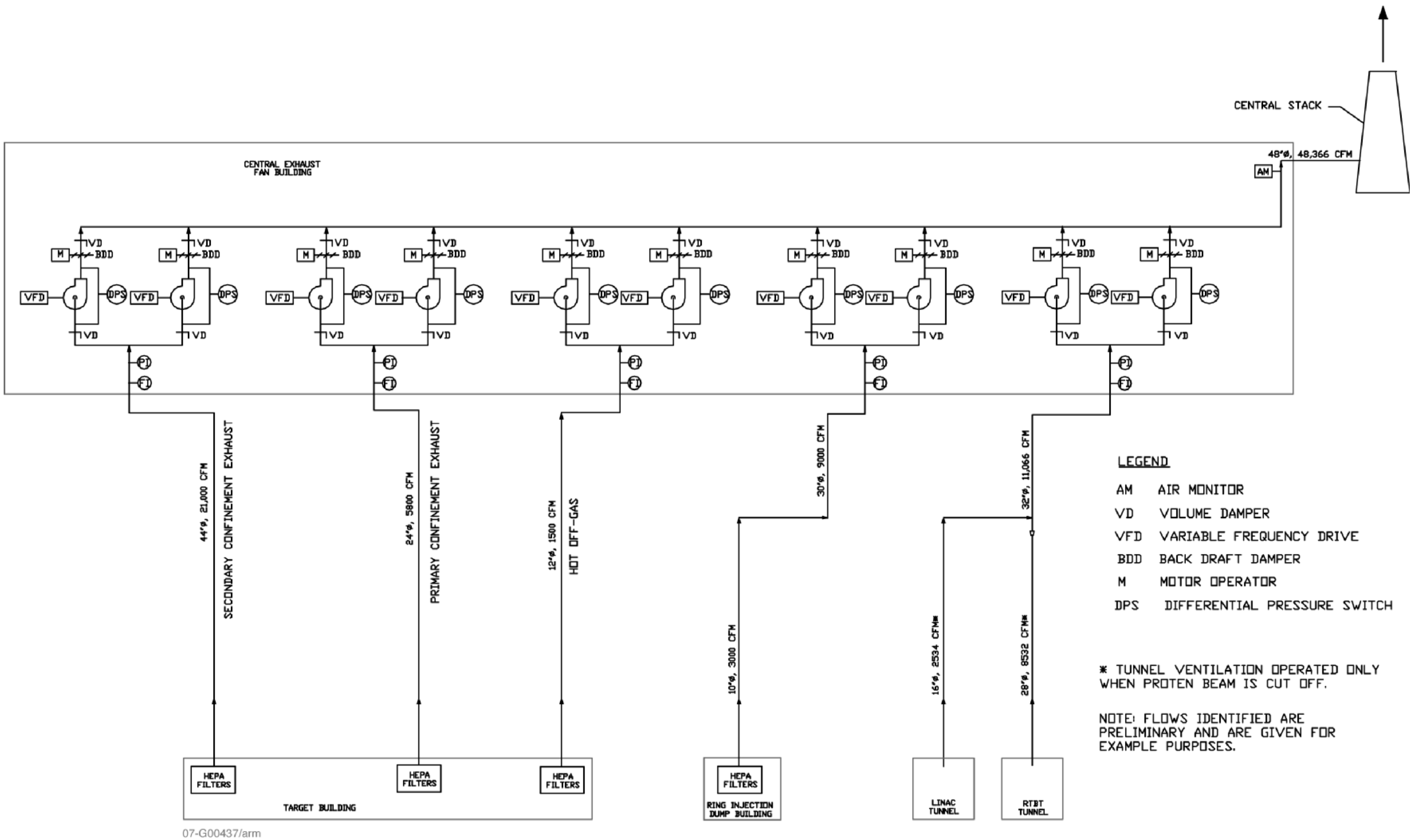

Figure 3.2.4.2.2-1 Schematic Diagram of Central Ventilation System

The exhaust duct connections to the tunnel complex are coordinated with the location of makeup air inlets to effect a sweep of air through the tunnel progressing from the area of least radioactive activation (Front End Building has no activation) towards the area of greatest potential activation (high-energy end of the LINAC, the Ring, and transport tunnels). The number of exhaust and supply connections to the tunnel were minimized because of the requirement for shielding at each penetration—each connection incorporates at least two 90º changes of direction near the tunnel to minimize radiation streaming. The effect of intermediate shield walls on airflow in tunnels was taken into account in the determination of the number of exhaust and makeup points necessary for complete coverage of the tunnel.

The exhaust systems from the Target and Injection Dump buildings convey exhaust air from the Injection Dump and Target building confinement systems via underground ducting to the centralized exhaust stack. The Injection Dump Building has its own confinement exhaust. The Target Building confinement systems that vent to this system are the HOG, the PCE, and the SCE systems (see FSAD for Neutron Facilities). Each of these exhausts is HEPA filtered. The use of HEPA filters for Target or dump exhaust filtration is not a requirement but is a good ALARA practice that minimizes the potential for routine spread of radioactive contamination. Where ducts are manifolded together for common routing to the stack, backflow prevention is provided to prevent the possibility of reverse flow and to isolate branches when they are inactive (no flow). Dedicated ducts are provided for the exhaust from the Target Building up to the point of connection to the stack. Air measuring stations and isolation dampers are provided for each exhaust system.

A smoke removal system to facilitate manual fire-fighting operations is provided in the LINAC tunnel and in the HEBT/Ring/RTBT tunnels. The smoke removal system is manually activated for smoke removal purposes. In addition, the LINAC smoke removal system is automatically activated for ODH mitigation purposes (on detected low-oxygen level, as discussed in Sections 3.2.3.11 and 5.2.3). The automatically actuating ODH mitigating feature is referred to as the LINAC Emergency Ventilation System. Operation of a smoke removal system causes unrelated ventilation systems in the area to shut down. Using NFPA 92A[3-21] and the *SFPE Handbook of Fire Protection Engineering*[3-22] as the basis of design, the smoke removal systems provide an average capture velocity of 50 to 100 ft per min. throughout most of the accelerator enclosures. The capture velocity provided results in approximately seven to ten air changes per hour. The smoke removal systems are arranged to utilize related HVAC openings and equipment to the greatest extent possible. This arrangement is intended to minimize the number and size of tunnel penetrations dedicated solely for smoke venting (penetrations are a radiological concern) and optimize the costs associated with providing effective smoke removal systems.

In conjunction with a limited amount of combustible materials and a fire sprinkler system, the design flow velocities would minimize the back flow of smoke in the tunnel areas and ensure that entrance time into the tunnel areas by emergency response personnel would not be excessively delayed. Ventilation equipment exposed to the ventilation airflow is designed to remain operational for a minimum of one hour in an air stream temperature of 482°F (250°C). Power for the smoke exhaust systems is from a reliable source not expected to be adversely affected by a fire in the tunnel.

3.2.4.2.3 Mechanical/Piping Utility Systems

3.2.4.2.3.1 *Mechanical/Piping Utility Systems*

Mechanical/piping utility systems include: (1) the tower cooling water system; (2) the chilled water system; (3) the building heating water system; (4) the process water system; (5) the sanitary waste system; (6) the potable water system; (7) the compressed air system; and (8) the natural gas system. The mechanical/piping utility systems are designed: to last 40 y; provide for ease of inspection, testing, and maintenance activities; and to permit routine testing without causing a change in plant operating status. They were designed, constructed, and procured in accordance with appropriate codes and standards.

3.2.4.2.3.2 *Tower Cooling Water System*

The tower cooling water system provides adequate coolant flow and pressure to remove heat from the chilled water and DI cooling water systems and other water-cooled equipment throughout the facility. The system has a maximum coolant temperature of 82°F at design atmosphere conditions of 77°F WB (wet bulb) and 94°F DB (dry bulb). It maintains cooling water quality such that fouling, corrosion, and blockage of heat exchangers, as well as other detrimental effects, are prevented; it also has a means of adding environmentally acceptable biocides and corrosion protection materials to the open cycle cooling water system. The evaporative cooling towers are located with respect to prevailing winds to minimize fogging, icing, noise intrusion, deposition of drift, etc., on and to adjacent plant structures with special consideration given to high voltage equipment. Cooling tower blowdown is routed to the conventional liquid waste collection system (see Section 3.2.4.2.4.2). The tower cooling water system operates at a higher pressure than the components served where the components can become activated.

3.2.4.2.3.3 *Chilled Water System*

The chilled water system provides adequate chilled water flow, temperature, and pressure to remove heat from the HVAC air handling units, the activated and inactivated DI chilled water systems, and other chilled water users. The system is capable of operating all water chillers between 20 and 100% of full chiller capacity to meet varying chilled water demands and reject heat generated by the chillers to the tower cooling water system. It operates at a higher pressure than the components served where the components can become activated, such as the 10 resonance control cooling systems (RCCS), quadrupole magnet cooling system (QMCS), and the Ring RF cooling system.

3.2.4.2.3.4 *Building Heating Water System*

The building heating water system supplies adequate water flow, temperature, and pressure to hot water heating coils in air handling units and unit heaters throughout the facility. The system provides the exterior underground piping to distribute and return hot water at a suitable temperature for space heating for identified buildings.

3.2.4.2.3.5 *Process Water System*

The process water system supplies non-potable water to various systems requiring a clean source of makeup or process water. The system provides the exterior underground piping to distribute process water throughout the site. It is supplied by the potable water system with all direct connections between the two systems having reduced pressure backflow preventers to prevent contamination of the potable water system.

3.2.4.2.3.6 *Sanitary Waste System*

The sanitary waste system collects sanitary waste from fixtures served by the potable water system and from floor drains in restrooms and change rooms. The sanitary sewage is collected at sewage transfer station(s) for pumping to the ORNL sewage plant for treatment and disposal.

3.2.4.2.3.7 *Potable Water System*

The potable water system provides clean water to the combined fire and domestic water supply system. The system provides water to the firewater storage tank and distributes potable water for domestic and firewater usage throughout the SNS facility. Reduced-pressure backflow preventers isolate all non-potable water tie-ins to the system, including fire protection headers. A separate water supply system for safety showers and eyewash stations using only key lock valves in the piping is provided. The system provides hot and cold potable water to all fountains, lunchrooms, showers, and restrooms located in office buildings, support buildings, and the main control room.

Water is provided from the site utilities water system. The system includes a 300,000 gallon elevated, combined, fire-process-potable water storage tank; a combined, looped water distribution system; fire hydrant connections, control valves, and building fire suppression system tie-ins. Nine sprinkler system tie-ins and one standpipe tie-in are provided on the water distribution system.

The basis of design for the elevated water storage tank capacity considered maximum potable and process water demands concurrent with firewater demands and required a minimum 259,400-gallon supply to meet those demands for a 2-h duration. The elevated tank is filled by three 550 gpm (gallons per min.) booster pumps, which draw water from the existing 24-in. city water main. The booster pumps are capable of being manually reconfigured to supply water directly to the looped water distribution system in the event that the water tower is out of service.

3.2.4.2.3.8 *Compressed Air System*

The compressed air system provides pressurized clean air to instruments, pneumatic devices such as air-operated valves, and service air outlets throughout the facility. The system has two compressor packages located in the CUB that provide a continuous supply of oil-free, clean, dry air.

3.2.4.2.3.9 *Natural Gas System*

The natural gas system provides a source of fuel for heating the building heating water system and various hot water heaters. The system receives natural gas from a line tying into the ORNL gas transmission line downstream of the pressure reducing and metering station at 100 psig and supplies it to building heating boilers and natural gas-fired water heaters at less than 5 psig. Natural gas is not supplied to the Target Building.

3.2.4.2.4 Waste Systems

Waste systems includes the central functions that collect and process all generated wastes and discharge them to appropriate repositories. This includes portions of the process waste system and the sanitary liquid waste system.

3.2.4.2.4.1 *Process Waste Collection System*

The process waste system collects wastewater from the normal operations and from any anticipated abnormal occurrences. As guided by the ORNL SBMS requirements for wastewater management, sampling is used to ensure that process waste with non-negligible radioactivity is diverted to LLLW treatment.

Included in the system are diversion tanks within buildings and underground piping and manholes to the sanitary sewer system. The piping layout is designed for gravity flow from collection manholes in the SNS area into the sanitary sewer system. Any LLLW originating as a result of accelerator operations is directed into a tank truck for transport to the ORNL LLLW treatment system.

3.2.4.2.4.2 *Conventional Liquid Waste System*

The conventional liquid waste system transfers cooling tower blowdown to the storm water retention basin for retention and stabilization prior to release to White Oak Creek. The system ensures water discharged to the storm water retention basin does not have excessive chlorine and is cooled to ambient temperature before it is discharged to the creek through an National Pollutant Discharge Elimination System (NPDES)-permitted outfall that measures flow, temperature, and facilitates periodic sampling to verify permit compliance. Instrumentation and controls are compatible with the plant operating systems.

3.2.4.2.4.3 *Conventional Solid Waste*

Conventional solid waste handling utilizes a series of dumpsters for sanitary waste, paper/cardboard, white and miscellaneous paper, glass, and metal. The method of collection facilitates materials recycling.

3.2.4.2.4.4 *Hazardous and Mixed Waste*

Hazardous and mixed waste collected as necessary from the SNS site include oils, solvents, and reactive metals for offsite disposal. The procedures and equipment comply with the ORNL SBMS for hazardous and mixed waste, including transportation and facility acceptance and have the capability to temporarily store remote handled mixed wastes at the SNS site.

The SNS operates as a scientific user facility in which a wide variety of samples are brought in for neutron scattering measurements. Some of these samples are, or may become, hazardous, but they are all subject to SNS and ORNL procedures. As shown below, multiple means are utilized to ensure appropriate handling and disposal:

- The SNS tracking system for experiments tracks location and disposal of all used experiments; ORNL procedures for shipping ensure DOE and DOT compliant shipping.

- Experimenters are required to undergo training to ensure they follow ORNL requirements regarding the introduction of materials to the SNS site as well as taking materials away from the SNS site.
- SNS employs a full complement of radiation control technicians and personnel exit-scanning instruments.

3.2.4.2.5 Maintenance and General Purpose Equipment

Maintenance and general purpose equipment provides the maintenance and shop equipment needed to support normal operations, achieve plant availability and predictability, and support user experiments. Areas included are: (1) handling and transportation equipment; (2) technical laboratories and shop equipment; (3) yards and grounds maintenance facilities equipment; and (4) material control and storage facilities equipment.

Handling and transportation equipment provide mobile handling and transportation equipment as necessary for the repair, removal, relocation, and installation of complete or partially disassembled items of equipment that cannot be serviced by installed equipment. Included are mobile cranes, forklifts, mobile platforms, dollies, air pads, and other equipment necessary to transport material, equipment, and supplies from one area of the plant to another. Mobile platforms and scaffolds are used for access to and maintenance of installed equipment only in areas where permanent platforms are not practical and access is infrequent. Only electrical and/or manual transportation equipment are used in areas where fueled equipment is not practical or safe.

Technical laboratories and shop equipment provide the equipment needed for plant maintenance crafts (pipe fitters, millwrights, carpenters, refrigeration mechanics, etc.) to perform day-to-day maintenance of non-radioactive and uncontaminated mechanical, electrical, and instrument equipment, as well as radioactive and contaminated equipment.

Cabinets meeting OSHA[3-20] requirements are provided in each area for the storage, control, and disposal of hazardous chemicals that are used in each area. Electrical tools, equipment, and workbenches have nonconductive surfaces for troubleshooting, testing, repairing, and calibrating plant electrical systems and components. Portable welding machines, equipment, tools, and accessories are provided to perform the following welding processes: shielded metal arc, tungsten inert gas, metal inert gas, oxyacetylene, and plasma cutting system. A welding fume exhaust system is used for welding operations separate from the building HVAC system.

3.2.4.2.6 Fire Protection System

Fire protection system provides the water supply necessary for potential fire fighting efforts throughout the SNS site. Included are an elevated, combined, fire-process-potable water storage tank, fire hydrants, and building fire suppression system tie-ins. Associated pumps and valving are included in the potable system.

The system, in accordance with NFPA and DOE standards, has a minimum capacity of two hours of firewater flow at the maximum anticipated water demand at peak domestic demand. Hydrants are positioned, and firewater supplied, within the guidance of NFPA 1141, *Standard for Fire Protection in Planned Building Groups*.[3-23] No hydrant is closer than 50 ft to a building. Pressure at any hydrant is at least 20 psig at the maximum anticipated fire demand. Each hydrant has an isolation water control valve.

3.2.4.2.7 Conventional Facilities Instrumentation

Conventional Facilities instrumentation provides control and system status of all Conventional Facilities systems and associated components—this includes the support and utility systems that are needed for accelerator operation but are not part of the technical systems involved in the production of the proton beam. Both local control/monitoring functions, located near each system or component, and remote control/monitoring functions, located at a control center in the Central Utilities Building, are provided. Remote control functions for all of the Conventional Facilities equipment are provided via one standalone human machine interface (HMI) database system with multi-screen display for accessing the various systems for control and status information. The SNS Conventional Facilities Instrumentation is divided into the following subsystems: (1) the electric power monitoring system; (2) the HVAC control system; (3) the mechanical systems control system; (4) waste systems control system; and (5) the plant security system.

In addition to the capabilities in the above paragraph, the following capabilities are provided in the main accelerator control room located in the CLO building: (1) EPICS-based view-only monitoring capability is provided for all utilities, and (2) control capability is provided for the skid-mounted cooling water systems that serve accelerator components.

3.2.4.2.8 Emergency Power Systems

The site is served by two separate 161 kV power supplies to provide redundant power to the SNS. In addition to this, SNS also has emergency onsite ac power supplies and uninterruptible power supplies to ensure the site has electrical power adequate and reliable to support equipment protection and mission continuity.

3.2.4.2.9 Emergency Onsite AC Power Supply

The emergency onsite ac power supply consists of multiple diesel-engine-generator units installed at various locations at the SNS site. Emergency power is supplied at 480 V ac to normal/emergency distribution equipment serving the essential loads described below. In general, uninterruptible power supply (UPS) loads requiring power beyond the maximum backup period provided by the UPS also can be supplied from the emergency onsite ac power supply system. The essential loads supplied are the:

- safety interlock system (a mission continuity feature only, since these systems fail to a safe state on loss of power);
- vacuum system instrumentation and controls and control PLCs for the SCL cryogenic systems;
- main control room servers and hardware;
- selected telecommunications equipment;
- selected alarm systems, including fire alarms;
- access control system;
- standby ventilation fans for Target cells and tunnels;
- emergency lighting systems for tunnels; and
- standby lighting systems.

The emergency onsite ac power supply system is capable of automatically supplying the connected loads upon loss of the plant primary power supply.

The system’s power supplies and associated distribution systems is provided with instrumentation to monitor variables and components so facility Operations personnel can evaluate whether these systems are performing the intended functions to support SNS loads.

3.2.4.2.10 Uninterruptible Power Supply System

The UPS systems employed at SNS consist of that portion of the facility electrical power system that inverts dc power to ac power and distributes this power to loads requiring a continuous source of power. Such loads are considered essential to providing for the general operational safety of facility personnel and/or preventing severe economic loss in the event of primary power supply failure. Loads requiring UPS systems include the:

- safety interlock system (a mission continuity feature only, since these systems fail to a safe state on loss of power);
- vacuum system instrumentation and controls;
- critical power supply controls and protection;
- main control room servers and network hardware;
- selected telecommunications equipment; and
- selected alarm systems (PPS radiation, fire alarm, etc.).

The UPS systems provide 120 V ac, nominal, single-phase, two-wire, 60 Hz and 120/208 V ac nominal, three-phase, four-wire, 60 Hz uninterruptible power to essential loads.

3.3 OPERATIONS

The operational goal of the SNS is to provide safe, efficient, and responsive operations in support of the world class neutron research user facility. Current organizations are focused on achieving and maintaining rated design conditions for the accelerator and to emphasize an integrated approach to operations.

The responsibility for safety rests with line management, flowing from the SNS Executive Director, who is also the ORNL Associate Laboratory Director for the Neutron Sciences Directorate. The SNS Operations Manager, who reports to the Associate Laboratory Director, is responsible for providing safety support, information, and oversight. The SNS Operations Manager is the ultimate authority on ES&H issues within the SNS complex.

The Research Accelerator Division is responsible for operating the proton facilities. The SNS is operated from the Central Control Room (CCR), staffed by members of both the Accelerator Operations and the Target Systems Groups within the Research Accelerator Division (RAD). This operational integration provides smooth coordination between proton and neutron facility operational activities, with unambiguous lines of authority and responsibility to ensure prompt and appropriate response to operational off-normal conditions up to and including site emergency response.

3.3.1 ORGANIZATION FOR OPERATIONS

The Division Director of the Research Accelerator Division has line responsibility for operational activities of both the proton facilities and neutron facilities with the exception of the Neutron Instruments which operate under the authority of the Neutron Scattering Science Division Director. Groups reporting to the Research Accelerator Division Director include: Accelerator Operations, Target Systems, Accelerator Physics, Beam Instrumentation, Control Systems, Ion Source, Cryogenic Systems, Electrical Systems, Mechanical Systems, RF Systems, and Vacuum Systems. Other representatives also reporting to the Director are the RAD ES&H Coordinator, the RAD Quality Assurance representative and the Chief Vacuum Engineer.

3.3.2 ENVIRONMENT, SAFETY, AND HEALTH ORGANIZATION AND INTERFACE WITH OPERATIONS

As depicted in Figure 3.3.2-1, the SNS is part of the Neutron Sciences Directorate. The SNS ES&H staff is led by the SNS Operations Manager, a position reporting to the SNS Executive Director. Policies for the safe and environmentally sound operation of the SNS are developed and approved by the Operations Manager. The ES&H staff is responsible for providing direction and support to SNS line organizations.

Where cost effective, ES&H services such as health physics support, environmental permit development, and radiation shielding calculations are purchased by the SNS from ORNL support organizations or subcontractors. Currently, staff with expertise in safety documentation, radiation protection, shielding, industrial safety, industrial hygiene, construction safety, environmental issues, and waste management are assigned to the SNS ES&H organization.

To ensure uniform and effective implementation of key ES&H issues throughout the SNS, committees to evaluate and develop ES&H policies are established as needed. For example, the Accelerator Safety Review Committee, Radiation Safety Committee, Electrical Safety Committee, Cryogenic Safety Committee and Instrument Systems Safety Committee, and the Experiment Review Committee have been chartered. Committees are multidisciplinary, as necessary, to ensure comprehensive reviews.

3.3.3 DESCRIPTION OF OPERATIONS

3.3.3.1 Proton Facilities

The SNS proton facilities are operated, and maintained by personnel from the Research Accelerator Division. Within the Research Accelerator Division, the specific responsibility for operations is assigned to the Accelerator Operations Group. The Operations Team consists of an Accelerator Operations Manager (Group Leader of the Accelerator Operations Group), a Deputy Accelerator Operations Manager, an Operations Coordinator, Control Room Shift Supervisors, and Control Room Accelerator Specialists.

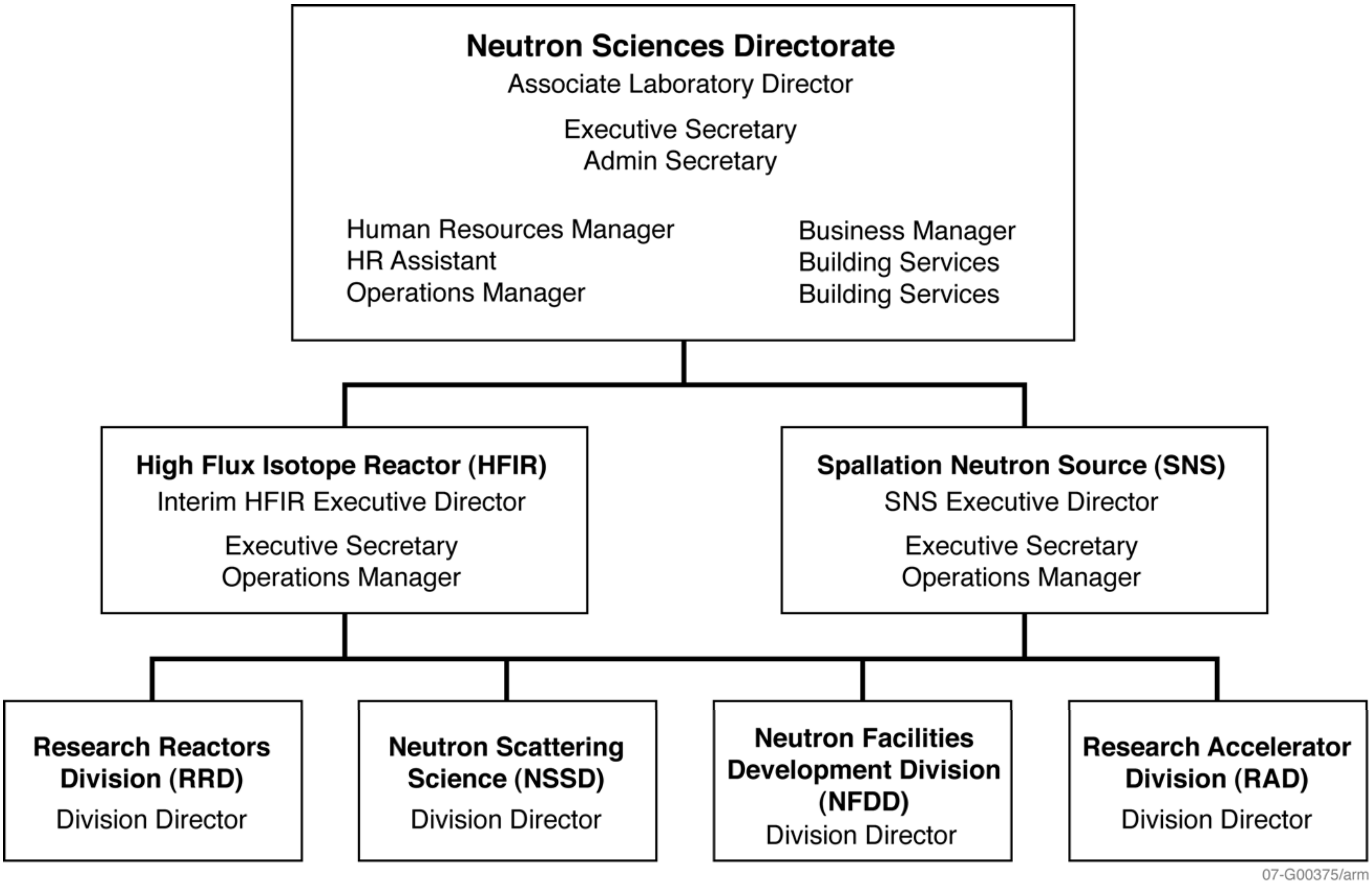

Figure 3.3.2-1 Spallation Neutron Source Organization Chart

Additionally, as discussed in the FSAD for Neutron Facilities, the Target operations Shift Technicians operate the mercury target systems and are part of the RAD Target Systems group. The Operations Group Leader has the overall responsibility for operation of the SNS accelerator, with responsibilities that include:

- Direct the preparation of tracking and reporting of operational and maintenance statistics for the purpose of maximizing the scientific throughput of the facility. Participate in the planning for, and execution of, acceptance and installation tests of accelerator systems.
- Assist in the review of planning and preparation of documents with an eye to the operability and maintainability of accelerator systems, including budgeting for long-term operation.
- Direct and assist in the development and maintenance of operational tools for the accelerator systems, including computer screen interfaces.
- Supervise the preparation of training and certification documentation for personnel in collaboration with other Research Accelerator Division team leaders.
- Be involved with the design and implementation of personnel and equipment safety systems including: (1) beam and accelerator subsystem interlock and (2) access and testing modes.
- Ensure team, group, and individual compliance with ES&H requirements, including ISMS.

The current plan calls for rotating shifts staffed by three Research Accelerator Division personnel: a Control Room Shift Supervisor and two Control Room Accelerator Specialists. A Control Room Shift Supervisor may function as an Accelerator Specialist when on shift. Target Systems personnel are on shift 24 h per day when the target is running. System specialists are not on shift 24 h per day but are called in as needed through an organized call-in structure.

The Central Control Room has a sufficient number of centrally located and compact multifunction workstation screens simultaneously accessible to the Operations personnel and other support personnel as necessary.

The design goal of SNS accelerator operations is to provide 5000 h of beam to the Target per year for scheduled research utilization of neutron beams. The run plan to achieve this is outlined below including the assumptions that have been made and justification for those assumptions. <u>The numerical goals below should not be regarded as commitments or requirements since the information is only intended (in this context) to provide an approximate picture of normal operations</u>.

The goal of Target Systems is for nine weeks of operation between Target changes if at full proton beam power. The planned Target change period is seven days.

One 8-h shift per week for preventative maintenance (PM) is assumed. If entry into the primary beam areas is required for the PM, then a cool-down period with the beam off may take place. An additional approximately 8-h period would be required to restore the beam to operation.

The goal for operational availability is 95%. Should the combined availability exceed 95%, a management decision could be made to extend the running hours beyond 5000 or to extend the shutdown.

- Hours per week 168
- One shift of PM per week 8
- Two shifts for PM cool-down/recovery per week 16
- Assumed availability 0.95
- Net beam available hours per week 136

An operational cycle is defined as the period of running between the start of Target changes, which is ten weeks. The weekly/hourly breakdown of an operational cycle is as follows:

- Operational weeks/hours 10/1680
- Target replacement week/hours 1/168
- Weeks per cycle 10
- Cycles of run weeks 4.2
- Total beam hours 5178

Consequently, 4.2 cycles of ten weeks per cycle yield the required 5000 operational hours for beam to Target plus some contingency. This program occupies 42 of the 52 weeks in the year. Depending on electric power demands, the accelerator could run two ten-week cycles in the winter/spring and two ten-week cycles, plus two weeks, in the summer/fall. This would allow for two five-week, programmed, shutdown periods per year.

Maintenance and development that takes more than seven days is scheduled into the two five-week shutdowns each year. Examples of this maintenance include replacement of the beam windows for the primary Target and beam-dump windows as needed.

Operations Procedures

Both operations and maintenance activities are performed in accordance with approved written procedures. Maintenances are conducted through a work authorization process that ensures configuration control of facility credited engineered controls.

A number of facilities have well-established, proven operations procedures that SNS reviewed for use as a guideline in the development of the SNS OPM.[3-19] Of these facilities, the one with the most comprehensive set of documentation similar in application to that required for the SNS is the Collider-Accelerator (C-A) Department at BNL. SNS has taken a similarly comprehensive approach in the development of the SNS OPM.

Technical procedures specific to the SNS are provided to Operations by the Senior Team Leaders and Group Leaders, primarily in the Research Accelerator Division. These procedures are incorporated into the SNS OPM. The Neutron Scattering Science Division also utilizes the OPM for procedures regarding the Neutron Instruments. The OPM procedures address normal and off normal, as well as non-physics, operations; the level of detail devoted to off-normal operations, events, or alarms is commensurate to potential safety or environmental consequences. The SNS OPM is accessible at: https://neutrons.ornl.gov/x/operations/SNS-OPM_Folder_Tree/.

3.3.3.2 Neutron Facilities

Operations specific to the SNS Neutron Facilities are described in the FSAD-NF.[3-25]

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4.0 SAFETY ANALYSIS

This chapter provides evaluations necessary to achieve two major objectives of the FSAD:

1. Evaluate hazards posed by operation of the SNS that are unique to accelerators and make sure they are adequately controlled/mitigated. As discussed below, standard industrial and laboratory hazards are not covered in detail because they are safely managed through the ORNL SBMS.
2. Identify those controls–either engineered controls or administrative controls that are essential to safety, so that they may be given close attention throughout operational and maintenance activities in accordance with the *SNS Quality Manual*[4-1] (see Chapter 7). Controls that fall into this category are referred to as “credited engineered controls” (CECs) and “credited administrative controls” (CACs).

The basic approach followed in this chapter is to complete a hazard analysis for accelerator-unique hazards in each major segment of the proton facilities. Hazard analysis is the standard method for applying the DOE graded approach for minimizing risk to workers, the public and the environment. It is well suited to identifying and understanding risk because it requires facility designers and operations personnel to consider both the likelihood and the potential consequences of hazards. The product of likelihood and consequence constitutes risk. In the hazard analyses presented in this chapter, the approach is to evaluate the risk and to identify controls—preventive and mitigative features—that ensure risk is low or extremely low. Controls that provide essential primary protection against serious worker injury or fatality are designated as credited controls (CECs or CACs). Controls that work to reinforce the primary controls by contributing to the layers of overall safety assurance are typically not designated as credited controls. Criteria and guidance applied by SNS in designating credited controls are described in Section 4.1.2. The CECs for Proton Facilities are summarized in Table 4.0-1. Essential safety aspects of CECs are summarized in Chapter 5.

Standard industrial and laboratory hazards do not require credited controls because they are safely managed as part of ORNL’s established institutional safety programs. ORNL implements institutional safety through the ORNL Standards Based Management System (SBMS). Promulgation of the SBMS is a key part of ORNL application of the principles of integrated safety management. Furthermore, the SNS job hazard analysis (JHA) policy, as explained in Section 4.1.3.1, requires that all work at the SNS be conducted only after appropriate JHA is performed.

Section 4.1 of this chapter explains the SNS implementation of the DOE graded approach to risk minimization. Section 4.2 lists the major features that can be called upon in hazard analysis to provide prevention and/or mitigation. Section 4.3 provides hazard analysis summaries for each major segment of the SNS, except for the neutron facilities, the safety of which is addressed in the Final Safety Assessment Document for Neutron Facilities.

Table 4.0-1

Summary of Proton Facilities CECs

Hazard	Location	CEC	Chapter 4 Hazard Analysis Reference(s)
Prompt radiation inside beam enclosures	All beam enclosures (LINAC, HEBT, Ring, RTBT)	PPS access control	Section 4.3.1, Table 4.3.1-1
Prompt radiation outside beam enclosures	Areas adjacent to beam enclosures	PPS chipmunks	Section 4.3.1, Table 4.3.1-2
Inert gases (He, N_2) used in cryogenic systems for superconducting LINAC.	LINAC	ODH monitoring & alarm; LINAC Emergency Ventilation System (EVS)	Section 4.3.1, Table 4.3.1-3
Inert gases processed in CHL to support superconducting LINAC	CHL cold box room	ODH monitoring & alarm	Section 4.3.1, Table 4.3.1-4
Inert gases used in CHL cryogenic systems	CHL Compressor room	Side wall air inlet panels, roof exhaust vents	Section 4.3.1.5, Table 4.3.1-4
Prompt radiation and/or decay radiation from short lived water activation radionuclides	Ring injection dump vault	PPS access control of vault	Section 4.3.2, and Table 4.3.2-2

4.1 HAZARD ANALYSIS METHODOLOGY

Hazard analysis includes the following steps: (1) hazard identification and screening; (2) assessment of the frequency and potential consequences of unmitigated risk; (3) identification of relevant and effective mitigation/preventive measures; and (4) assessment of mitigated risk. Hazard analysis is a process whereby it is possible to understand the risk and make informed risk mitigation or acceptance decisions. It is desirable to identify and apply safety measures that make the Accelerator Facility risks fall into the "extremely low" category (see Figure 4.1.1-1 below) as shown by this FSAD.

4.1.1 GENERAL APPROACH TO RISK MINIMIZATION

The steps in the hazard analysis process and general decision criteria are shown below.

Hazard identification produces a comprehensive list of the hazards present in a process or facility, and the screening phase removes all hazards below a threshold of concern or that are covered by recognized industrial codes and standards. The standard industrial hazards that are "screened out" do not need to be studied in a hazard analysis because their risks are already well understood and mitigated by standard means.

For each hazard retained for hazard analysis, the unmitigated risk is first evaluated in terms of frequency and consequence. This places it on the risk matrix, illustrated by Figure 4.1.1-1. An adaptation of the Figure 4.1.1-1 risk matrix is utilized for the evaluation of potential radioactive material release accidents in the target building hazard analysis as described in Chapter 4 of the FSAD-NF.[4-2] The following assumptions govern the determinations of unmitigated risk:

- The unmitigated risk does not include active safety or control systems or administrative controls.
- Assigned frequencies (labeled "Probability Level" on Figure 4.1.1-1) are qualitative and are typically based on engineering judgment. For the unmitigated evaluation, the frequency is that of the unmitigated initiating event. See Appendix A for examples.
- Assigned consequence can be qualitative but must be conservative.
- The hazard analysis is not carried further if the unmitigated risk is extremely low.

At this point, the risk is reevaluated considering the mitigating factors in place that would either reduce the consequence or make the challenge less frequent. This should move the location on the risk matrix based on assumed conditional probabilities of failure for the mitigating systems (see Appendix A for discussion on assignment of conditional probabilities to failure of mitigating systems or actions).

Consequence Level

High	**Low Risk—** Acceptable	Medium Risk— Unacceptable	High Risk— Unacceptable	High Risk— Unacceptable
Medium	Extremely Low **Desirable**	**Low Risk—** **Acceptable**	Medium Risk— Unacceptable	High Risk— Unacceptable
Low	Extremely Low **Desirable**	Extremely Low **Desirable**	**Low Risk—** **Acceptable**	Medium Risk— Unacceptable
Extremely Low	Extremely Low **Desirable**	Extremely Low **Desirable**	Extremely Low **Desirable**	**Low Risk—** **Acceptable**
	Extremely Unlikely ($<10^{-4}$/y)	**Unlikely (between 10^{-4}/y and 10^{-2}/y)**	**Anticipated – Medium (between 10^{-2}/y and 10^{-1}/y)**	**Anticipated—High (above 10^{-1}/y)**

Probability Level

NOTE: 10 CFR 835[4-5] ALARA may require more stringent limits for anticipated events.

Definition of Consequence Levels	
Level	**Definition**
Extremely Low	Will not result in a significant injury or occupational illness or provide a significant impact on the environment.
Low	Minor on-site with negligible off-site impact. May cause minor injury or minor occupational illness or minor impact on the environment.
Medium	Major impact on site or off site. May cause severe injuries or occupational illness to personnel, a single accidental death, or major damage to a facility or operation or minor impact on the environment.
High	Serious impact on site or off site. May cause deaths or loss of the facility/operation. Possible significant impact on the environment.

Figure 4.1.1-1 The Risk Matrix

- The mitigated risk should be either low or extremely low. For low risk, the evaluation should be reviewed to determine if there are preventive or mitigative features that could be added to bring the risk to extremely low. The risk of serious consequences should be made extremely low if that is reasonably achievable.
- The last step is to determine whether it is necessary to designate any equipment as Credited Engineered Controls using criteria presented in Section 4.1.2.

A credited control is one determined through hazard evaluation to be essential for safe operation directly related to the protection of personnel or the environment. The number of credited controls should be a limited subset of the total number of controls employed for overall facility operation. Credited controls should be assigned a higher degree of operational assurance than other controls. Since credited controls are essential for acceptably safe operations, they are addressed in the ASE.

4.1.1.1 Risk Minimization for Radiation Hazards

Prompt radiation hazards associated with operation of the SNS Proton Facilities are minimized through passive shielding and the personnel protection system (PPS). As described in Section 3.2.3, the PPS utilizes a system of automatic interlocks and beam cut-offs to render the beam enclosures inaccessible during beam operation and to help ensure that beam enclosures are cleared of personnel prior to beam operation. In addition, the PPS helps to protect area radiation designations outside beam enclosures through a system of area radiation monitors. The *SNS Shielding Policy*[4-61] (maintained as a separate controlled document) establishes project policy expectations for preventing exposure to ionizing and non-ionizing radiation, the performance and configuration control of shielding and the control of access to radiological areas. Comprehensive radiological risk minimization is ensured through application of the ORNL SBMS Radiological control Subject Areas, which promulgate procedures and requirements applied throughout ORNL including SNS for full implementation of 10 CFR 835.[4-5]

Discussions of accelerator faults provided in Sections 4.3 and 4.4 speak of protecting area designations. These areas—for example, Radiation Areas as defined in 10 CFR 835, etc.—are established to control the flow and behavior of workers in each area such that workers receive the minimum radiation exposure coincident with operating the facility to achieve its authorized research mission. Area boundaries are set with the expectation and verification that radiation levels will not exceed certain specified maxima depending on the type of posting. The SNS Project expects the area radiation limits to be met considering both the base level of residual radiation fields and the integrated effect of the short bursts typical of beam faults. The different area radiological postings utilized at the SNS for minimizing worker and visitor exposures to external radiation are governed by the ORNL SBMS Radiological Control Subject Areas. The PPS, through a system of area radiation detectors (Chipmunks) helps ensure the integrity of area designations by alarming or tripping the proton beam when specified thresholds are exceeded.

4.1.1.2 Risk Minimization for Fire Hazards

Fire is a standard industrial hazard that is mitigated at the SNS through the ORNL SBMS Fire Protection, Prevention, and Control Subject Area that implements the DOE fire-related directives and NFPA standards. Although workers are not present in the accelerator beam enclosures during routine operations, the tunnel-like geometry of the beam enclosures, combined with the existence of combustible materials in the tunnel require life safety evaluation. The general approach to ensure an acceptable level of fire risk is through provisions of SBMS which require compliance with the *Code for Safety to Life from Fire in Buildings and Structures* (NFPA 101),[4-9] construction per the *Standard Building Code*,[4-10] and applicable NFPA codes.

4.1.2 SELECTION OF CREDITED CONTROLS

A credited control is one determined through hazard evaluation to be essential for safe operation directly related to the protection of personnel or the environment from significant injury. In accordance with DOE Guide 420.2-1,[4-64] the number of credited controls should be a limited subset of the total number of controls employed for overall facility operation. Credited controls are assigned a higher degree of operational assurance than other controls.

Criteria for the selection of credited controls is established by SNS Policy, which satisfies the DOE accelerator safety order[4-2] requirement to ensure that risks have been mitigated to acceptable levels through controls and/or limits on the operation of the facility. Selection criteria relevant to credible hazards associated with the SNS Proton Facilities are summarized below:

1. If the unmitigated radiation dose to a worker exceeds 25 rem, a credited level of control shall be identified.
2. If the unmitigated radiation dose to a worker outside the building exceeds 25 rem and occurs at an estimated frequency exceeding 10^{-4}/year, at least two separate credited levels of control shall be identified.
3. For each unmitigated accidental release of inert gas from the cryogenic systems that serve the superconducting LINAC that could cause a worker to experience breathing air with oxygen

concentration below 12.5 volume percent and for which existing SBMS do not provide adequate design or operational requirements adequate to assure worker safety; a credited level of control shall be identified.

As used above, the term “level of control” refers to one or more CECs and/or CACs that are sufficient to mitigate the identified accelerator hazard. The criteria for designating credited controls are described in more detail in Section 4 of the FSAD for Neutron Facilities.

4.1.3 JOB HAZARD ANALYSIS

All workers at SNS have a responsibility for identifying and understanding the hazards they may encounter in the workplace. Understanding the hazards and the risks they present is an essential foundation for achieving excellence in environment, health, and safety performance.

Hazard analysis is a process by which workers plan work as well as identify and mitigate the environmental, safety, and health hazards involved in any work activity. This analysis helps to identify the specific work processes and materials necessary to safely complete a project, task, or work activity. This tool assures that activities in the work process are defined, understood, and anticipated by all those involved who actively participate. It also assures that hazards, either inherent in the activity or workplace, or that may occur as a result of the activity, have been identified and safely mitigated. The hazard analysis is utilized to ensure workers understand their role in the work to be performed, as well as the role of others involved in that project or task.

4.1.3.1 SNS Job Hazard Analysis Policy

All work activities performed at SNS shall be reviewed, using a Job Hazard Analysis, before the work is initiated to identify the environmental, safety and health hazards of the activity and the controls that are necessary to minimize the probability of an accident. In some cases, posting of JHA requirements and/or availability may be necessary to ensure worker use of and access to JHAs. For example, JHA requirements for work in cryogenic areas are posted in the LINAC and CHL buildings.

4.1.3.2 SNS Job Hazard Analysis Methodology

The SNS JHA procedure is consistent with the DOE’s *Integrated Safety Management Guide*,[4-11] including the five core functions.

Figure 4.1.3.2-1 provides an example JHA documentation form and guidelines for completing a routine SNS JHA. This section provides further guidance below.

The supervisor and employees identify work activities, the hazards associated with the activity, and the procedures and precautions that are followed in performing the work. The hazard analysis includes or involves the following:

- Detailed scope of work, including how the person/team intends to complete work
- Walk-down or inspection of the work area while planning the work
- Identification of hazards
- Identification of work requirements, controls, procedures, instructions, and personal protective equipment (PPE) necessary to perform the work safely (including permits)
- Involvement of the workers in the preparation of the hazard analysis

The level of detail of the hazard analysis should be correlated to the complexity of the work and the hazards involved with the activity. For instance, straightforward welding in an approved hood would require less detail than if one were welding in the tunnel while standing on a ladder.

The work activity must be completed in accordance with the hazard analysis. If there is a change in the work scope, if work conditions change or new hazards are identified, or the controls prove inadequate or ineffective, the hazard analysis is reviewed by the employees and supervisor, revised as necessary, and approval/concurrence obtained before the work is continued. After the activity is completed, the hazard analysis and/or job procedure should be updated to include improvements identified while performing the work.

Figure 4.1.3.2-1
Job Hazard Analysis Example Form and Guidelines

(This demonstrates how to do each of the three parts of a JHA.)

Job:____

Supervisor Approval:______________________________ Date:______________

Sequence of Basic Job Steps	Potential Hazards	Recommended Actions
• Examining a specific job by breaking it down into a series of steps or tasks will enable you to discover potential hazards employees may encounter. • Each job or operation will consist of a set of steps or tasks. For example, the job might be to move a box from a conveyor in the receiving area to a shelf in the storage area, to determine where a step begins or ends, look for a change of activity, change in direction, or movement. • Picking up the box from the conveyor and placing it on a handtruck is one step. The next step might be to push the loaded handtruck to the storage area (a change in activity). Moving the boxes from the truck and placing them on a shelf is another step. The final step might be returning the handtruck to the receiving area. • Be sure to list all the steps needed to perform the job. Some steps may not be performed each time; an example may be checking the casters on the truck. However, if that step is generally part of the job, it should be listed.	• A hazard is a potential danger. The purpose of the JHA is to identify all hazards—both those produced by the environment or conditions and those connected with the job procedure. • To identify hazards, ask yourself these questions about each step: Can the employee be caught in, by, or between objects? Is there a potential for slipping, tripping, or falling? Could the employee suffer strains from pushing, pulling, lifting, bending, or twisting? Is the environment hazardous to safety/or health (toxic gas, vapor, mist, fumes, dust, heat, or radiation)? • Close observation and knowledge of the job is important. Examine each step carefully to find and identify hazards—the actions, conditions, and possibilities that could lead to an accident. Compiling an accurate and complete list of potential hazards will allow you to develop the recommended safe job procedures needed to prevent accidents.	• Using the first two columns as a guide, decide what actions or procedures are necessary to eliminate or minimize the hazards that could lead to an accident, injury, or occupational illness. • Begin by trying to: (1) engineer the hazard out; (2) provide guards, safety devices, etc.; (3) provide PPE; (4) provide job instruction training; (5) maintain good housekeeping; (6) ensure good ergonomics (positioning the person in relation to the machine or other elements in such a way to improve safety). • List the recommended safe operating procedures. Begin with an action word. Say exactly what needs to be done to correct the hazard. Avoid general statements such as, "be careful." • List the required or recommended PPE necessary to perform each step of the job. • Give a recommended action or procedure for each hazard. • Finally, review your input on all three columns for accuracy and completeness. Determine if the recommended actions or procedures have been put in place. Re-evaluate the JHA as necessary.

Note: Before filling out the JHA form, consider the following:

- The purpose of the job:
  - What has to be done?
  - Who has to do it?
- The activities involved:
  - How is it done?
  - When is it done?
  - Where is it done

4.2 PHYSICAL FEATURES AND ADMINISTRATIVE CONTROLS PROVIDED TO PREVENT OR TO MITIGATE ACCIDENTS

The purpose of this section is to list in one central location a brief summary the various system features and administrative programs that help to control hazards or to minimize risk of various hazards.

4.2.1 RADIATION BARRIERS

The *SNS Shielding Policy*[4-61] signifies the commitment of SNS management to ensure acceptable shielding is provided for radiation protection and that worker radiation exposures are as low as low as reasonably achievable (ALARA).

The bulk shielding is designed to mitigate the prompt and residual radiation hazard that may be present at the SNS. In locations where the losses may be greater (e.g., collimators), physical barriers may be required and, depending on the area classification, these may be "engineered barriers" (e.g., locked) or simply posted.

With the intense beam of the SNS facility, there is the potential of relatively high residual activity in several locations (i.e., collimators, Ring injection region, Ring extraction region). To work near these locations ALARA procedures are applied as needed. Local and customized movable shielding may be brought into place using the remote capability of a crane in most cases. This greatly minimizes the potential integrated man-dose for work performed within the beam enclosures. Furthermore, a cool-down period after shutdown of the accelerator systems is typically observed prior to entering these areas to reduce the background residual dose.

4.2.1.1 Bulk Shielding

Shielding design analyses have been integrated into the overall facility design. The permanent shielding and access control areas are configured to support the ORNL SBMS Radiological Control requirements, which implement the 10 CFR 835[4-5] requirements, including ALARA considerations. Extensive radiation surveys of normal operations, as well as low-intensity simulated, beam faults have been conducted during commissioning and initial operations. Radiation surveys are conducted periodically during routine operations. Shielding surveillance includes periodic inspections of the condition of the berm shielding. These visual and radiation measurement surveys provide assurance and verification of the adequacy of the shielding. In addition, shielding is configuration controlled by procedure in the OPM.[4-44]

4.2.1.1.1 Criteria

Early in design, the SNS Project adopted the following guideline for shielding—the shielding should be designed such that, during normal operations, the dose rate on accessible outside surfaces of the shield should be less than 0.25 mrem/h in areas under access control (Controlled Area or higher) but with no occupancy restriction for workers. This is a guideline rather than a requirement because it is derived from an extremely conservative postulate: 100% occupancy at the shield face outer surface, i.e., such that 2000 h/y residence time at 0.25 mrem/h would yield an annual exposure of 500 mrem. It was desired to adopt a shielding goal below the 0.5 mrem/h objective of 10 CFR 835.1002(b)[4-5] as a means of ensuring that shielding design meets ALARA requirements. Where mission and/or cost considerations make meeting the goal impracticable, the shield is optimized as described in Section 4.6, "ALARA." Since there are many ways to control access and residence time by area designations, training, and signage, and since physical factors dictate decrease of dose rate with distance from the shield surface, significantly higher dose rates are often acceptable. Therefore, in the following subsections, shields are evaluated in terms of the 0.25 mrem/h guideline value, but instances where higher values are acceptable are mentioned to indicate examples of where area designations or other factors play a major role in minimizing radiation exposures.

4.2.1.1.2 Methodology

A strategy utilizing coupled Monte Carlo and multidimensional discrete ordinates calculations has been implemented[4-12] to perform radiation transport analyses when pure Monte Carlo analyses cannot give statistically satisfactory answers. The methodologies are explained in Appendix B, "Shielding Analysis Methodology."

4.2.1.1.3 Permanent Shielding Materials

The permanent bulk shielding materials for the SNS are primarily the type of materials typically found at existing accelerator facilities. For example, concrete and earth provide protection for personnel outside the tunnel for the proton beam transport system (LINAC, HEBT, Ring, and RTBT external to the Target Building). The concrete for the structural walls is ordinary concrete (~2.34 g/cm^3), and the earthen material (indigenous to the SNS site) has an approximate density range of 1.76 g/cm^3 to 1.99 g/cm^3 and an equilibrium moisture content between 20% and 22%.

The primary shielding material for the RTBT inside the Target Building, the Target shielding monolith, the Target service bay, and the neutron beam lines is steel and/or concrete. The types of steel utilized in the shielding include low carbon steel easily machined into complex shapes required in many areas of the SNS shield design, recycled steel shield blocks (some of which contain low levels of non-removable bulk radioactive contamination) of fixed specific sizes, and inexpens333ive off-specification steel obtained from the end of a steel mill run (Note: The off-specification steel is generated as the mill transitions from one grade of steel to another and does not generally contain elements that could cause activation problems; at any rate, the content of the off-specification steel is known and is considered in purchasing.). The different types of concrete utilized for the SNS include ordinary structural concrete, high-density concrete (density ~3.93 g/cm^3) specifically designed for shielding, and borated concrete (boron content typically on the order of 0.5 wt % to 0.75 wt %). In the design of the permanent shielding for the SNS, the concrete utilized for structural design was integrated into the shield design. In addition to the materials mentioned above, paraffin, borated paraffin, polyethylene, borated polyethylene, cadmium, boron carbide, and lead are used for local shielding and in special circumstances.

4.2.1.1.4 Front End Building

The principal Front End beam line components inside the Front End Building are the ion source, the LEBT line, the RF Quadrupole (RFQ) LINAC, and the MEBT line including the first two DTL tanks. The primary sources of radiation in this area are due to (a) neutron and gamma production by the interaction of proton beam losses with the DTL structural elements (copper), (b) X-ray production by RF in the Front End and DTL, and (c) back-streaming radiation from the operation of the LINAC. Calculations based on expected beam losses and measurements of dose buildup due to dark current effects have provided the basis for concrete and steel shielding around the DTL tanks to yield the desired dose rates in the Front End Building. An optimized shielding configuration addresses the back-streaming radiation component.[4-13] Shielding features of the production front end components are reproduced in the ion test stand as needed to ensure that test stand activities have a similarly low radiation profile.

4.2.1.1.5 LINAC

The principal LINAC components include DTL, CCL, and SCL sections that accelerate the H^- beam to the required energy (~1 GeV energy range). The permanent shielding for the LINAC is designed to protect personnel from anticipated normal operational beam losses[4-14] as defined by the SNS/AP Technical Note 07.[4-15]

The permanent shielding for the LINAC is comprised of the 1.5 ft-thick concrete LINAC Tunnel structural walls and a 17 ft-thick earth berm made of earthen material indigenous to the SNS site (see

Figure 3.2.4.1.3-1 for a sketch of the typical berm cross section). Between the LINAC Tunnel and Klystron Building, the permanent shielding consists of the 1.5 ft-thick concrete LINAC Tunnel structural walls, a 15 ft 10 in.-thick earth berm, and a 1.5 ft-thick concrete Klystron Building structural wall. The dose rate on top of the berm and inside the Klystron Building due to normal operational beam losses in the LINAC is measured as less than ~1 mrem/h.[4-16] The klystrons emit a field of X-rays yielding a localized dose rate of ~ 0.3 mrem/h (without external shielding).

Several penetrations through the earth berm require additional consideration with respect to the shield design. In particular, the penetrations include the personnel and equipment egresses, klystron waveguides, survey pipes, and ventilation exhaust and intake ducts. Close to the chase penetrations on the Klystron Gallery north wall, dose rates depend on the details of the loss pattern, but are generally below 1 mrem/h. Inserting a tuning beam stop downstream of the CCL (e.g., as was necessary for certain commissioning activities) creates a loss point that has been modeled in detail. The resulting localized radiation is reduced by shadow shielding in the beam tunnel and/or by block walls in the Klystron Gallery. In the Klystron Gallery, Radiation Buffer Areas may be created near penetrations in klystron housings - these radiation fields are appropriately shielded and/or posted. Detailed analyses (including streaming) have been performed for penetrations connecting the Klystron Gallery to the beam tunnel.[4-62,4-65] Various types of shielding (filling the chase with shielding material, stacked concrete blocks, and other appropriate countermeasures) have been evaluated and installed as needed to protect workers in the Klystron Gallery from radiation produced by operations in the beam tunnel.

4.2.1.1.6 HEBT, Ring, and RTBT

The remainder of the proton beam transport system includes the HEBT Tunnel, the Ring, and the RTBT Tunnel. The HEBT transports the H^- beam exiting the SCL for injection into the Ring, and the RTBT transports the proton beam from the Ring extraction point to the Target. The HEBT consists of a straight section of the LINAC Tunnel, a 90° arc, and another straight section leading into the Ring. After being accelerated to the full energy of 1 GeV, the H^- beam is passed through two transverse collimators before being transported into the bend section of the HEBT. The maximum losses at the transverse collimators are assumed by calculation to be 10^{-5} of proton beam current.

The Ring accumulates the protons from the LINAC in pulses. It includes four major straight sections: (1) injection, (2) collimation, (3) extraction, and (4) RF linked together by 90° arcs. The permanent shielding for the HEBT, Ring, and RTBT is designed to protect personnel from normal uncontrolled operational beam losses of a maximum of 1 W/m. The maximum controlled losses for a collimator in the collimator section are assumed to be about 10^{-3} of the total proton beam current.

The dose rates on top of the berm due to normal operational beam losses in the HEBT, Ring, and RTBT are calculated to range up to about 1 mrem/h for the HEBT and RTBT and the injection, RF, and extraction sections of the Ring, with values less than 0.25 mrem/h[4-19,4-20] measured at approximately 1 MW beam power. Dose rates on the order of 1 mrem/h on the top of the berm would be acceptable because the berm is occupied only a small fraction of the time.

As is the case with the LINAC, there are several penetrations through the earth berm that require additional consideration with respect to the shield design. In particular, the penetrations include the personnel egresses, truck accesses for the HEBT and RTBT, survey pipes, and ventilation exhaust and intake ducts. Penetration analyses have been performed[4-21,4-22,4-23,4-24] to determine that the dose rate emanating from these penetrations is less than 0.25 mrem/h and this has been verified by surveys at ~1 MW beam power. A permanently installed shield wall labyrinth in the HEBT tunnel protects the maintenance and service personnel in the Ring from radiation generated by beam spills during the tuning of the LINAC Systems. This shield wall labyrinth is designed for the worst case of 7.5 kW beam power incident to the first dipole face.

4.2.1.1.7 LINAC Tuning, Ring Injection, Ring Extraction Proton Beam Dumps, and HEBT Arc Dumps

Three proton beam dumps are located outside the Accelerator Tunnel: (1) a LINAC Tuning Dump designed for 7.5 kW; (2) the Ring Injection Dump designed for 150 kW; and (3) a Ring Extraction Dump designed for 7.5 kW.[4-26] The low-power LINAC and Extraction dumps are designed to be passively cooled, whereas the injection dump is water cooled. The bulk shielding for all dumps is designed the same with respect to materials and layout.

The permanent bulk shield region is composed of multi-ton shield blocks with miscellaneous smaller blocks surrounding the beam stop enclosure and the proton beam tube. The bulk shield blocks are supported by the building concrete structure/foundation and enclosed in a steel liner. The bulk shield is designed to provide adequate radiation shielding to permit intermittent occupancy in the service area located above the Ring Injection Beam Dump vault and to mitigate significant soil and groundwater activation for all beam dumps (see Section 4.5.1.2 Prevention of Radiation Contamination of Groundwater). For mitigation of soil and groundwater activation, the permanent shielding was designed to reduce the neutron flux entering the soil to a level less than 10^4 n/cm^2-sec.[4-27]

The three rooms located above the Ring Injection Beam Dump are part of the Beam Dump Building. They are the dump vault, the utility service vault, and the electrical service vault. The dose rates in these rooms due to normal operation of the beam dump are calculated to be ~1–2 mrem/h, tens of rem/h, and less than 0.25 mrem/h, respectively. The higher dose rates in the utility service vault of the Ring Injection Dump occur only during full power beam operation and are due to water activation products (including Be-7, which plates out inside cooling water pipes) within the primary cooling loops. As discussed in Section 4.3.2, the PPS controls access to the utility vault of the injection dump. Within minutes after beam cutoff, the radiation level in the injection dump utility service vault has decreased to the much lower level dominated by the longer-lived Be-7. Localized shielding is utilized to help mitigate these sources of radiation with respect to personnel access for maintenance procedures. The walls of the three beam dump vault rooms are made of ordinary concrete with the thickness determined by a combination of structural and shielding requirements.

4.2.1.1.8 Target Shielding Monolith, Neutron Beam Line, Basement Utility Vaults, and Utility Water Chases

Information on these topics is included in the FSAD for Neutron Facilities (FSAD-NF[4-02]).

4.2.1.1.9 Transportation and Storage

Adequate shielding is provided to protect the personnel and the public from the transportation and storage of radioactive materials. Interfaces for the shipping casks and transfer areas (i.e., Target service cell, beam dump vault room, etc.) are designed to mitigate radiation streaming. The SNS has an on-site storage facility for the storage of used components (e.g., magnets, shutters, etc.). Adequate shielding is provided[4-43] to protect site personnel, the public, and the environment from these sources of radiation in accordance with 10 CFR 835[4-5] and the *SNS Shielding Policy.*[4-6].

4.2.1.2 Moveable Shielding

There is the possibility of a significant radiological hazard to facility workers and researchers if moveable shielding were displaced without proper care and oversight. The threat involves both prompt (beam-on) and residual (beam-off) radiation. Two simplifying assumptions are reasonable: (1) any shielding blocking a significant hazard is too heavy to be moved by an unaided individual and (2) under almost all circumstances, the radiation at a given location is higher when the beam is on than when the beam is off. Safety involving moveable shielding is, therefore, based on configuration control and independent confirmation of acceptable radiation levels under operational conditions.

Shielding that protects workers from a significant hazard typically either weighs at least on the order of a ton or consists of hundreds of concrete blocks; this shielding is either too heavy or unwieldy to be moved by a single, unaided worker in a reasonable time without detection. Operational procedures require a proper review and approval of any planned reduction or change in shielding. The basic approach is tailored to the hazard, considering how radiation levels could change with changes in the shielding. Shielding important to worker safety is either installed in such a way that removal requires special equipment and planning, or is designated and labeled as configuration controlled shielding. Routine inspections by Operations staff and periodic area radiological surveys by qualified Radiological Control Technicians (RCTs) confirm the adequacy and integrity of installed shielding. Start-up and periodic radiological area surveys provide independent confirmation that shielding modifications have not compromised safety and that radiological postings remain appropriate. This process provides reasonable assurance that shielding changes do not affect worker safety.

Ensuring radiation safety when shielding has been removed may require that beam operation be prevented or be restricted from reaching the area with decreased shielding. The "Hold for Radiation Safety (RS Hold)" administrative system of locking and tagging of equipment or beamlines has been developed and is used for such cases. A written procedure specifies requirements for establishing and removing radiation safety locks and tags. For critical movable shielding the procedure requires the application of dual RS Holds—one by the RSO or division radiation control officer and the other by accelerator operational personnel. In some circumstances, protection against potentially lethal levels of radiation requires that beam be restricted by two independent methods, either of which can prevent beam from reaching the location of removed or decreased shielding.

PPS interlocks may be used for critical items of movable shielding in certain cases where the administrative controls approach described above is not entirely adequate. For example, PPS trap key interlocks provide assurance that steel shield blocks are in place at the HEBT and RTBT truck locks, and on the plug-door between the Front End and LINAC sections.

4.2.2 RADIATION MONITORS

4.2.2.1 Retrospective Radiation Dose Measurements

The long-term integrated radiation dose in areas accessible to the public and other individuals not wearing personnel dosimeters is measured to establish the background in these areas and to confirm that the doses are acceptable. Thermoluminescent dosimeters (TLDs) identical to those worn by radiation workers are mounted in locations specified by the Radiation Safety Officer (RSO) for this purpose. The dose recorded by these TLDs is indicative of the exposure of a person spending full time at that location. Neutron albedo dosimeters, if their use is indicated for this purpose, are attached to phantoms or other suitable moderators to simulate use by personnel.

4.2.2.2 Real-Time Radiation Monitors

Fixed-location area radiation monitors provide real-time dose information for two purposes: (1) dose rate information is provided to the PPS so that it can turn the beam off in case of elevated radiation levels in potentially occupied areas, and (2) local radiation monitors warn workers of unexpected, elevated dose rates. General locations have been selected for the real-time monitors based on radiation modeling under operating and accident conditions; exact locations are refined based on beam-loss tests (normal and/or fault conditions, as needed) conducted during commissioning activities and on radiation surveys during operations. The RSO determines area radiation monitoring instrument locations and subsequent relocations. Some monitors selected for this application are sensitive to both gammas and neutrons, while gamma-only monitors are more appropriate in other applications.

Hard-wired, fail-safe radiation monitors popularly known as Chipmunks (described in Section 3.2.3.9) are located outside the protective shielding at points adjacent to possible high-loss areas along the beam path. For additional protection and monitoring purposes, Chipmunks may also be placed in unoccupied beam areas, and correlated with measured levels in adjacent occupied areas. Chipmunks are interlocked to the beam and trigger a shutdown in as little as one or two seconds if radiation levels in these occupied areas become significantly greater than expected. This technique is currently standard practice at other accelerator facilities around the country; the intent is to maintain personnel safety and area classification compliance by providing a robust and rapid beam-inhibit if any monitor exceeds a preset interlock limit. Instruments used for this purpose are included as part of the PPS.

The RSO, subject to review by the Radiation Safety Committee, determines the location and the number of Chipmunks. Factors considered in optimizing Chipmunk coverage include routine periodic radiation surveys, beam fault studies, shielding calculations, and potential personnel occupancy or use. The RSO determines the appropriate quality factor setting for each instrument location and the PPS group is responsible for ensuring the appropriate setting is implemented. Quality factors used to adjust the instrument sensitivity are determined based on predicted and measured neutron/gamma ratios and, where available, neutron energies. For each radiation detection instrument connected to the PPS, justification of the instrument location, the effective quality factor, and any changes are documented by the RSO.

Instruments connected to the PPS are subject to the same level of configuration control as the rest of the PPS. These instruments are calibrated periodically against NIST standards in accordance with ORNL procedures.

4.2.2.3 Portable Radiation Monitors

Portable radiation detection instruments are an essential part of any robust radiological control program and are used by Radiological Control Technicians (RCTs) at the SNS. ORNL requirements and procedures relating to portable radiation monitors are included in the SBMS Radiological Control Subject Area.

4.2.2.4 Frisking Instruments

Instruments used to frisk personnel who are exiting posted areas that might contain removable contamination are appropriate for the expected types and energies of the contamination. ORNL requirements and procedures relating to frisking and frisking instruments are included in the SBMS Radiological Control Subject Area.

4.2.2.5 Personnel Dosimetry

All radiation workers wear TLDs while working in areas posted for actual radiation hazards (e.g., Radiation Areas designate an actual hazard). Other workers are issued appropriate dosimetry for their work assignment, including consideration of potential accident scenarios. In addition to the standard ORNL dosimeter that measures beta, gamma, and gross neutron radiation exposures, workers who are likely to be exposed to measurable levels of neutron radiation are issued special neutron dosimeters that provide a more accurate assessment of neutron dose. Selection of appropriate neutron dosimetry is based on predicted neutron dose rate, integrated dose, and energy spectrum.

ORNL requirements and procedures relating to personnel dosimetry are included in the SBMS Radiological Control Subject Area.

4.2.3 PERSONNEL PROTECTION SYSTEM

4.2.3.1 Administrative Policy for Access Control

Access to beam enclosures is physically prevented by the PPS, thereby making the enclosures inaccessible when beam may be present. In addition, access at any time is controlled administratively to ensure compliance with ORNL SBMS Radiological Control requirements by SNS requirements that allow access only to workers who have a specific need to be in the area and who have appropriate training and dosimetry. The specific training, qualification and record-keeping requirements are detailed in the SNS OPM.[4-44]

4.2.3.2 Personnel Protection System

The PPS is designed as a configuration-controlled safety system with a PLC basis, as described in Section 3.2.3. Modification to the PPS is managed in accordance with the PPS configuration control procedure. The primary purpose of the PPS is protection against accelerator prompt radiation.

4.2.4 ELECTRICAL SAFEGUARDS

Electrical safety is covered in the ORNL SBMS Subject Area "Electrical Work" and in the SNS OPM.[4-44] As a standard industrial safety concern, electrical hazards are not specifically analyzed in the SAD and the safety of workers is ensured through compliance with ORNL SBMS requirements, e.g., implementation of NFPA 70E *Standard for Electrical Safety in the Workplace*. One aspect of electrical safety and hazard mitigation related directly to the SNS role as an accelerator and this is explained below.

It is the general intention of the SNS to require accessible electrical buss conductors to be fully covered in the accelerator technical equipment areas to reduce/prevent electrical hazards in these areas. However, the SNS design requires an exception to this general rule—magnet power connections in HEBT, Ring, and RTBT have exposed conductors. These buss connections are not covered in the tunnel for the following reasons:

- ALARA: The use of grounded (metallic) buss covers would require removal of these covers during maintenance, which would increase worker time in the radiation field.
- ALARA and Waste Minimization: It is expected that the radiation field would cause plastic or other organic covers to crumble, thereby creating a waste stream and requiring additional worker time in a radiation field.

Automatic protective devices and the SBMS and SNS administrative procedures are used to achieve the above objectives while ensuring electrical safety. The PPS removes the prime power feed for all power supplies that power devices in a beam enclosure area in Controlled Access Mode for that area. Workers are trained to assume that magnets are powered in all cases and treat them accordingly. This requires remaining outside the limited approach and arc flash boundaries which are clearly marked on the floor and identified during ring access training. In cases where workers are required to work on or near a magnet, the magnet power supply is locked out and tagged out. In some cases, it is necessary to perform measurements near magnetic elements while powered. A separate Magnet-Power-On Mode of the PPS is used in these cases. Appropriate control over access during this mode, as well as training requirements, addresses these concerns for exposed powered conductors and magnetic fields, and appropriate PPE must be worn for workers who cross the restricted approach and/or arc flash boundaries. A minimum of two workers are assigned to these tasks, with one serving as a safeguard. Additionally, where electrical hazards are present to SNS personnel working in the area, LO/TO procedures are required to be in place and to be part of the SNS Training Program.

4.2.5 LOCKOUT/TAGOUT

SNS follows the requirements and procedures of the ORNL SBMS Subject Area "Lockout/Tagout."

4.2.6 SAFETY REVIEWS AND COMMITTEES

As discussed in Section 3.3.2, standing safety committees have been chartered and are utilized to focus project expertise on safety and to help maintain configuration control.

4.2.7 TRAINING

Worker training and qualification are important parts of the overall ES&H plan for SNS. Training and qualification of workers are described in the SNS OPM.[4-44] All SNS personnel and experimenters are required to have an appropriate level of training to ensure their familiarity with possible hazards and emergency conditions to protect the environment and to ensure the health and safety of personnel at the SNS complex. Workers are trained in tunnel access, LO/TO, radiation worker, cryogenic hazard, emergency response, first aid and CPR procedures, and other subjects consistent with their positions at SNS.

The number and type of training sessions/modules are assigned using a tailored approach commensurate with the staff members' responsibilities, work areas, level of access, etc. For example, only specifically trained and qualified workers are allowed to perform pre-beam sweeping tasks in PPS-protected beam enclosures. An up-to-date record of worker training is kept at the SNS and/or ORNL in an accessible database. Radiation work and tunnel access is only allowed if adequate training is documented, except in cases of emergency. Training procedures are reviewed and updated periodically. Tunnel access training is specific to hazards present in SNS tunnels, including cryogenic and oxygen deficiency hazards. Two levels of cryogenic safety training are used: (1) the general cryogenic hazard training that is incorporated into tunnel access training, and (2) a more in-depth training for individuals who do work on cryogenic components. The more in-depth training is required for individuals who do work on the cryogenic components and who may require unescorted access into the Central Helium Liquifier building.

Within each SNS working group, there are also specific operating procedures that, in most cases, require retraining at a specific frequency (e.g., annually), as well as many procedures that require formal training and specific use of subsets of the procedures for each use (e.g., sweep procedures for beam enclosures). The SNS Project accomplishes this training via several mechanisms including but not limited to: Web-based courses, formal classroom courses, and specialized SNS equipment training.

The operations procedures manual (OPM) is the primary resource for safety procedures for operations.

4.2.8 PERSONAL PROTECTIVE EQUIPMENT

SNS use of PPE is governed by ORNL SBMS requirements.

4.2.9 CONTROL AND USE OF RADIOACTIVE MATERIALS

The SNS ensures worker safety regarding the radioactive materials and sources by implementation of the ORNL SBMS Radiological Control requirements and procedures.

4.2.10 CONTROL AND USE OF HAZARDOUS MATERIALS

The SNS ensures worker safety regarding hazardous materials in accordance with the ORNL SBMS Area, including the Worker Safety and Health Management System, the Work/Project Planning and Control Management System and the Chemical Safety subject area.

4.2.11 HAZARDOUS WASTE MINIMIZATION

Environmental hazards are minimized, mitigated, and monitored in accordance with the ORNL SBMS Environmental Management System requirements and procedures. See Section 4.5, "Environmental Hazards."

4.2.12 FIRE PROTECTION AND PREVENTION

Fire protection and prevention are ensured through implementation of the ORNL SBMS Subject Area Fire Protection, Prevention and Control. The following material summarizes the results of the SNS post-construction fires hazards analyses for the Proton Facilities including two instances where equivalency analyses were performed as required by the unique accelerator specific configuration of the SNS. All facilities are being provided with a level of fire protection that is sufficient to have filled the requirements of the best-protected class of industrial risks and provide protection to achieve multiple layers of protection. Unless otherwise noted below, standard fire protection features for all accelerator facilities and support buildings include emergency lighting and exit signs, egress arrangements in accordance with NFPA 101,[4-9] fire area separation from adjacent buildings, automatic fire sprinkler protection in accordance with NFPA 13,[4-47] a fire alarm system in accordance with NFPA 72,[4-48] and portable fire extinguishers in accordance with NFPA 10.[4-49]

Building fire alarm systems include manual pull stations and occupant alarm notification in accordance with NFPA 101,[4-9] alarm monitoring and supervision of all fire suppression systems, HVAC smoke detection in accordance with NFPA 90A,[4-50] and fire detection for special hazard areas. Fire detection provided for special hazards is noted below.

The MPFL for all fire areas is either within the limits established by DOE, or redundant fire protection is being provided that meets DOE objectives. MPFL details are provided in the various building Fire Hazards Analyses (FHAs—see Appendix E).

Fire prevention includes the use of a welding/burning/hot work permit system (SNS-specific procedure) to control these ignition hazards and the use of an impairment tracking system (ORNL program) to control the hazards associated with impaired fire suppression systems. A JHA procedure (SNS-specific procedure) is also intended to identify and to prevent potential fire hazards associated with job-specific tasks.

The FHAs that have been generated for all significant building and for the SNS site provide detailed fire hazards identification and mitigation descriptions for each of the areas of the SNS complex. Appendix E provides a link to the FHA documents in Projectwise. The Title II FHAs have been updated to reflect post construction conditions. Primary changes to the preliminary FHAs for the proton facilities include the addition of redundant smoke detection in the Klystron Building, the elimination of firestopping for the wave guides, and redefining of the fire area boundaries. The updated fire protection documents describe fire hazards and fire protection related design features of each building and describe how applicable NFPA standards are met. In a limited number of circumstances approved equivalency evaluations are referenced when an SNS implementation differs from the NFPA standard. In two instances SNS required a unique implementation in order to ensure both fire safety and radiation safety in the accelerator tunnel.

- Equivalency analysis in which the PPS gate locking arrangements throughout the accelerator tunnel complex are found to be equivalent to NFPA 101[4-9] requirements, and
- Equivalency analysis in which the non-standard fire barrier that serves both as a shielding labyrinth and as a horizontal exit from the Ring to/through the HEBT is shown to be equivalent to NFPA 101[4-9] requirements.

Future modifications, if any, to either the PPS gates or the HEBT/Ring shielding labyrinth will have to meet both PPS and fire safety requirements.

4.3 HAZARD IDENTIFICATION AND ANALYSIS

This section describes the hazard identification and analysis performed for each of the major portions of the SNS Proton Facilities. Hazards of the Neutron Facilities in the target building are addressed in the FSAD for Neutron Facilities.[4-2] The evaluations are performed using the methodology described in Section 4.1 above.

The focus in this section is on accelerator-specific hazards. Standard industrial and laboratory hazards, which may exist throughout SNS facilities, are not addressed because they are effectively managed through the ORNL institutional safety program as promulgated through the SBMS implementation of applicable codes, standards, and regulations, as summarized in the Section 4.0. This includes, for example, modulator testing and coupler conditioning authorized in the RFTF building and RF Annex under the SBMS Research Safety Summary (RSS) system and managed per SBMS procedures that cover the applicable hazards.

The SNS work control policy ensures that JHAs (see Section 4.1.3.1) are done, as needed, to identify the standard industrial and laboratory hazards and to match them to control measures to be applied by workers in the field.

4.3.1 BEAM ENCLOSURES AND RELATED SUPPORT FACILITIES

This section discusses accelerator specific hazards present in Proton Facilities including the beam enclosures (tunnels) and support buildings such as the CHL Facility and Ring Support Building, not including the three major beam dumps which are addressed in the next section. Tables 4.3.1-1 through 4.3.1-6 summarize the conclusions reached for the identified and reviewed major hazards.

4.3.1.1 Radiation Hazards

Ionizing Radiation. All forms of radiological hazard are mitigated through the ORNL SBMS Radiological Protection Management System. This section defines radiological hazards unique to the SNS proton facilities—primarily prompt radiation associated with the proton beam—and their mitigation. Tables 4.3.1-1 and 4.3.1-2 summarize the hazard analysis for protection of workers against prompt radiation inside and outside the beam enclosures.

Sources of radiation inside the tunnels may include prompt radiation associated with normal beam operation, radiation from activated materials, and prompt radiation due to transient beam faults. During beam operations, the SNS beam generates prompt radiation (primarily fast neutrons) due to local beam loss at discrete locations of the accelerator lattice. The relatively large ratio of physical apertures to nominal beam sizes, as well as the relatively narrow tuning range of most of the devices in the facility, limits credible fault of uncontrolled beam loss at any *single* point. Collimators are placed at strategic locations in the HEBT, the Ring, and the RTBT to control beam losses. Bulk shielding sufficiently attenuates the prompt radiation due to local beam losses to meet the defined classifications for areas adjacent to and nearby the beam enclosures. Dose rates due to transient excursions greater than this amount have been estimated by detailed calculation and, where necessary, are mitigated by additional shielding and/or radiation monitors (e.g., Fermilab style "Chipmunks" or equivalent) in the PPS system to help ensure the integrity of area classification (see also discussion in Sections 4.1.1.1 and 4.4.1.2). Depending on each area classification, associated access restrictions apply and training requirements are defined and provided for SNS personnel.

The prompt radiation level inside the tunnels can be high and hazardous during beam operation. However, this prompt radiation hazard is properly mitigated for workers outside the beam enclosure due to the presence of installed passive shielding in place and under configuration control (earth berm and/or additional shielding). Additional mitigating factors preventing personnel from receiving an unplanned dose include the use of the high integrity PPS. The PPS is used to restrict and/or to prevent access to the beam enclosure as a function of the state (or mode) of the accelerator (see Sections 3.2.3 and 4.2.3) and to interlock the beam to external radiation detectors and to movable shielding. PPS functions include locking and monitoring of all beam enclosure access doors, beam interlock functions, beam cutoff based on radiation monitors ("Chipmunks"), and (in order to ensure it is in place) interlocks on movable shielding deemed critical (see Section 4.2.1.2). The Machine Protection System (MPS) has several means of monitoring beam acceleration and transport and provides an additional beam interlock if the facility is not operating properly. Administrative controls play a significant role in the safe operation of any accelerator facility, including the SNS. As with other facilities of this type, a strong emphasis on integrating safety into every aspect of the workplace is part of the training and procedures. These combine to make this risk extremely low.

Table 4.3.1-1 summarizes the hazard evaluation for workers inside the beam tunnel; it concludes that the PPS tunnel access control and beam interlock functions are credited engineered controls. Table 4.3.1-2 summarizes the hazard evaluation for prompt radiation exposure to workers outside the beam tunnel due to beam spill events inside the tunnel. It considers both the general case of a worker at the worst location on top of the earthen berm as well as the absolute worst case for the unlikely event that a worker is standing in front of an unshielded tunnel-to-Ring Service Building penetration at the same time a full power beam spill occurs in the tunnel adjacent to the same penetration for a sustained period of time. For the case of a worker outdoors, multiple layers of protection, inherent as well as engineered, provide a high degree of protection against excessive radiation exposure due to proton beam spill incidents without the need to designate a credited control. By contrast, the high dose rates at worst case locations in front of unshielded penetrations in potentially occupied areas in the Ring Service building (or the similar locations at the high energy end of the Klystron Building) require that the PPS beam cut-off based on chipmunk-based radiation alarm signals be designated as a credited engineered control. See Section 4.4.1 for additional discussion of postulated beam spill events.

Access control combined with massive shielding protects workers from prompt radiation associated with beam production. Should shielding be inadvertently removed or altered such that it no longer provided sufficient shielding, workers could potentially be exposed to excessive levels of radiation. Section 4.2.1.2 addresses hazards and controls associated with moveable shielding. Table 4.3.1-6 summarizes the qualitative analysis of risks associated with the inadvertent removal of shielding and finds that the risk is adequately addressed by provisions of the ORNL Radiological Protection Program and defense in depth items listed in the table.

Activated structural materials create a residual radiation level inside the tunnel that is an ALARA consideration for personnel who must access the tunnel. Numerous locations within the beam enclosures have residual activation. Controlling and immunizing worker exposure to activated components is well managed as part of the ORNL Radiological Protection SBMS Management System.

When RF power is delivered to the LINAC structures, the x-ray hazard in the LINAC beam enclosure can create a High Radiation Area. Compared to the radiation levels present in the tunnel when the proton beam is on, the x-ray hazard is low. Therefore, consistent with requirements for a High Radiation area, access to the LINAC or HEBT is restricted during RF System Operation. Due to the potential x-ray hazard, as well as anticipated residual activity in most of the SNS beam enclosures (after normal operation), these areas are locally shielded and access controlled. The PPS prevents power to the RF supplies (klystrons) when the tunnel is open for worker access. In the Klystron Gallery, the klystrons generate x-ray radiation but shielding is installed to ensure nearly full attenuation of the source term.

Non-ionizing radiation. With regard to potential sources of non-ionizing radiation, the waveguides between the klystrons and the LINAC accelerating cavities could become a hazard if opened while under power. For both concerns, there are strict configuration control policies in place for all operating modes as well as prominent postings of possible hazards where required. Class IV lasers are in service in Proton Facilities (currently in the front end building, LINAC Tunnel and HEBT service building); they are controlled and used in accordance with ORNL SBMS requirements.

4.3.1.1.1 Front End

Most of the electrons extracted together with the negative ions are steered towards and intercepted by the e-dump, which is kept at a positive voltage in the range of 2 to 7 kV with respect to the source body. Depending on this voltage, the extractor voltage, and the state of cesiation, a fraction of the electrons miss the e-dump and most impact on the e-target; mounted on the extractor. A few appear to miss the extractor and impact on the vacuum enclosure. The impact energies between 65 and 85 kV can cause a radiation field in excess of about 1 mrem/hour. This is not a significant hazard but is mitigated, as needed, with lead shielding to minimize worker exposure in accordance with ALARA.

With a maximum beam energy of ~2.5 MeV in the MEBT, there may be a measurable dose rate (e.g., from the p-Cu65 and p-Ti interactions) if the beam is mis-steered onto any copper structure. In addition, there may be beam loss resulting in prompt radiation controls and/or local shielding required in the area. A measurable neutron dose rate has been observed near the MEBT rebuncher in an occupied area due to p-n reactions in copper at 2.5 MeV. In addition, localized gamma dose rates of up to 80 mrem/h have been found in the MEBT rebuncher area. Radiological surveys are performed regularly to document conditions and the area is posted appropriately for the measured conditions.

Radiation hazards associated with test stand(s) that may be operated in this area are similar or lesser than the operational ion source equipment and are operated in accordance with the same radiation safety and ALARA requirements.

4.3.1.1.2 Warm LINAC

The normal conducting (warm) LINAC structures are composed of a DTL, which accelerates the beam to ~87 MeV, followed immediately by a CCL, which further accelerates the H^- beam to ~186 MeV. In both types of LINAC structures, the primary loss points of concern are those located adjacent to penetrations in the bulk shielding for RF waveguides and utilities. These have been properly estimated for packing factors (cables, water lines, etc.) and the attenuation factors for prompt radiation calculated (as a function of beam energy).

4.3.1.1.3 Superconducting LINAC (SCL)

These two SCL structures have geometric beta (i.e., relative-phase velocity) design fixed at beta = 0.61 (accelerating the beam to ~330 MeV) and beta = 0.81 producing a final beam energy at the end of the LINAC of ~1.0 GeV. Transverse focusing of the beam is provided in normal (warm) conducting straight sections throughout the SCL; these are locations where beam loss (if any) is most likely to occur. The same concerns noted for the warm LINAC structures also apply in these cases. Once again, the penetrations have been carefully evaluated and potentially occupied areas adjacent to these beam enclosures appropriately classified.

4.3.1.1.4 Ring and Transport Lines Beam Dumps

Hazards of beam dumps located outside the tunnels are analyzed in Section 4.3.2. The off-momentum beam stop is located inside the HEBT Tunnel, and it has a design very similar to the collimators. Similar to the collimators it is provided with local shielding to minimize the radiation field in the tunnel when workers access the tunnel after beam operation. The HEBT off-momentum dump is water cooled and designed to operate at 5 kW or less. The beam line connecting to the off-momentum beam stop is equipped with a collection of beam current transformers (BCTs), beam loss monitors (BLMs) and thermocouples within each beam dump. Some of these diagnostics are used as inputs to the MPS to remove the beam permit (inhibit the beam) if potentially damaging beam conditions occur. In addition, interlocking radiation monitors (e.g., Fermilab-style "Chipmunks") are placed outside the beam enclosures to detect significantly elevated radiation levels.

4.3.1.1.5 HEBT, Ring, and RTBT

These beam areas have essentially all the diagnostic capabilities (and mitigation methods) listed for the beam dumps. Additional interlocking Chipmunks are placed over areas where losses may be expected (such as Injection, Extraction, and the Ring collimators), as well as at the access points to these beam enclosures.

4.3.1.1.6 RF Test Facility

Conditioning of superconducting cavities takes place in the shielded cave in the RF Test Facility. The conditioning is a controlled process that has the potential to create a high radiation area due to X-ray production. For this reason an access control interlock system equivalent to the PPS, but implemented separately for this facility, is provided. Although the radiation hazard is lower than the radiation hazard in the accelerator tunnel, the test cave access control interlock system is designed and maintained in a similar fashion as the PPS. The RF test cave access control interlock system also provides oxygen deficiency monitoring for the cave with audible and visible alarms in the event that low oxygen is detected due to an inadvertent helium release in the cave (see also Section 4.3.1.5).

Modules being tested and evaluated in the test cave are considered to be R&D devices, and radiation generating device (RGD) requirements do not apply. Per the requirements of the RF Test Facility RSS, the PPS-equivalent protection system is certified annually and meets the physical control requirements for high and very high radiation areas detailed in 10 CFR 835.502. The test cave facility will not be operated unless the access control interlock system is fully functional and in certification.

4.3.1.2 Electrical Hazards

As indicated in Section 4.2.4, the SNS design requires the power supply connections to certain tunnel magnets to have exposed connectors. Table 4.3.1-5 summarizes the hazard analysis for exposed conductors in the tunnel, documenting the SNS implementation of ORNL SBMS electrical safety requirements. Access to these areas is granted to personnel who have the proper training, who plan the work to be done, and who follow procedures for LO/TO and/or working hot in accordance with the SNS OPM. The PPS automatically de-energizes the power supplies in a given area during access, except the Controlled Access-Magnets Energized Mode allowed by the PPS. This controlled access mode allows access for trained personnel to certain enclosures with electrical equipment energized.

All electrical maintenance/surveillance, etc., electrical hazard to SNS personnel doing the work or working in the area is controlled to meet the requirements of the ORNL SBMS Electrical Safety subject area.

4.3.1.3 Magnetic Hazards

In a few instances, it may be necessary to work near magnetic elements while powered. Appropriate control over access modes and training requirements address these concerns for high magnetic fields (see discussion in Section 4.2.4, “Electrical Safeguards”). In addition, procedures note that nonferrous materials must be used for work around elements with a high magnetic field, both for the protection of the worker and to eliminate the possibility of damage to equipment.

4.3.1.4 Fire Hazards

Fire is a standard industrial hazard controlled through the ORNL SBMS Fire Protection, Prevention and Suppression Subject Area. SNS implementation of NFPA codes is discussed in Section 4.2.12.

4.3.1.5 Oxygen deficiency hazard (ODH)

The large quantity of cryogenic inert gases needed for operation of the superconducting LINAC present an ODH in the LINAC and CHL. Tables 4.3.1-3 and 4.3.1-4 summarize the hazard evaluations for ODH in the LINAC tunnel (helium) and in the CHL building (helium and nitrogen). Table 4.3.1-3 illustrates the risk evaluation for workers in three different locations. The X1 worker is assumed to be in the SCL part of the LINAC, directly adjacent to a large break or leak of cryogenic helium. Escaping without serious injury would require the X1 worker to see and promptly flee the visible fog cloud accompanying any such large leak. The oxygen monitoring and alarm system would not necessarily be of help to a worker in the immediate vicinity of the large leak because a non-evacuating worker could be overcome before the ODH system initiates the audible and visible alarms. By contrast, the X2 workers are assumed to be some distance from the break. X2 workers could be severely injured in the unmitigated case but the assigned frequency is lower because that would require an extended large leak that, essentially, fills the tunnel, an extremely unlikely occurrence. The potentially larger consequence (i.e., possibly affecting multiple workers), is easily mitigated by the ODH alarm system that would warn workers to evacuate (or not to enter) the LINAC. See Section 4.4.2 for a discussion of the SNS approach to ODH safety and hazard analysis. The oxygen monitoring and alarm systems (i.e., one for CHL and one for LINAC) are described in Section 3.2.3.11.

Worker X3 occupies either the Front End Building, tunnel regions outside of the LINAC. The postulated accident sequence involves a long term helium release that occurs in the LINAC tunnel when the tunnel is not in beam permit and the central control room (CCR) is unoccupied. Although it has been SNS policy to continually man the CCR, it is conceivable that there might be times when all beam related operations are terminated and the CCR becomes unmanned for some period of time. The sustained release of He into the LINAC tunnel could potentially cause oxygen deficiency not only in the LINAC tunnel but also in the adjacent front end building and the remaining areas of the tunnels. The LINAC tunnel is protected by the LINAC ODH system; however, no such protection is provided in the Front End Building or remaining portions of the tunnel. Should such a postulated sustained release occur, workers in the Front End Building or remaining portions of the tunnel could be at risk of ODH exposure (see Appendix F). The EVS is credited with preventing oxygen deficiency in these adjacent areas by routing the inadvertently released helium directly to the outdoors. The EVS does not require a credited backup power system in the event of a loss of power scenario because loss of site power is not an initiating event for a long term helium release. The probability that an undetected randomly occurring helium release in the LINAC occurs concurrently with a loss of offsite power and that a worker enters the affected zone(s) is considered beyond credible. The LINAC ODH system monitors power to the EVS and provides a warning should power be lost.

As described in Sections 3.2.1.4, 3.2.3.11, and 4.4.2.2, two rooms within the CHL present ODH hazards. The Cold Box Room utilizes liquid nitrogen to cool the helium. Liquid nitrogen or helium accidentally released would have the potential to cause very low O2 concentrations inside the cold box room which could be dangerous for entering workers. The room is fitted with O2 sensors with warning alarms and with blue light warning stations at the entrance door (see Section 3.2.3.11). The relative ODH hazard in the Compressor Room is far less because helium in the compressor room is non-cryogenic, very buoyant. If released, the He would flow by natural circulation out the ceiling vents, with the large outdoor air inlets (6, 3 on the north side and 3 on the south side) letting outdoor air in to replace the helium-air mixture flowing out the ceiling. [Note: The basic design purpose of the compressor room air inlets is to provide an abundant flow of outdoor air for removal of compressor heat by natural circulation.]

Activities in the RFTF have an ODH when cryogenic helium is piped into the RF test cave for conditioning of cryomodules, which occurs periodically. An inadvertent leak of helium into the test cave could result in decreased oxygen concentration in the cave. The scale of a potential helium release in the RFTF cave is small compared to potential releases described above for the LINAC and CHL. An ODH system is provided for the RFTF and is designed and maintained in a similar fashion as the ODH system used to protect the LINAC. ODH hazards associated with the RFTF are safely managed under the provisions of the SBMS which requires a Research Safety Summary (RSS). Appropriate layers of safety for workers entering the cave when He is present such as:

- Appropriate Training (includes cryogenic fluid hazards and “see and flee” recognition and response of possible inadvertent helium leakage).
- ODH Monitoring and Alarms - The test cave oxygen deficiency monitoring and alarm system shall be functional (unless a compensatory provision, such as a portable oxygen monitor is used).

Table 4.3.1-1
Qualitative Risk Assessment for
Prompt Radiation inside the Proton Beam Enclosures

FACILITY NAME: SNS Accelerator Systems NUMBER: AS-1
SYSTEM: Beam Enclosures
SUB-SYSTEM: LINAC, HEBT, Ring, RTBT
HAZARD: Prompt Radiation (Proton Beam) Inside Beam Enclosures

Event	Person inside enclosure during proton beam operation.
Possible Consequences, Hazards	Personal injury or death due to prompt radiation associated with the proton beam. Worker dose could exceed 25 rem.
Potential Initiators	Person enters enclosure inadvertently; person(s) fail to leave before beam initiated.

Risk Assessment Prior to Mitigation

Note: Refer to Figure 4.1.1-1 for an explanation of consequence, frequency, and risk levels. "Low" and "Extremely Low" risk levels are considered acceptable.

Consequence:	( ) High	(X) Medium	( ) Low	( ) Extremely low
Probability w/o mitigation:	( ) Anticipated High	(X) Anticipated Medium	( ) Unlikely	( ) Extremely Unlikely
Risk Category:	( ) High Risk	**(X) Medium**	( ) Low Risk	( ) Extremely Low

Does the hazard require a Credited Control per Section 4.1.2? Y/N Yes

Hazard Mitigation	1. PPS access control and automatic beam cut off on access violation (CREDITED). 2. Accelerator operations procedures. 3. Worker training (e.g., tunnel access and sweep training). 4. PPS beam-on warning lights outside entrances. 5. Tunnel sweep procedures performed only by trained, qualified persons. 6. PPS features that support conduct of administrative sweep 7. Repeated audible and visual warnings initiated by PPS inside the tunnel before initiation of proton beam allow any remaining un-swept person sufficient time to evacuate or actuate a PPS manual beam shutdown station before the beam starts.

Risk Assessment Following Mitigation

Consequence	() High	(X) Medium	( ) Low	( ) Extremely low
Probability	( ) Anticipated High	( ) Anticipated Medium	( ) Unlikely	(X) Extremely Unlikely
Risk Category	( ) High Risk	( ) Medium	( ) Low Risk	**(X) Extremely Low**

Table 4.3.1-2
Qualitative Risk Assessment for
Prompt Radiation outside Proton Beam Enclosures

FACILITY NAME: SNS Accelerator Systems NUMBER: AS-2
SYSTEM: Areas Outside Beam Enclosures
SUB-SYSTEM: LINAC, HEBT, Ring, RTBT
HAZARD: Prompt Radiation (Proton Beam) Outside Beam Enclosures

Event	Sustained full power beam spill
Possible Consequences, Hazards	Radiation levels above 10 CFR 835[4-5] allowed levels, possible excessive worker exposures, or worker exposures not ALARA. If sustained beam spill adjacent to unshielded penetration, worker located at the penetration could receive exposure exceeding 25 rem.
Potential Initiators	Failure of magnet or magnet power supply.

Risk Assessment Prior to Mitigation

Note: X1 location is a worker at a worst case location on top of the berm. X2 location is a worker in front of a penetration inside the ring service building or high energy end of the LINAC.

Consequence	( ) High	(X2) Medium	(X1) Low	() Extremely low
Frequency	() Anticipated High	(X1, X2) Anticipated Medium	( ) Unlikely	( ) Extremely Unlikely
Risk Category	( ) High Risk	(X2) Moderate	**(X1) Low Risk**	( ) Extremely Low

Does the hazard require a Credited Control per Section 4.1.2? Y/N Yes (for X2 location)

Hazard Mitigation	1. PPS Chipmunk-based automatic beam cutoff on high radiation for Chipmunks that protect accessible areas near tunnel penetrations where excessive dose potential exists. (CREDITED) 2. Beam information display alerts operator to take action upon indication of significant beam loss. 3. Operations personnel training. 4. Automatic beam monitoring and control. 5. MPS monitoring of beam loss and successive beam current monitors; the MPS removes the beam permit if these devices detect the beam is outside of the nominal operating range. 6. Localized beam spill at high beam power would tend to cause failure of beam tube boundary with subsequent loss of beam tube vacuum, effectively cutting off the beam. 7. Low occupancy of spaces directly in front of tunnel penetrations.

Risk Assessment Following Mitigation

Consequence	( ) High	( ) Medium	(X2) Low	(X1) Extremely low
Probability	( ) Anticipated High	( ) Anticipated Medium	( ) Unlikely	(X1&X2) Extremely Unlikely
Risk Category	( ) High Risk	( ) Moderate	( ) Low Risk	**(X1&X2) Extremely Low**

Table 4.3.1-3

Qualitative Risk Assessment for Oxygen Deficiency Hazard in the LINAC Tunnel

FACILITY NAME: SNS Accelerator Systems NUMBER: AS-3
SYSTEM: SC LINAC Tunnel, CHL Facility
SUBSYSTEM: Cryogenic Helium System, SC LINAC
HAZARD: Oxygen Deficiency

Event	Helium release inside tunnel
Possible Consequences, Hazards	Insufficient oxygen, lung damage, unconsciousness, death possible for worker in immediate area of the release (and enveloped in the nearby cryogenic helium cloud). For sustained release, widespread oxygen deficiency is possible. Oxygen deficiency is possible in the LINAC and adjacent spaces (Ring, Front End).
Potential Initiators	Boundary failure, excess pressure, maintenance error

Risk Assessment Prior to Mitigation

Note: In table below X1 refers to a worker in the tunnel directly adjacent to a large break and X2 refers to multiple workers at a distance from the break. Worker X3

Consequence	(X2) High	(X1,X3) Medium	( ) Low	( ) Extremely low
Frequency	( ) Anticipated High	(X1) Anticipated Medium	(X2,X3) Unlikely	() Extremely Unlikely
Risk Category	( ) High Risk	**(X1,X2,X3) Medium**	() Low Risk	( ) Extremely Low

Does the hazard require a Credited Control per Section 4.1.2? Y/N Yes

Hazard Mitigation	1. Automatic initiation of LINAC Tunnel Emergency Ventilation on low oxygen signal (CREDITED to protect workers in Front End, or tunnel outside of LINAC) 2. ODH Oxygen sensor-based monitoring and alarm system warnings in the SCL and at entrances. (CREDITED) 3. Cryogenic system boundary integrity. 4. Process controls and alarms for the cryogenic system reduce probability of long, sustained release. 5. Cryogenic operations procedures and cryogenic/ODH hazard training. Access to areas with potential large-scale release is limited to personnel having training in signs of, and response to, cryogenic release (including see and flee response). 6. Training, LO/TO, operating procedures and/or JHA for cryogenic unit maintenance. 7. The placement of ceiling lintels help confine leaked helium to the superconducting section and vent it to the atmosphere.

Risk Assessment Following Mitigation

Consequence	(X2) High	(X1,X3) Medium	( ) Low	() Extremely low
Probability	( ) Anticipated High	() Anticipated Medium	(X1) Unlikely	(X2,X3) Extremely Unlikely
Risk Category	( ) High Risk	( ) Moderate	**(X1 & X2) Low Risk**	() Extremely Low

Table 4.3.1-4
Qualitative Risk Assessment for
Oxygen Deficiency Hazard in the Central Helium Liquefier Building

FACILITY NAME: SNS Accelerator Systems NUMBER: AS-4
SYSTEM: CHL Facility
SUBSYSTEM: Cryogenic Helium System
HAZARD: Oxygen Deficiency

Event	Helium release inside CHL Building cold box or compressor area; Nitrogen release in cold box room.
Possible Consequences, Hazards	Insufficient oxygen, lung damage, unconsciousness, death
Potential Initiators	Boundary failure, excess pressure, maintenance error

Risk Assessment Prior to Mitigation
Note: Refer to Figure 4.1.1-1 for an explanation of consequence, frequency, and risk levels. "Low" and "Extremely Low" risk levels are considered acceptable.

Consequence	( ) High	(X) Medium	( ) Low	( ) Extremely low
Frequency	( ) Anticipated High	(X) Anticipated Medium	( ) Unlikely	( ) Extremely Unlikely
Risk Category	( ) High Risk	**(X) Medium**	(X) Low Risk	( ) Extremely Low

Does the hazard require a Credited Control per Section 4.1.2? Y/N Yes

Hazard Mitigation	1. Cryogenic system boundary integrity. 2. Cryogenic operations procedures and CHL worker training. 3. For compressor room, side wall air inlet vents and roof-level exhaust vents are adequate to prevent overall room oxygen concentration from sinking to dangerous value except in immediate vicinity of the leak (CREDITED) 4. Training and LO/TO procedures and JHA for cryogenic unit maintenance. Access to areas with potential large-scale release is limited to personnel having training in signs of, and response to, cryogenic release. See and flee training for cryogenic discharges that create fog by condensing atmospheric moisture. 5. Automatic oxygen sensor-based ODH warnings in the Cold Box Room (CREDITED) 6. Automatic oxygen sensor-based ODH warnings in the Compressor Room. 7. Automatic initiation of ventilation exhaust fan in the cold box room for defense-in-depth.

Risk Assessment Following Mitigation

Consequence	( ) High	(X) Medium	( ) Low	( ) Extremely low
Probability	( ) Anticipated High	( ) Anticipated Medium	(**X**) Unlikely	( ) Extremely Unlikely
Risk Category	( ) High Risk	( ) Moderate	**(X) Low Risk**	( ) Extremely Low

Table 4.3.1-5
Qualitative Risk Assessment for the Accelerator
Exposed Conductors

FACILITY NAME: SNS Accelerator Systems NUMBER: AS-5
SYSTEM: LINAC, HEBT, Ring, RTBT
SUBSYSTEM: Magnets
HAZARD: Exposed Electrical Conductors in Region Accessible to Workers

Event	Worker contacts energized conductor
Possible Consequences, Hazards	Electrocution
Potential Initiators	Worker falls into, fails to control position of limbs or tools

Risk Assessment Prior to Mitigation

Note: Refer to Figure 4.1.1-1 for an explanation of consequence, frequency, and risk levels. “Low” and “Extremely Low” risk levels are considered acceptable.

Consequence	( ) High	(X) Medium	( ) Low	( ) Extremely low
Frequency	(X) Anticipated High	( ) Anticipated Medium	( ) Unlikely	( ) Extremely Unlikely
Risk Category	**(X) High Risk**	( ) Medium	( ) Low Risk	( ) Extremely Low

Does the hazard require a Credited Control per Section 4.1.2? Y/N No—hazard adequately addressed through the- ORNL SBMS electrical safety requirements.

Hazard Mitigation	1. Tunnel access training covers the restricted approach areas in HEBT, Ring, and RTBT, denoted by red lines on the floor in these areas, workers do not approach potentially energized exposed magnet power supply connections. 2. Work planning prior to performing the work to identify the possible hazard(s) and the corresponding mitigations. Per the ORNL SBMS Electrical Safety requirements, all maintenance/work on magnets requires standard LO/TO (i.e., work on magnets with exposed conductors does not rely on the PPS disconnect of power magnet power supply). 3. Most tunnel accesses occur with PPS in Controlled or Restricted Access modes, in which the PPS discontinues power supply to all magnets. A special PPS mode called Controlled Access-Magnets Energized is utilized when it is necessary to make a measurement with magnets energized.

Risk Assessment Following Mitigation

Consequence	( ) High	(X) Medium	( ) Low	( ) Extremely low
Probability	( ) Anticipated High	( ) Anticipated Medium	( ) Unlikely	(X) Extremely Unlikely
Risk Category	( ) High Risk	( ) Moderate	( ) Low Risk	**(X) Extremely Low**

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Table 4.3.1-6
Qualitative Risk Assessment for
Inadvertent or Unauthorized Removal of Radiation Shielding

FACILITY NAME: SNS Accelerator Systems NUMBER: AS-7
SYSTEM: Areas Inside and at the Boundary of Beam Enclosures
SUB-SYSTEM: LINAC, HEBT, Ring, RTBT
HAZARD: Prompt Radiation Outside Beam Enclosures

Event	Removal of necessary radiation shielding within or at boundary of beam enclosure resulting in excess radiation outside of the enclosure
Possible Consequences, Hazards	Passive shielding and inherent factors prevent any credible possibility of injury due to radiation exposure. 10 CFR 835[4-5] regulations regarding area designations could temporarily be violated for unmitigated event.
Potential Initiators	Personnel not following shielding configuration control policies and procedures.

Risk Assessment Prior to Mitigation

Consequence	( ) High	(X) Medium	() Low	() Extremely low
Frequency	() Anticipated High	() Anticipated Medium	(**X**) Unlikely	( ) Extremely Unlikely
Risk Category	( ) High Risk	( ) Moderate	(**X**) Low Risk	( ) Extremely Low

Does the hazard require a Credited Control per Section 4.1.2? Y/N No—Hazard adequately addressed by ORNL Radiological Protection Program and defense in depth items as listed below.

Hazard Mitigation	1. ORNL Radiological Protection Program 2. Heavy weight of critical shielding is an inherent safety factor helping prevent unauthorized removal of shielding. 3. Staff training on shielding configuration control procedures 4. Tailored approach to shielding control: a. Posting and Labeling of configuration controlled shielding. b. Painting the exterior of removable blocks aids in the identification of missing blocks c. Securing shielding to require removal by tooling d. PPS-interlocks for critical, movable shielding 5. Supervision of SNS Radiological Safety Officer, including use of RS Hold locks where appropriate. 6. Inspection tours by Operations Personnel while securing the beam enclosures and periodic surveys per ORNL SBMS Radiological Controls procedures 7. Chipmunk PPS-interlocked for beam cutoff.

Risk Assessment Following Mitigation

Consequence	( ) High	( ) Medium	(X) Low	( ) Extremely low
Probability	( ) Anticipated High	( ) Anticipated Medium	( ) Unlikely	(X) Extremely Unlikely
Risk Category	( ) High Risk	( ) Moderate	( ) Low Risk	**(X) Extremely Low**

4.3.2 BEAM DUMPS HAZARD ANALYSIS

Since the Ring Injection Dump is the only one of the 3 beam dumps with building rooms that are accessible by workers, this section applies primarily to the beam injection dump. This dump has a collection of common industrial equipment hazards including pressurized water and gas systems, electrical equipment, and some chemical processing equipment. The standard industrial hazards associated with this equipment are mitigated and minimized by following the appropriate ORNL SBMS standards relating to worker safety. The architectural and structural design of the buildings is in accordance with the appropriate sections of the *Standard Building Code, 1997* (SBC)[4-10] and the OSHA standards for workplace safety. Two aspects of the operation of the injection dump require additional explanation and may not be covered by normal industrial practices. Both of these situations, discussed below, are common to laboratories handling radioactive materials and energetic particle beams.

Operation of the beam dumps at powers significantly beyond the design capacity would significantly damage equipment and has the potential for releasing radioactive material into the environment where contact with SNS personnel is possible. This hazard has been identified and a risk assessment worksheet has been completed (see Table 4.3.2-1). The risk associated with this hazard is classified as low for both the unmitigated and mitigated situations.

Another related hazard is the failure of the Ring Injection Beam Dump cooling system. Even with the power at design levels, sustained operation with no cooling water flow would result in the same risk as the excessive power condition evaluated in Table 4.3.2-1. An MPS monitoring water flow, water temperature, thermocouples, and differential pressure is installed to protect the equipment. Appendix C addresses airborne radioactive material hazards involving the beam dumps (injection dump in particular), including spillage of activated cooling water, and concludes that the hazard is minor and no credited engineered controls are necessary. Direct radiation hazard due to spillage of injection dump cooling water is negligible because the dominant activation radionuclides are short-lived and spilling the water allows them to decay quickly.

The Ring Injection Dump is equipped with several different types of sensors to protect these areas. The passive dumps are equipped with thermocouples at the beam stop to protect the equipment. The access to the MPS inputs is restricted to qualified personnel. These inputs are bypassed only as described in the SNS OPM.[4-44]

The MPS instrument package installed to protect the beam dump and surrounding equipment consists of instrumentation such as loss monitors, current monitors, harps, and a number of sensors monitoring the dump. Any abnormality from these sensors causes the beam to turn off and alert operations to the fault. The loss monitors indicate a fault if the measured losses or radiation levels exceed a predetermined limit. The current sensors indicate a fault if the measured current difference from an upstream sensor and the current measured in the dump line exceed a predetermined limit. In addition, a monitor is used for the source to measure the duty factor of the beam. It is designed to inhibit beam if the source delivers more beam than the present operating mode of the machine allows. The harps give a measure of the charge distribution upstream of the window and dump and of the current at this device. This gives a fault indication if the current density increases beyond a predetermined limit. The sensors in the dump controls include temperature, flow, and pressure of the dump cooling system. Any parameters exceeding predetermined settings cause a fault and turn off the beam.

Normal operation of the Ring Injection Beam Dump involves production of ^{16}N and other radionuclides in the water-cooling loops and some radiolytic decomposition of the water. The decay tank is purged to maintain the gas space below the lower flammability limit ($\ll$4% H_2). This activated water emits a strong gamma radiation dose during beam operation and is contained in shielded piping runs inside the shielded utility vault. SNS personnel could be exposed to this radiation without the proper protection. This hazard is identified, and its evaluation is summarized in Table 4.3.2-2. The unmitigated risk associated with this hazard is classified as high because (1) the radiation level inside the vault during operations has not been measured, and (2) it is assumed that, with absolutely no administrative controls on vault access the exposure time could be significant. Access to the vault is controlled by a PPS interlock associated with the door that shuts of the beam if the door were opened during beam operation. The net effect of administrative controls and the PPS door interlock mitigates the consequences, and shifts the risk to extremely low. The PPS door interlock is designated a Credited Engineered Control. This designation may be revisited should future measured radiation levels indicate crediting is not warranted.

Table 4.3.2-1
Qualitative Risk Assessment for the Beam Injection Dump
Excessive Beam Power

FACILITY NAME: SNS Accelerator NUMBER: BD-1
SYSTEM: Beam Dumps
SUB-SYSTEM: All
HAZARD: Excessive Beam Power

Event	Proton beam energy or currents that exceed the design limits (or failed cooling system)
Possible Consequences and Hazards	Damage beam stop, potential release of activated materials
Potential Initiators	Failure of the magnet control system, failure of the beam diagnostics system, failure of the cooling system

Risk Assessment Prior to Mitigation

Note: Refer to Figure 4.1.1-1 for an explanation of consequence, frequency, and risk levels. "Low" and "Extremely Low" risk levels are considered acceptable.

Consequence	( ) High	( ) Medium	(X) Low	( ) Extremely Low
Probability	( ) Anticipated High	(X) Anticipated Medium	( ) Unlikely	( ) Extremely Unlikely
Risk Category	( ) High Risk	( ) Moderate	**(X) Low Risk**	( ) Extremely Low

Does the hazard require a Credited Control per Section 4.1.2? Y/N No

Hazard Mitigation	1. Even with no mitigation, the high power beam would simply heat the beam stop and melt the beam stop materials. The full power beam would quickly melt the vacuum window, and the helium from the enclosure would backfill into the proton beam tube. Any molten materials would drop out of the beam into the cavity below. The water-cooling system would be melted and open to the helium atmosphere in the beam stop enclosure. This would add water vapor to the helium in proton beam tube. With the accelerator beam tubes filled with helium and water vapor (instead of high vacuum), the beam would shut down and energy deposition at the beam stop would cease. The helium in the enclosure is normally exhausted to the HOG system, and it would contain any water vapor. 2. For these reasons, it is unlikely there would be any exposure to vaporized activated materials by SNS personnel or the general public. 3. For equipment protection the magnet control system is designed with high-integrity lockouts that prevent excessive power beams from striking the beam dump. 4. For equipment protection in the case of a cooling system failure, the cooling system flow rates, differential pressures, and temperatures are monitored and alarmed. In the case of the injection dump, the MPS provides a high-integrity lockout when cooling-water flow is lost.

Risk Assessment Following Mitigation

Consequence	( ) High	( ) Medium	(X) Low	( ) Extremely Low
Probability	( ) Anticipated High	( ) Anticipated Medium	(X) Unlikely	( ) Extremely Unlikely
Risk Category	( ) High Risk	( ) Moderate	( ) Low Risk	**(X) Extremely Low**

Table 4.3.2-2
Qualitative Risk Assessment for the Beam Injection Dump Personnel Radiation Exposure

FACILITY NAME: SNS Accelerator NUMBER: BD-2
SYSTEM: Beam Dumps
SUB-SYSTEM: All
HAZARD: Personnel Radiation Exposure

Event	Person inside injection dump utility vault during full power beam operation
Possible Consequences & Hazards	Radiation levels in the utility vault are, in absence of radiation survey results inside the vault, assumed to be high enough to lead to health effects for credible exposures.
Potential Initiators	Workers access the utility vault during full beam power operation

Risk Assessment Prior to Mitigation

Consequence	( ) High	(X) Medium	( ) Low	( ) Extremely low
Probability	(X) Anticipated High	( ) Anticipated Medium	( ) Unlikely	( ) Extremely Unlikely
Risk Category	**(X) High Risk**	( ) Moderate	( ) Low Risk	( ) Extremely Low

Does the hazard require a Credited Control per Section 4.1.2? Y/N Yes

Hazard Mitigation	1. The PPS controls access to the utility vault and provides an automatic proton beam cutoff for unauthorized access to the vault during beam operation. (Credited) 2. ORNL Radiological Protection Program, including RWP access control and posting of radiological areas as required. 3. Work procedures and worker training Note: this assessment may be revisited if and when radiation survey results inside the vault become available.

Risk Assessment Following Mitigation

Consequence	( ) High	() Medium	( ) Low	(x) Extremely low
Probability	( ) Anticipated High	( ) Anticipated Medium	( ) Unlikely	(X) Extremely Unlikely
Risk Category	( ) High Risk	( ) Moderate	( ) Low Risk	**(X) Extremely Low**

4.4 ACCIDENT ANALYSIS

4.4.1 MAXIMUM CREDIBLE FAULT BEAM SPILL

The SNS accelerator is designed to produce and transport, essentially undiminished to the Target, a beam of pulsed high-energy protons. The many devices in the LINAC, HEBT, Ring, and RTBT are designed to accelerate, accumulate, focus, and shape the beam pulses with only very small losses to ensure that a maximum number of protons reach the target. A failure of one or more of the accelerator beam conditioning devices could result in misdirection of some fraction of the beam so that it impacts the beam tube and surrounding structures inside the beam enclosure. A maximum *credible* fault would be one that produces the greatest beam loss for the longest period of time without transcending the realm of plausibility. A further stipulation for the present discussion is that the loss be such as to cause elevated radiation levels in area(s) that could be accessed by workers. This section discusses faults that could cause beam spill, provides bounding dose rate estimates for beam spill accidents, and demonstrates that a combination of inherent factors and automatic control features yield a negligible mitigated hazard.

4.4.1.1 Fault Mechanisms

During beam operations, the SNS generates prompt radiation due to local beam loss at discrete locations of the accelerator lattice. The relatively large ratios of physical apertures to nominal beam sizes, as well as the relatively narrow tuning range of most of the devices in the facility, result in very low normal losses. Various equipment faults could allow this ideal situation to degrade. Four types of failure scenarios are presented below: (1) magnetics failure; (2) RF failure; (3) control system failure; and (4) human error.

1. Magnetics failure. The failure of the magnetics system to remain at the correct value for beam transport due to possible failure of a magnetic element, the power supply, the control system, or human error leads to unintended beam loss.

   The ratio of the “operating beam emittance” to the physical acceptance is relatively small once the beam is accelerated beyond the Cu structures. This means that the likelihood of an “off-momentum” and/or “off-trajectory” particle being lost within superconducting accelerator structure or beam transport sections, other than at collimator locations, is quite small. Once lost, that portion of the beam can no longer be lost elsewhere. This is also true in the Ring due to the fact that the collimator acceptance is less than the dynamic aperture of the circulating beam.

With only a few exceptions the magnetic elements of the SNS are constructed using solid core iron yokes; therefore, due to large eddy currents, the magnetic field rise (and fall) time is large (effective persistence of the magnetic field) compared with the nominal beam pulse width of 1 ms. This inherent physical characteristic ensures that the beam control system and MPS are highly likely to stop beam production before a significant portion of the beam can stray out of the beam tube.

The MPS is a protection system designed to prevent damage to and excessive irradiation of accelerator system components. One MPS system designed specifically for this purpose is the Beam Loss Monitor System. The Beam Loss Monitor System consists of approximately 260 ion chambers distributed around the LINAC, Ring, and beam transport lines. These ion chambers detect beam loss by detecting the secondary particles from lost beam interactions. Predetermined and experimentally measured loss limits are used to set the maximum acceptable losses allowed by the Beam Loss Monitor system. The MPS is designed to prevent the beam from doing damage to equipment and is designed to detect faults and to interrupt the beam very quickly, in many cases within 20 µs. The Beam Loss Monitor system is designed to truncate the beam pulse train in mid pulse, count down the repetition rate of the accelerator or turn it off depending on the severity of the beam loss. Additionally, the MPS system is used to detect current failure in a number of critical beam isolation magnets via PLC analog input modules. The MPS is described in Section 3.2.2.3.

Other magnetic systems failures are detected and reported via the EPICS control system. The anticipated response time of the EPICS control system fault detection is one second. See Section 3.2.2.2 for an explanation of the relationship between the PPS, the MPS, and the EPICS-based supervisory control system. The PPS is described in Section 3.2.3.

As part of the commissioning process, the shielding attenuation factors were verified throughout the SNS Accelerator Facility using the beam in controlled studies at low average intensity (fault studies).

2. <u>RF system failure</u>. Failure of the RF system leads to the inability of the accelerator system to deliver the full energy of the beam. The most serious of these losses, from an occupational exposure standpoint, may prove to be loss of RF in the first DTL section. Loss of RF phase or amplitude leads to complete loss of beam in the first DTL section. The MPS monitors these systems and takes the appropriate action.

3. Control systems failure. Control systems failures are assumed to have the same consequences as magnetics or RF system failures.

4. Human/management system error. Failures due to human error are assumed to have the same consequences as magnetics or RF system failures.

4.4.1.2 Doses outside Enclosures during Normal Operation and Maximum Credible Fault

Doses outside the beam enclosures during normal beam operation are within the regulatory limits set by 10 CFR 835,[4-5] including the application of ALARA. The areas immediately outside the beam enclosures, including the large area of the top and side of the earth berm may be posted as Controlled or Radiation Buffer areas should the need arise. The top and sides of the earth berm are not routinely occupied. Personnel inhabit these areas only for specified tasks. As discussed in Section 4.2.1, normal radiation levels have been calculated to be in the neighborhood of 0.25 mrem/h for most areas outside the tunnel shielding, with higher levels above the relatively small number of components that have higher expected steady state losses, such as collimators. Radiation dose rate measurements at near-design power levels typically find no measureable radiation in occupied areas adjacent to proton facility beam tunnel enclosures.

Radiation levels go up outside beam enclosures during significant localized beam spills as the accelerated charged particles strike the beam tube and surrounding structures. The situation is inherently a transient one. For example, it takes time for actual beam loss conditions to occur (e.g., as explained above, loss of magnetic flux does not diminish instantly following power supply loss). Several mitigative factors serve to minimize the impact and duration of a high power localized beam spill including:

1. Beam loss monitors tied to the MPS system are designed to interrupt the beam in a time frame less than that of a single pulse.
2. An inherent physics-based protection against the most severe beam spills is that a highly localized beam loss at high beam power would cause failure of the beam tube’s vacuum boundary thus inhibiting beam.
3. If such a beam spill were to occur in the superconducting portion of the LINAC, beam loss, resulting in heating of the niobium structure would lead to beam shutdown through the MPS via the LINAC Vacuum and RF systems in addition to the Beam Loss Monitors
4. Control room indications provide the operator with timely warnings of significant beam problems allowing the operator to shut the beam down in a controlled fashion. It is

speculated that 10 minutes is a plausible maximum time that such a condition could exist without operator intervention.

5. Since such a spill would be localized by its nature, the probability that an individual occupies the area adjacent to the spill at the exact same time that the spill occurs is small.

Calculations have been completed for a range of highly unlikely, worst case beam faults. Each of these faults would be highly unlikely because of all the simultaneous failures that would have to take place concomitantly. The results provide bounding estimates of accident related radiation dose rates outside the enclosures by making highly improbable assumptions that:

- the entire beam at full 2 MW nominal evaluation power is lost instantaneously at one location; and
- the misdirected beam continues in its misdirected path, regardless of:
  - the effect of a localized high power beam loss on the beam tube integrity;
  - the automatic beam trips; and
  - the action of Operations personnel.

The purpose of these calculations is to provide sufficient quantification to allow hazard analysis to be completed and mitigation adequacy to be evaluated. The calculations were done for the LINAC, HEBT and Ring portion of the accelerator because this is where one could, under the hypothetical assumptions made above, plausibly postulate localized loss of a large fraction of the beam. Two basic failure geometries were investigated:

1. Failure of turning magnets such that the spilled beam exits the beam tube in a tangential path toward the tunnel side wall without passing through any other major structures before hitting the sidewall (Note: These magnets are monitored by the MPS.)
2. An unspecified failure in which the beam hits a major structure (assumed to be a dipole in this case) close to the middle portion of the tunnel

The results bracket the instantaneous radiation dose rate at the worst point on top of the shielding berm at about 1 rem/h for the first case and at about 20 rem/h for the second case. The longer length of shielding berm through which the radiation has to travel explains the lower results for the first case. For workers in the Klystron Gallery, penetrations to the LINAC tunnel provide a path for streaming radiation should a full power beam spill occur in the tunnel adjacent to the penetrations. The streaming path is attenuated by a combination of shielding strategies that include backfilling of the penetrations with polybeads and the placement of concrete shield blocks at the penetrations in the klystron gallery. Resulting worst case accident dose rates in very localized areas of the klystron gallery at the penetrations are estimated at 85 R/hr.[4-62, 4-65]

For workers inside the ring service building (which is not routinely occupied) the range was from about 3 rem/h (general area) to about 1000 rem/h directly in front of an unshielded penetration.[4-62] The calculations indicate that a localized full beam spill could result in significant radiation exposure to an individual in the unlikely event that the individual were standing at the unshielded penetration at the same time a full beam spill occurred in the tunnel adjacent to the same penetration, and that the spill persisted for an extended period of time. The range of dose rates is non-negligible from a hazard analysis perspective, so the adequacy of mitigating factors is evaluated below.

Utilizing the methods presented in Section 4.1, we see that doses in the potentially injurious range, i.e., greater than 25 rem, are not feasible for workers outdoors on the berm or in the general areas indoors due to the preponderance of mitigating factors (multiple layers of protection), any one of which would bring the maximum dose down by at least an order of magnitude below the threshold for designating credited controls.

By contrast, workers at worst case locations inside the Ring Support or Klystron Building could receive a worst case accident dose exceeding 25 rem assuming that the beam tube can survive a sustained 2 MW beam spill and that no automatic controls function to terminate the beam spill. Consequently, it is concluded that a Credited Control is necessary to control risk to a worker standing near the unshielded penetrations where excessive accident condition radiation dose is possible. The network of Chipmunk-based radiation detectors (see Section 4.2.2.2) connected to the PPS, including those positioned to protect locations where excessive accident condition radiation dose rates are possible in the Ring Service and Klystron Buildings are designated as Credited Engineered Controls. If the radiation level increases to designated set points above the routinely expected levels, the PPS alarms and automatically cuts off the proton beam.

Table 4.4.1.2-1 presents personnel doses associated with the worst case beam spill scenarios postulated above assuming that mitigation is provided by the designated control. Doses shown in the table indicate that mitigated doses are below 10 CFR 835 limits.

Table 4.4.1.2-1

Mitigated Doses To Worst Case Individual—Maximum Beam Spill

Approximate bounding dose received at worst locations given that only one physical phenomenon or device functions.

Device or Phenomenon	Time Required	Total Dose at Worst Point Berm Surface	Total Dose at Worst Point Unshielded Penetration
MPS	2 machine pulses	Negligible	Negligible
PPS chipmunk-based beam trip	~2 sec	~11 mrem	~550 mrem
Errant beam heats beam tube wall, which fails, spoiling the vacuum and, thus, stopping the beam	See note below[a]	See note below[a]	See note below[a]

[a]It is speculative to estimate the time required since many factors would be involved; however, for a point loss it would be very rapid—at full or high beam power, it would be on the order of seconds. Even for a point loss, the spill would, of course, not become localized until decay of turning magnet flux, which takes a few seconds. For a variety of glancing or diffuse beam spills, the beam tube integrity might not be compromised, but such spills would have lower peak dose rates than the point losses evaluated above.

We see that any one of the control actions or physical phenomena would prevent exposures from causing radiation injury. Therefore, even if an individual worker is located at the worst spot on the berm surface, their risk of radiation injury would be low, even for the beyond-credible events examined. Occupancy of the berm exterior is low because of the small number of tasks that require berm access. Similarly, occupancy of the Klystron Gallery and Ring Service Building during beam operations is intermittent.

4.4.2 SNS APPROACH TO ODH SAFETY AND HAZARD ANALYSIS

4.4.2.1 ODH Safety of SNS Facility Designs

Cryogenic systems in the SCL and CHL have a recognized ODH. The way this hazard was handled in conceptual and preliminary design was to team with the JLab as a partner laboratory. JLab scientists and engineers worked with SNS to finalize the designs that are closely based on the JLab cryogenic systems design that has been proven effective over the past decade. Through the course of design, commissioning and operation of the CEBAF, the JLab personnel completed hazard analysis, held extensive reviews, and have conducted large-scale helium spill tests in the CEBAF LINAC Tunnel utilizing the actual LINAC cryogenic helium system. The tests conducted in the CEBAF beam enclosure showed that the extremely cold liquid helium spilled in the tunnel vaporizes quickly, readily becomes buoyant (and visible due to condensed moisture), and flows out the vents that are placed in the tunnel ceiling inside the partial height lintels.

The SNS has utilized computational fluid dynamics (CFD) modeling to study the movement of accidentally released helium and the resulting oxygen displacement as part of its comprehensive hazard analysis process. CFD modeling supports the findings of the CEBAF spill tests and has aided in the formation of *Safety for Cryogenic Operations at SNS* (see Appendix D). The SNS design includes vent paths in the tunnel ceiling that vent locally at an elevation above the berm. Based on CEBAF designs, both active and passive ventilation features are provided in the CHL Building. The SNS automatic ODH system utilizes oxygen sensors to provide a warning/evacuation alarm for personnel who may be present inside the LINAC or CHL at the time of a spill.

Although the SNS design for cryogenic safety is closely based on proven JLab configurations and concepts, it was necessary to ensure that the cumulative effect of minor differences does not in any way constitute a deficit in safety performance. The SNS Project has performed hazard and accident analyses (e.g., see Appendix F) to verify that the SNS design configuration provides the expected high degree of safety, and to determine if any structures, systems, or components need to be designated as Credited Engineered Controls.

The approach to ODH analysis and control developed for the CHL and LINAC has been extended to other cryogenic operations at the SNS. For example, cryogenic operation in the RF Test Facility test/conditioning cave requires ODH monitoring. This monitoring is provided by the PPS-style interlock system in the RF Test Facility.

4.4.2.2 SNS ODH Analysis

4.4.2.2.1 Hazard Analysis Process

What follows is an exposition of the basic assumptions employed in ODH analysis. Cryogenic systems are a necessary component of experimentation in particle beam physics. There are several categories of hazards associated with cryogenic systems: brittleness of structural material, over-pressurization transients, exposure to extreme cold, and oxygen enrichment/displacement. To a large extent, all of these categories must be addressed in the design stage since no amount of operational alteration can completely compensate for safety shortcomings in design. Conversely, a well-thought-out design, which includes recognition of operational practices that could lead to safety problems, can mitigate human error. Design for safety is considered elsewhere in the FSAD and makes hazard analysis an integral part of the process.

Operational cryogenic safety assessment at the SNS is detailed in *Safety for Cryogenic Operations at SNS* (see Appendix D) and, in some respects (e.g., oxygen deficiency), parallels the process developed at Fermilab and subsequently adopted for use at BNL and JLab. Essentially, this involves the use of design parameters in a hazard analysis model that starts by identifying the maximum credible unmitigated release and characterizing the source term of released helium. The source term and the geometry of the enclosing environment are then used as inputs to general ventilation, or other, models as a means of estimating the resultant oxygen level. The objective is to determine if it is warranted to categorize the system and its environment as a cryogenic area and to determine if mitigation features need to be designated as Credited Engineered Controls. Cryogenic areas have the potential for the ambient oxygen concentration to decrease below 16% (a level below which the ability to evacuate begins to be impaired) in the event of an inadvertent release of cryogenic fluid. These requirements are specified in Appendix D.

The next step in the hazard analysis process for a cryogenic area is to determine if the risk is great enough to require mitigation. This has been done for the two main cryogenic areas at SNS, the SCL (LINAC Tunnel) and the CHL Facility, and is documented below (see Section 4.4.2.2.2). The anticipated oxygen concentration in combination with the likelihood of a release (severity and frequency) establishes the need for mitigation. Mitigating features that are established to reduce either the frequency or severity of the anticipated event may, depending on the unmitigated consequence and the initiating event frequency, be designated as "Credited Engineered Controls." The number of mitigating features, in concert with the anticipated hazard level, is used to specify the safety-integrity level (SIL) for one or more of the automatic mitigating systems, e.g., oxygen sensors/alarms. Certain safety features are required for cryogenic areas as a matter of SNS policy, regardless of the hazard analysis findings. These standard requirements are specified in Table D-1, "Basic Safety Requirements for Cryogenic Areas/Work," of *Safety for Cryogenic Operations at SNS* (see Appendix D).

The SNS has adopted 19.5% oxygen as the nominal setpoint for the evacuation-related ODH alarm threshold based on the OSHA definition of an oxygen deficient atmosphere and a corresponding minimum acceptable effective evacuation setpoint of 132 torr O_2 partial pressure based on the AICGH definition of the threshold for an oxygen deficient atmophere[4-63] The difference between the nominal and minimum acceptable setpoints establishes a safe limit on the allowable variation in initiation of evacuation alarm due to parameters such as atmospheric humidity, pressure, and instrument drift.

The oxygen level that is rapidly fatal or incapacitating can be readily determined by considering oxygen needs of oxygen-sensitive tissues. Suppose a person breaths air containing 5% oxygen at STP rather than the 20.9% that is normal. Water has a vapor pressure of 47 mm (millimeters) Hg at normal body temperature and this must be subtracted from the barometric pressure to achieve the "dry" state. The partial pressure of 5% oxygen that is inhaled is then 0.05(760-47) = 35.65 mm Hg. Under normal conditions, tissues within the body that need oxygen for cellular respiration have an oxygen partial pressure of 30–40 mm Hg, thus, venous blood being pumped to the lungs for oxygenation is at equilibrium with the tissues, say at 35 mm Hg. Since the blood arriving at the lungs finds the air at relatively the same oxygen partial pressure, it receives no oxygen from the lungs. That blood is pumped to the brain, which immediately "turns off" because of oxygen deprivation, and the person passes out. Holding the breath works, at least until the next breath, because the oxygen partial pressure from air in the lungs after normally oxygenating blood on the first pass is around 70 mm Hg, thus acting as a reservoir. However, if that person must release the held breath and gulp air that has 5% or less oxygen, collapse would be sudden.

Based on the above physiological rationale, SNS has for hazard analysis purposes adopted 5% as its "Highest" severity (death or permanent disability) category for risk analysis. The "Medium" ($5\% \leq \%O_2 \leq 12.5\%$), "Low" ($12.5\% \leq \%O_2 \leq 16\%$), and "Extremely Low" ($\%O_2 \geq 16\%$) categories are taken from the ANSI respiratory protection standard (Z88.2 [1992]).[4-53] ANSI[4-53] specifies 12.5% as the IDLH level (30 min. escape time) and the more conservative OSHA lists 16% as level above which oxygen deficiency would not interfere with an individual's ability to escape from a dangerous atmosphere. The fact that worker evacuation times from SNS cryogenic areas would be well below 30 minutes provides additional assurance that these category definitions are appropriate for risk analysis.

The ODH risk assessment process takes credit for some time within which a person can escape at a given oxygen level, albeit conservatively. The way this is done is by considering the oxygen concentration in the near field and far field (oxygen levels are always lower in the near field than the far field until equilibrium is attained after generation has stopped or become equal to the rate of purging) and the velocity of the advancing plume. If the plume is advancing at a rate greater than five feet per second (the value used for designing escape routes in fire protection engineering) the oxygen concentration for input into the hazard analysis matrix is the near field concentration (inside the plume). If less than five feet per second, the far field concentration is used.

4.4.2.2.2 ODH Analysis Results

Safety for Cryogenic Operations at SNS (see Appendix D) and hazard analysis methodology discussed above have been applied to the LINAC and to the CHL Facility. The LINAC hazard analysis

(Appendix F) is provided as an example of the level of detail typically applied. The results of the LINAC and CHL hazard analyses are summarized in Table 4.4.2.2.2-1.

Table 4.4.2.2.2-1

ODH Analysis Results

Facility	**Mitigation Features**	
	Defense in Depth Features	**Credited Engineered Controls**
LINAC/Tunnel	ODH cyrogenic safety training Tunnel ventilation system (if beam off) Oxygen monitors with alarms and rotating beacons	Oxygen monitors and alarms and rotating beacons Automatic initiation of Tunnel Emergency Ventilation System blowers fans (2) in LINAC
CHL—Cold Box	ODH/Cryogenic safety training Room ventilation fans	Oxygen monitors and alarms and rotating beacons
CHL—Compressor Room	Oxygen monitors and alarms and rotating beacons Room ventilation	Passive ventilation features (air inlet openings in the side of the building and outlet openings in the roof)
RF Test Facility test cave	ODH cryogenic safety training; Oxygen monitor with alarms and rotating beacons (either as part of the test cave access control and interlock system or as a portable monitor placed in the cave per JHA or procedure).	Not applicable (hazards safely managed under SBMS RSS system).

4.5 ENVIRONMENTAL HAZARDS

Environmental hazards are minimized, mitigated, and monitored in accordance with the ORNL SBMS Environmental Management System requirements and procedures. Potential environmental impacts for the SNS Project were analyzed and published in the draft and final environmental impact statement.[4-54] In cases where an impact could be minimized, a mitigation plan was written. The mitigation plan was implemented during site preparation and construction activities.

Following the DOE's decision to move from final construction to operation of the SNS, a number of environmental permits have been acquired for current and future emissions from the SNS. These include an NPDES permit for emissions to surface waters, operational air permits (included in the ORNL site-wide Title V Air Permit) for boiler emissions to the atmosphere, and a construction air permit for the Central Exhaust Facility.

The *Spallation Neutron Source Waste Management Plan*[4-55] was issued in preliminary form in 2002. The plan addresses the entire 40-y life cycle of all waste streams foreseen to be generated as the result of SNS operations and maintenance. The *Waste Management Plan*[4-55] has been updated following reexamination of facility waste streams and Title II and Title III design evolution and was finalized prior to obtaining CD-4 authorization.

4.5.1 WATER EMISSIONS

Water and other liquid effluents from SNS operations are regulated under the *Clean Water Act* (CWA).[4-56] Reference 4-56, *ORNL Work Smart Standards*, lists applicable federal and state environmental protection statutes and regulations including the following: the CWA, the *Spill Prevention Control and Countermeasures (SPCC) Plan,* the *Clean Air Act* (CAA), the *Resource Conservation and Recovery Act* (RCRA), and the *Federal Facility Compliance Agreement*. The U.S. Environmental Protection Agency (EPA) has delegated authority for implementation and enforcement of the CWA[4-56] to the State of Tennessee. Water pollution control rules are developed and administered by the Tennessee Department of Environment and Conservation (TDEC). The SNS ES&H Program is responsible for permitting, compliance, inspection, and documentation to ensure operations remain compliant with all federal and state water pollution control regulations. Regulatory compliance with the CWA[4-56] is focused on five elements: (1) NPDES; (2) Groundwater Protection; (3) Sanitary Wastewater; (4) Aquatic Resources Protection; (5) and Oil Pollution Prevention.

4.5.1.1 National Pollutant Discharge Elimination System (NPDES)

The NPDES permitting program is designed to protect surface waters by limiting effluent discharges into streams, reservoirs, wetlands, and other surface waters. To protect surface waters**,** process (cooling) and runoff waters from the SNS are collected in a retention basin located south of the SNS facility. The waters are routed (piped) from the retention basin to a point south of the existing monitoring weir and subsequently discharged into White Oak Creek. This discharge and minor secondary points of discharge are currently permitted under a State-issued NPDES permit for the SNS. Inherent in the permit are requirements for environmental monitoring. Should a massive spill occur (i.e., from a tanker truck located on the parking lot), potential pollutants are captured in the retention basin and prevented from discharging into the surface waters of White Oak Creek. In addition, the retention basin allows for reduction in the temperature of the water prior to discharge in White Oak Creek. Furthermore, although the cooling tower blowdown is dechlorinated prior to reaching the basin, the retention basin allows further dissipation of chlorine should that be necessary.

4.5.1.2 Prevention of Radioactive Contamination of Groundwater

The groundwater protection program is designed to address concerns associated with the spallation and neutron activation of soils in the shielding berm. Operation of the SNS has the potential for inducing radioactivity in the shielding berm surrounding the LINAC, Rings, and/or beam transport lines. The result would be radioactive contamination of berm soils by radionuclides. A principal issue of concern for stakeholders is the potential for water infiltrating the berm soils to transport radionuclide contamination to saturated groundwater zones, especially those that are, or could become, sources of potable water.

The berm is designed to isolate radionuclide contamination generated by the SNS particle beam and to provide radiation protection for outside areas around the beam and Ring tunnels. The amount of such activation is minimized by beam loss control and passive shielding. Nevertheless, the berm is constructed of compacted native soils and is engineered to isolate activation products by minimizing the amount of water infiltrating the berm. The SNS berm groundwater study[4-57] estimates that the planned berm construction of compacted indigenous clay renders it relatively impermeable to water ($\ll 10^{-5}$cm/s). Nevertheless, a geo-textile membrane is included in the design to provide an additional degree of control against water penetration. The berm design incorporates a groundwater interceptor system to collect any water that might penetrate the engineered berm. This water is sampled and analyzed for radionuclides. If radioactivity is present, the water is managed as low-level radioactive waste. Otherwise, the water is released to the retention basin.

Studies completed to date[4-57] have shown that, even if some groundwater does percolate through the berm the migration of radionuclides of concern, except tritium, would be very slow. This provides additional assurance that groundwater will not be a problem for the SNS. However, as described above, the major objective of the SNS strategy is to prevent any migration of radionuclides to groundwater. At present, a baseline groundwater monitoring program has been implemented to establish baseline groundwater conditions prior to operation of the SNS.

4.5.1.3 Sanitary Wastewater

Sanitary wastewater from the SNS is managed separately from other liquid wastewater streams. The wastewater is routed, collected, treated at the ORNL on-site sewage treatment plant, and discharged into White Oak Creek. Wastewater discharged into this system is regulated by means of internally administered waste acceptance criteria based on the ORNL NPDES operating permit parameters. Wastewater streams currently processed include sanitary sewage, area runoff of rainwater that infiltrates the system, and specifically approved small volumes of non-hazardous biodegradable wastes such as scintillation fluids.

4.5.1.4 Protection of Aquatic Resources

Aquatic resources protection is associated with U.S. Army Corps of Engineers (COE), TVA, and TDEC permitting programs for projects and activities with the potential to affect aquatic resources, including navigable waters, surface waters (including tributaries), and wetlands. Wetlands are present on or near the SNS site, and the protection of these wetlands is addressed by the SNS ES&H program. In constructing the Bethel Valley Access Road, a minor impact to one wetland was required. Permits for construction of the road were obtained from the COE and TDEC. As part of the permit requirement, a wetland was constructed near the entrance to Bethel Valley Road. Per the SNS MAP,[4-58] the period of wetland monitoring is five years.

4.5.1.5 Oil Pollution Prevention

Section 311 of the CWA[4-56] regulates the discharges of oils or petroleum products to waters of the state and requires the development and implementation of a SPCC Plan[4-56] to minimize the potential for oil discharges. Oil P2 at the SNS is addressed by the SNS ES&H program. The program focuses on both administrative and engineering controls. Administrative controls may include providing spill containment and cleanup equipment and training. Engineering controls include construction of dikes and sumps where appropriate.

4.5.2 AIR EMISSIONS

Air emissions from SNS operations are regulated under the CAA.[4-56] The U.S. EPA has delegated authority for implementation and enforcement of the CAA[4-56] to the State of Tennessee as described in the State Implementation Plan. Air pollution control rules are developed and administered by the TDEC. The SNS ES&H Program is responsible for permitting, compliance, inspection, and documentation to ensure operations remain compliant with all federal and state air pollution control regulations. At present, boilers located in the Central Utility Building (CUB) and the Central Laboratory and Office Building (CLO) are operational and are permitted in the ORNL site-wide Title V Air Permit.

Radioactive emissions from the SNS fall under the CAA, Section 112: "National Emission Standards for Emissions of Radionuclides Other Than Radon from Department of Energy Facilities at 40 CFR 61, Subpart H."[4-56] Per regulations, radioactive emissions from facilities on the Oak Ridge Reservation (ORR) must fall below the Rad-National Emission Standards for Hazardous Air Pollutants (NESHAP) dose limit of 10 mrem/y to the most exposed member of the public. As a result of airborne radioactive emissions from the operation of the SNS, the general public living in the vicinity of the ORR will be exposed to low levels of radiation. However, emissions are well within the respective Rad-NESHAP dose limit for the ORR. Based on modeling of full operation of SNS at the 2 MW power level, the maximally exposed individual (MEI) would receive an annual radiation dose of 0.8 mrem, or 8% of the limit. Prior to construction, the SNS obtained a construction air permit for construction of the proposed radioactive emission stack, part of the system commonly referred to as the Central Exhaust Facility (CEF). When the SNS became operational, SNS personnel coordinated with Tennessee Department of Environment and Conservation (TDEC) to ensure CEF operations are permitted under the ORNL site-wide Title V Permit. A continuous monitoring program is implemented to ensure effluents from the radioactive emission stack are compliant with the permit.

In general, non-radioactive emissions from the SNS result from the combustion of natural gas, usage of cryogenically cooled superconducting magnets, and maintenance operations. Combustion of natural gas would emit oxides of carbon and nitrogen and particulate matter. Usage of cryogenically cooled superconducting magnets generates gaseous emissions of helium and nitrogen. Maintenance operations may generate fugitive dusts and trace quantities of vapors. The cumulative effects on regional air quality are expected to be minimal.

4.5.3 WASTE MANAGEMENT

As noted above, a comprehensive waste management plan for SNS operational wastes that addresses the management of solid industrial, hazardous, radioactive, mixed, and special waste was issued June 2002. The *SNS Waste Management Plan*[4-55] includes an updated forecast delineating categories, types, and quantities of wastes anticipated as the result of normal operations. It also includes a description of management options for each waste category and type. Information pertaining to waste categories and respective regulations is provided below.

4.5.3.1 Solid Industrial Waste

The regulation of non-hazardous (solid industrial) waste is the responsibility of the State of Tennessee pursuant to Subtitle D of the RCRA.[4-56] The proposed management of non-hazardous solid industrial waste at the SNS focuses on source reduction (through design, modification of practices to reduce materials usage, reuse of products and packages, and recovery for recycling). Presently, the DOE has two Class II operating industrial solid waste disposal landfills and two operating Class IV construction demolition landfills on the ORR. Solid industrial waste from the SNS is disposed in a permitted landfill.

4.5.3.2 Special Waste

The regulation of special waste is the responsibility of the State of Tennessee. Special waste is regulated as a subset of solid industrial waste and, therefore, is administered by the Tennessee Division of Solid Waste Management. Special waste generated by the SNS may be disposed in an on-site permitted landfill or processed in a permitted processing facility once a special waste approval from the Tennessee Division of Solid Waste Management is obtained. Examples of special wastes are sludge, process filters, sandblast grind media, and paint chips.

4.5.3.3 Hazardous Waste

In general, the U.S. EPA has authorized regulation of hazardous waste by the State of Tennessee pursuant to Subtitle C of RCRA.[4-56] Under Subtitle C, the TDEC oversees all aspects of the management of hazardous waste, from the point of generation to the treatment, storage, and disposal. In addition, the 1984 RCRA[4-56] amendments established land disposal restrictions, which prohibit the land disposal of untreated hazardous wastes. Hazardous waste from the SNS will be sent for off-site treatment and/or disposal per applicable laws and regulations.

4.5.3.4 Radioactive Waste

The regulation of radioactive waste is the responsibility of the DOE pursuant to DOE Order 435.1.[4-46] Radioactive liquid waste from the SNS is sent for on-site treatment at permitted facilities. Radioactive solid waste is sent for off-site treatment and/or disposal per applicable laws, regulations, and policies.

4.5.3.5 Mixed Waste

The *Federal Facility Compliance Agreement* was signed on October 6, 1992,[4-56] to bring federal facilities into full compliance with RCRA.[4-56] RCRA[4-56] requires that DOE facilities provide comprehensive data to EPA and state regulatory agencies on mixed-waste inventories, treatment capacities, and treatment plans for each site. TDEC is the authorized regulatory agency under the act for DOE facilities in the State of Tennessee. The proposed management of mixed waste at the SNS focuses on elimination and/or minimization of hazardous materials (through administrative and design controls, modification of operational practices to minimize usage of hazardous materials, substitution of non-hazardous materials for hazardous materials, and recovery for recycling). Mixed waste from the SNS will be sent, per current planning, for on-site treatment at permitted facilities or off-site treatment and/or disposal per applicable laws and regulations.

4.6 ALARA

4.6.1 INTRODUCTION

This section describes how the SNS implements ORNL SBMS procedures and guidelines to meet the regulatory requirements of 10 CFR 835 to maintain radiation exposures as low as reasonably achievable.

The minimization of radiation in occupied areas has been a primary consideration throughout the SNS Project life, from initial design through commissioning and continues throughout operations. Activities must be conducted with care to ensure that radiation exposures are ALARA. Shielding generally provides protection against prompt radiation. As a first step in providing optimum shielding, considerable continuing effort is dedicated to accurate modeling of expected radiation levels based on the facility design.

Significant residual radioactivity is also expected in accelerator components due to proton and neutron activation, so access to accelerator components and areas is carefully controlled even when the proton beam is off. Work on materials, or areas exposed to beams, is planned with minimization of dose as a major consideration, and a RWP is required for entry into Radiological Areas. The frequency of equipment change-out is considered as one possible parameter for minimizing exposures. In the Ring Tunnel, HEBT, and RTBT, overhead cranes facilitate device removal and installation while allowing personnel to remain distant from the activated device. Additionally, specially designed local shielding (re-configurable to be used in different areas) is provided to permit personnel to work near activated devices while receiving reduced whole-body dose. These local shielding pieces are movable with the use of rolling stands, overhead cranes or forklifts.

10 CFR 835[4-5] provides the regulatory basis for occupational radiation protection of workers at DOE facilities. The following quotation from 10 CFR 835, Section 835.1002, "Facility Design and Modifications,"[4-5] lists the major ALARA requirements:

> *During the design of new facilities or modification of existing facilities, the following objectives shall be adopted:*
>
> *(a) Optimization methods shall be used to assure that occupational exposure is maintained ALARA in developing and justifying facility design and physical controls.*
>
> *(b) The design objective for controlling personnel exposure from external sources of radiation in areas of continuous occupational occupancy (2000 hours per year) shall be*

to maintain exposure levels below an average of 0.5 mrem (5 microsieverts) per hour and as far below this average as is reasonably achievable. The design objectives for exposure rates for potential exposure to a radiological worker where occupancy differs from the above shall be ALARA and shall not exceed 20 percent of the applicable standards in § 835.202.

(c) Regarding the control of airborne radioactive material, the design objective shall be, under normal conditions, to avoid releases to the workplace atmosphere and in any situation, to control the inhalation of such material by workers to levels that are ALARA; confinement and ventilation shall normally be used.

(d) The design or modification of a facility and the selection of materials shall include features that facilitate operations, maintenance, decontamination and decommissioning.

With regard to 1002(a), SNS considers both the cost and the benefit to optimize design and physical access controls to maintain exposures ALARA. Since there was no dose history to consider during the design/construction phases of the project, source and shielding calculations were the primary dose predictors. Experience from similar projects and lessons-learned from partner sites also provide valuable indicators. ORNL has assigned an ALARA value of $2,000 to $10,000 per person-rem, depending on circumstances, but in practice higher values are considered reasonable by the project when predicted doses to individuals approach regulatory limits or guideline values. Since radiological optimization was incorporated into all major decisions in the initial design, optimization decisions are not documented separately.

With regard to 1002(b), SNS adopted a design goal of 0.25 mrem/h (2000-h annual average) for continuously occupied areas. For specific cases where it is recognized that this design goal is impractical, the SNS Radiation Safety Committee is designated to review the design. Exceptions are considered case-by-case, based on the expected occupancy and the convenience of restricting access. Although details of maintenance activities will continue to evolve, ORNL annually establishes an ALARA Control Level for all radiological workers. Division Directors may extend this Control Level, but a maximum ALARA goal of 1 rem/year is assumed for any individual SNS radiological worker. Prior approval of the ORNL ALARA Steering Committee is required for an individual expected to exceed a dose of 1 rem/year.

With regard to 1002(c), the SNS design objective has been to design confinement and ventilation systems so that workers are not exposed to any measurable airborne radioactivity during normal operations. For example, during routine proton beam operations the air in the LINAC Tunnel is not vented in order to confine activated components of the air. Measurements of airborne radioactivity in the tunnel air have indicated that tunnel exhaust is not required for radiological protection of workers entering the tunnel when the beam is off. In the future, a delay can be invoked prior to personnel entry to allow decay of short-lived radioactive components, followed by a flush that exhausts the remaining airborne radioactive material if measurements indicated the situation had changed and that this would be useful for ALARA dose reduction purposes.

With regard to 1002(d), the design and the materials used facilitate operations, maintenance, decontamination, and decommissioning. Examples of such decisions are scattered through this document and over thirty examples are cited below in the list of ALARA decisions.

4.6.2 ALARA DESIGN REVIEW

From Section IV, Subsection I of DOE Guide 441.1-2, "Occupational ALARA Program Guide for use with Title 10, Code of Federal Regulations, Part 835, Occupational Radiation Protection."[4-59] The ALARA design review should have six discrete phases:

1. Dose assessment
2. Review of radiological conditions against the trigger levels established by management, e.g., creation of a new radiation source or an increase in the dose rates from an existing source; increased operations, maintenance, production, research, inspection or decommissioning requirements in a radiological control area; projected expenditure of a collective dose of greater than 1,000 mrem
3. Identification of the applicable radiological design criteria
4. Review of previous similar jobs, designs, and processes with similar hazards to assist in the selection of design alternatives and selection of optimum alternatives using approved optimization methods for evaluating the various ALARA considerations
5. Incorporation and documentation in the design package of features to reduce dose and the spread of radioactive materials
6. Reviews of effectiveness of engineering features to reduce dose and the spread of radioactive materials to provide feedback to the design engineers and to help refine the design process

<u>Dose Assessment</u>

SNS design phase dose assessments were calculated based on estimated source terms and planned shielding using state-of-the-art codes. The methodology was reviewed by recognized experts, and independent verification confirmed the accuracy of the calculations. Additional details are discussed in other sections of this document. Continuous (2000 h/y) occupancy by workers is assumed as the default for all unrestricted areas although lesser occupancy may be considered on a case-by-case basis.

On-line records of all positive radiation doses are made available to division Radiological Control Officers by the ORNL dosimetry program. These records include TLD results (quarterly results are supplied since that is the standard dosimeter exchange frequency) and doses accumulated under each Radiological Work permit (RWP), either cumulative or individual. Estimated personnel doses from electronic dosimetry are available immediately following work in posted areas and are used to track dose by RWP and task for ALARA planning purposes. ALARA planning has also been used to limit exposures of workers during jobs in areas with elevated radiation levels. Estimated doses received in Radiological Areas are recorded as part of the job permit process and are tracked. This system provides a method of estimating individual and cumulative doses between quarterly dosimeter exchanges.

Review of Radiological Conditions against Trigger Levels

ALARA reviews have been assigned to the SNS Radiation Safety Committee by management, in addition to the informal reviews that take place as designs, operations, and work practices are developed. Reviews may be triggered by the cumulative dose triggers discussed in this section, by management concerns, or by other factors such as DOE, employee, or public concerns. Reviews are often requested by groups or projects as a best practice or in anticipation of cumulative doses below, but potentially near, trigger levels. Reviews are often seen as helpful and as a source of useful improvements. An ALARA Working Group has been chartered to review jobs with the possibility of contamination or high doses. Review by this group is not a formal ALARA review under 10 CFR 835 requirements but a best management practice.

SNS has established an ALARA review trigger level of 0.5 person-rem per year for any work package. The typical active phases of an activity at SNS consist of installation, operation, maintenance, and replacement (including rebuilding or removal). ALARA reviews are considered for any or all of these project phases, and multiple reviews may be required for different phases of a given project.

Identification of Applicable Design Criteria

Applicable radiological design criteria are identified in the SNS Project design criteria documents. In general, all areas except the beam tunnel are initially assumed to be continuously occupied. 10 CFR 835[4-5] requires a design objective of 0.5 mrem/h (average) in areas of continual occupational occupancy; a shield-face design goal of 0.25 mrem/h (whole body) is established in the SNS design criteria for continuously occupied areas. For areas where it is not cost-effective or technically possible to limit projected dose rates to this level, access control is considered as an alternative to further dose reduction. For example, the Klystron Gallery is normally locked, with access limited to those with designated training and job descriptions. This precaution is taken in part because dose rates in some areas of this building that are not occupied continuously may exceed 0.25 mrem/h. In addition, compliance with the posting requirements of 10 CFR 835[4-5] helps ensure that workers are not inadvertently exposed to significantly elevated dose rates. For the SNS, the applicable ALARA design criteria for the minimization of dose to workers and users include a dose-rate design goal, an alternative access control objective, and posting requirements. If these design criteria are met, the personnel dose limitation objectives of the SNS Shielding Policy are met.

Review of Previous Similar Activities

SNS draws on experiences at all participating national laboratories in learning lessons developing innovative ways of reducing radiation exposures. Personnel from all over the world participated in the planning, design, construction, and installation of systems and components for the SNS and some of these individuals have become part of the operating staff at SNS, bringing their collective knowledge of past similar activities and ALARA approaches.

Similar installations at other sites have been specifically reviewed to assist in the selection of design alternatives. As one example, the DTL tanks at the Los Alamos LANSCE accelerator were evaluated to estimate the dark current radiation to be expected during tank conditioning. Dose rate maps were generated based on data collected while those tanks were conditioning after a shutdown (see report by Tanke et al.).[4-60] The results of this study were scaled to the conditions expected during conditioning at SNS, and shielding/access designed accordingly. As operating experience is accumulated at SNS, dose information is gathered to aid in future ALARA planning and optimization activities.

Incorporation of Features to Reduce Dose and the Spread of Radioactivity

ALARA considerations have been incorporated into all major design decisions as the facility design has evolved. These ALARA decisions have not generally been documented as separate design reviews because of the iterative nature of major facility design development. ALARA decisions have of necessity been based on calculated source terms and dose estimates rather than on dose histories and measured exposure rates. In effect, ALARA is considered in all aspects of the facility design, and numerous dose-reduction features have been incorporated into the design package as a result of ALARA considerations.

Several are mentioned below; others are scattered throughout this document. A brief list of some of the dose-reduction features includes:

Examples of ALARA Design Features in Proton Facilities

- Beam-loss monitors (described elsewhere) minimize activation of beam-line components by triggering alarms or terminating the beam if losses exceed thresholds.
- Machine Protection System trips are set to minimize beam losses and activation due to mis-steered beam.
- The shielding berm thickness of earth over the LINAC and ring was optimized at 15 ft.
- A membrane on the berm prevents ground runoff water from becoming activated.
- Penetrations to the beam tunnel are aimed at the floor under the beam to reduce streaming of radiation.
- The number of exit stairways from the beam tunnel has been minimized to reduce radiation leak points. In addition, the stairways have been relocated to increase the distance from predicted major sources of radiation.
- The Ring crane was added to aid remote handling of activated components.
- Collimators were designed-in to provide specific heavily shielded loss points, reducing activation along the rest of the beamline.
- Air exchange between the tunnel and connected buildings is minimized during beam operations to prevent release of activated air.
- Beamline components are designed in modules and with quick-disconnect connections to minimize worker exposures during component exchanges.
- The PPS has been segmented to reduce dose to searchers.
- The Ring has an exposed magnet power bus to simplify repairs/replacements, reducing worker dose by reducing time spent near activated components.
- Access to buildings adjacent to beam enclosures is restricted by locked doors/prox readers to limit access to necessary personnel.
- The superconducting and ring sections of the LINAC have large apertures to reduce beam loss and the resulting activation of components.
- "Gamma blockers" (steel shielding pieces) have been added to prevent backstreaming of radiation from the highly activated target and Ring Injection beam dump to potentially occupied areas of the RTBT and Ring (respectively) after beam shutdown.

Reviews of Effectiveness

Periodic surveys of the facility are planned to provide feedback on the effectiveness of the dose-reduction features described here. Details of the routine surveys are documented in a Radiological Surveillance Plan. As part of the radiological surveillance plan for the facility, potentially occupied areas are surveyed periodically to confirm the effectiveness of shielding and to refine the administrative controls used to further limit doses. In addition to the routine radiological surveys, the following reviews have confirmed the effectiveness of the SNS Shielding Policy:

- Fault studies aimed at proving the effectiveness of shielding and the optimum placement of fixed radiation monitoring instruments were conducted as part of commissioning activities.
- Chipmunk quality factors are verified by measurements and calculations, as needed.
- Each segment of the PPS is certified before use and tested annually after initial certification.
- Fixed and removable shielding necessary for safety is inspected and certified as being adequate by the RSO prior to beam operations.
- Groundwater monitoring results are reviewed annually by SNS management.
- Collective dose is reviewed annually by the Radiation Safety Officer.
- Occurrence reports involving SNS are reviewed annually by management for trends which might be counter to radiation safety, ALARA, or environmental concern.

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5. CREDITED CONTROLS AND BASIS FOR THE ACCELERATOR SAFETY ENVELOPE

5.1 INTRODUCTION

The ASE provides a concise framework of limitations on accelerator operation for the assurance of worker safety and that of the environment and the public. The SNS Accelerator Safety Envelope[5-1] addresses requirements associated with both the Proton Facilities and the Neutron Facilities. This section explains the development and structure of the ASE and develops the basis for ASE requirements for Proton Facilities related Credited Controls (see Chapter 5 of the FSAD-NF for Neutron Facilities ASE basis).

Although ASE requirements are essential for safety, many additional protections exist outside the ASE. For example, the ORNL SBMS requirements for the Radiological Protection Program, are implemented throughout ORNL, including the SNS, and these are supplemented by SNS-specific operations procedures to provide additional training and administrative controls that contribute to worker protection and help ensure that worker exposure to all forms of radiation is ALARA.

The ASE defines the physical and administrative bounding conditions for safe operations based on the Safety Analysis (see Chapter 4). As noted in the Implementation Guide[5-2] for DOE O 420.2B:[5-3]

> "This is not to say that operations outside the envelope will necessarily result in an accident or unacceptable risk, but that the safety limitations and/or authorization bases established by the contractor and approved by the DOE for commissioning or operation of the facility are not satisfied."

5.1.1 SAFETY BASES

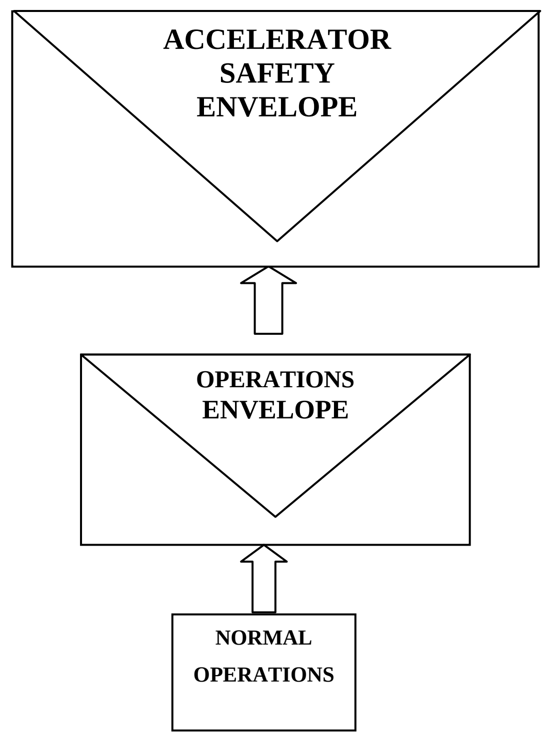
The hazard analyses of Section 4 have demonstrated for the accelerator prompt radiation and oxygen deficiency hazards that the following systems should be designated as Credited Engineered Controls: (1) the PPS, (2) the automatic safety instrumented systems that provide warning of oxygen deficiency in the tunnel or CHL and the LINAC Emergency Ventilation System, (3) the LINAC Emergency Ventilation System, and (4) passive design features of the CHL compressor room. These systems and features are an essential component of ensuring safety of workers who may enter the proton facilities, and requirements for them are addressed in Section 5.2.

Shielding for the SNS proton facilities is provided by the berm, concrete walls, steel blocks, and internal shielding structures and is designed to accommodate a maximum average power for beam operations of 2.0 MW. Shielding calculations (see Section 4.2.1) demonstrate margin for an upgrade of the LINAC output energy from the baseline value of 1 GeV to 1.3 GeV. The ASE for the target is 2 MW, based on target heat removal and radionuclide inventory safety analysis considerations. An increase of the LINAC energy above 1 GeV would require sufficient accelerator development studies (e.g., higher accelerating gradient of the SCL structures) and also the replacement of one of the key Ring injection dipole magnets. Therefore, operation significantly above 1 GeV is not a possible option without deliberate, necessary changes to the Accelerator Facility, any of which require dedicated downtime, thorough safety reviews, and management approval.

5.1.2 OPERATIONS ENVELOPE (OE) AND ALARA

The Implementation Guide[5-2] for DOE O 420.2B[5-3] explains the role of the OE in relation to that of the ASE.

> *"The contractor may choose to establish an Operations Envelope within the ASE for each subset of operations. By defining the nominal operation parameters beyond which the operating procedures would require adjustments to be made, an Operations Envelope serves to prevent the ASE from being exceeded. … Variations of operating parameters within an appropriate Operations Envelope of an accelerator would be considered normal operations. Variation outside the Operations Envelope, but within the ASE, merits appropriate attention (but) does not require termination of activities or notification of the DOE."*



The SNS Operations Procedures support an Operations Envelope in the spirit of the Implementation Guide. As illustrated above, the Operations Envelope is not a part of the ASE but is a part of the overall administrative control of the accelerator (see Section 3.3.3 for discussion of SNS Operations Procedures).

5.2 PROTON FACILITIES CREDITED CONTROLS

Credited controls are identified in accordance with the SNS Policy for Selection of Safety Related Credited Controls for the accident events analyzed in Chapter 4. This section addresses development of requirements for maintaining operability of the identified credited engineered controls (CECs). The general requirement for operability assurance is that the CEC is required to be operable when the hazard is or could be present.

It is sometimes necessary, for maintenance or other purposes, to take a credited control out of service. When bypassed, a system does not provide the designated protective function; therefore, compensatory measures must be invoked to provide an acceptable degree of safety during the bypass period. The system engineer for a protective system is responsible for deciding when a bypass is warranted and for establishing/documenting the rationale for the bypass that should include items such as: (1) compensatory measures that must be instituted during the bypass, (2) hold tags or other cautionary postings to be placed, and (3) the administrative approvals that must be secured before the bypass is executed. Bypass approvers include not only the system engineer but also Operations Management responsible for ensuring that the compensatory measures are in place before the bypass is executed.

5.2.1 PERSONNEL PROTECTION SYSTEM

5.2.1.1 Safety Function

The overall safety function of the PPS is protection of workers against prompt accelerator radiation. Among the various PPS functions listed in Section 3.2.3.3.3, the following are credited safety functions:

- Prevent beam operation in segments not cleared of personnel (beam containment).
- Shut off beam if personnel enter an operating segment.
- Shut off beam if the Target carriage is not in position to receive beam.
- Shut off beam if equipment faults or other failures cause radiation levels to increase over acceptable levels in occupied areas.

Radiation levels inside the beam enclosures are potentially injurious during beam operations. The PPS ensures the safety of workers against this hazard by automatically shutting off the beam if positive assurance of access control is lost. The ASE requires that those portions of the PPS required to support the applicable operational configuration be functional during beam operation.

Radiation levels outside beam enclosures are typically well below occupational limits during beam operations because the shielding is adequate for the maximum intended beam power. Radiation detectors placed outside the beam enclosures enable the PPS to initiate automatic beam cutoff if elevated radiation levels are experienced outside the enclosures as a result of beam mishaps (see Section 3.2.3.9 for more information on this aspect of the PPS). Hazard analyses (see Section 4.4.1) show that beam accidents do not generally provide a credible threat of radiation injury outside the beam enclosures; however, for certain hypothetical beam accidents, unacceptable radiation levels in potentially occupied areas would be plausible. Based on such cases, the PPS chipmunk-based beam cutoffs are assumed to perform a credited role and operability of chipmunk-based automatic beam cut-off is required by the ASE in order for the PPS to meet operability requirements.

5.2.1.2 System Description

The PPS is described in Section 3.2.3 of this document.

5.2.1.3 Functional Requirements

To ensure positive control of access to beam enclosures, the PPS detects the position of entry control devices (e.g., doors) and stops beam operation by disabling front end critical devices whenever the alignment of entry control devices does not bar personnel from being present inside the enclosure(s) in question. The PPS also controls power to the electromagnetic locks on tunnel entrance doors, keeping them locked during the “beam permit” mode.

To ensure beam containment to shielded enclosures, the PPS controls the power to beam transport critical devices that ensure that beam cannot be transmitted from active (cleared) enclosures to downstream segments not cleared of personnel. The PPS trips the beam by disabling front end critical devices prior to allowing power to any critical device for beam containment. The critical device depends on operating mode (see Section 3.2.3.5).

To ensure that radiation levels outside the beam enclosures do not result in excessive dose, the PPS monitors radiation using sensors (“chipmunks”) designed for detection of pulsed radiation sources. If any chipmunk indicates radiation level exceeding the lower threshold for a high radiation area, the PPS trips beam by interrupting front end power supplies. Although most chipmunks perform an ALARA-assurance function, they are all part of the PPS credited engineered control.

5.2.1.4 System Evaluation

The PPS achieves the highest protection system reliability attainable at an accelerator facility by incorporating protection system design features that have been proven in other major DOE accelerator facilities. In addition the PPS has followed established industry standards (e.g. ANSI/ISA-84.00.01, *Functional Safety: Safety Instrumented Systems for the Process Industry Sector*) to guide the entire safety life cycle from design, procurement, fabrication, testing, to operation and maintenance. Per this standard, the PPS safety functions have been evaluated and categorized as to safety integrity level. The most critical PPS safety functions, that protect workers against potentially lethal levels of radiation, are designed to meet or exceed safety integrity level 2 (SIL-2) per the standard.

As described in Section 3.2.3.4.1 *PLC Hardware*, the PPS employs a one-out-of-two logic structure, or equivalent, combined with fail-safe design features, e.g., trip on loss of power, to perform SIL-2 safety functions with assurance of very high reliability. The measures taken to ensure that the digital environment is consistent with a critical safety system are described in Sections 3.2.3.4.2 *PLC Software* and 3.2.3.4.3 *PPS Computer Displays*.

The ability of the PPS to reliably control the state of the accelerator, e.g. to cut off the beam when safety cannot be ensured, depends on its control of designated critical devices that control the ability to produce beam or to contain beam within certain bounds. PPS control of the critical devices is implemented in accordance with fail-safe principles as described in Section 3.2.3.5 Critical Devices.

5.2.1.5 Assurance of Continued Operability

The ASE requires that credited safety functions of the PPS be operable as necessary to support the operating mode the machine is in (see Table 3.2.3.3.2-1 for a listing of the modes). Annual certification in accordance with SNS Procedures ensures the reliability of the PPS.

5.2.2 OXYGEN DEFICIENCY HAZARD SAFETY INSTRUMENTED SYSTEM

5.2.2.1 Safety Function

The ODH system monitors oxygen levels in the superconducting LINAC (SCL) and the CHL and provides visible and audible alarms inside the areas and at entrances when the decreased oxygen level indicates a significant release of inert gas may have occurred from the cryogenic system.

5.2.2.2 System Description

See Sections 3.2.3.2 and 3.2.3.11.

5.2.2.3 Functional Requirements

The ODH system is required to measure the concentration of oxygen in air in designated areas of the tunnel and CHL building and if the system actuation threshold is met, to initiate audible and/or visible warnings for the affected areas. Oxygen sensors for the tunnel need to be able to measure oxygen level in the LINAC tunnel air in the event of helium releases and those in the CHL need to be able to measure oxygen level in the event of helium and/or nitrogen releases. If the actuation threshold is met in the LINAC, the ODH system sends a start signal to the Emergency Ventilation System.

5.2.2.4 System Evaluation

The ODH Alarm System is a safety instrumented system designed and maintained to provide reliability of safety function commensurate with the risk of the hazard. Although the PPS and ODH Alarm System are separate, they share the same basic design approach. The system evaluation of Section 5.2.1.4 applies.

5.2.2.5 Assurance of Continued Operability

The ODH system is required to be operable when the ODH is present. An ODH is defined to be present when sufficient inert gas could, through credible inadvertent release, cause workers to breath an atmosphere with less than the minimum 132 torr oxygen partial pressure recommended by the ACGIH[5-5] (equivalent to ~18% oxygen at the SNS site typical atmospheric pressure at 1030 ft elevation). Annual certification of the ODH system in accordance with approved SNS procedures is required to ensure continued operability.

5.2.3 EMERGENCY VENTILATION SYSTEM (EVS)

5.2.3.1 Safety Function

The EVS is an active ventilation exhaust system that can be initiated automatically by the LINAC ODH system. Its purpose is to provide a forced-flow exhaust path to the outdoor environment to help ensure that released helium would not spread to occupied spaces within the front end building or tunnel regions outside of the LINAC/HEBT tunnel in the event of a significant long term accidental release from the helium system of the superconducting LINAC.

The postulated accident sequence that requires designation of the EVS as a credited engineered control is a hypothetical scenario in which a long term helium release occurs when the tunnel is not in an operational status that would require the central control room to be occupied. (It has been SNS policy to continually man the CCR; however, it is conceivable that there might be a time when all beam related operations are terminated and the CCR becomes unmanned for some period). The sustained release of He into the LINAC tunnel could potentially cause oxygen deficiency not only in the LINAC tunnel but also in the remainder of the tunnel or front end building. The LINAC/HEBT tunnel is protected by the LINAC ODH system; however, no such protection is provided for the remainder of the tunnel or in the Front End Building. Should such a postulated sustained release occur, workers in the Front End Building, or tunnel regions outside of the LINAC/HEBT could be at risk of ODH exposure. Should the CCR be unmanned, ODH alarms in the control room could go unnoticed. The EVS is credited with preventing oxygen deficiency in these adjacent areas by routing the inadvertently released helium directly to the outdoors.

5.2.3.2 System Description

The EVS includes a limited portion of the tunnel smoke removal system (see Section 3.2.4.2.2.2 Tunnel Exhaust System for a general discussion on the smoke removal system) that has a designated ODH related safety function. The EVS is actuated automatically whenever the LINAC ODH system detects a release of helium sufficient to trip the ODH evacuation alarm. The EVS can also be started and stopped manually from the central control room in accordance with approved operating procedures. Although the EVS is designated as a CEC for protection of workers outside the LINAC, its operation would speed the recovery of safe oxygen levels inside the tunnel in the event of a significant helium release.

The EVS consists of the following parts of the LINAC smoke removal system: (1) two exhaust blowers located atop the LINAC berm, (2) ductwork connecting each blower to the interior tunnel atmosphere, (3) a blower inlet damper in each duct, and (4) associated infrastructure and instrumentation. The LINAC ODH system directly controls the blower motor starters and blower inlet dampers as needed to perform the safety function. In addition, the EVS includes a damper in the front end that is automatically opened upon EVS actuation to admit air directly from the outdoors into the LINAC tunnel at the entrance labyrinth between the front end entrance and LINAC.

The LINAC ODH system interfaces with parts of the smoke removal system that are not part of the EVS. Upon an ODH evacuation alarm, the LINAC ODH system sends a start signal to the smoke removal make-up air fans in the front end and in the HEBT section (i.e., the upstream and downstream entrances of the LINAC tunnel). Although beneficial, these parts of the LINAC smoke removal system are not part of the EVS because they are not necessary to perform the safety function of the EVS.

Each of the two EVS blowers is each rated at about 10,000 cfm, as set by the non-safety-credited smoke removal function.

5.2.3.3 System Evaluation

The maximum credible accident release rate of helium in a postulated extended release is 150 g/s (see Appendix F). This rate is equivalent to about 1900 cfm at room temperature and atmospheric pressure. Since the EVS blower nominal capacity is about 10,000 cfm per blower, the rate of a single exhaust blower is more than enough to confine the accidentally released helium to the LINAC.

5.2.3.4 Assurance of Continued Operability

The ASE requires the EVS to be operable whenever a potential ODH could exist unless appropriate compensatory measures are taken. Annual certification of the ODH and EVS system in accordance with approved SNS procedures is required to ensure continued operability.

5.2.4 CHL COMPRESSOR ROOM PASSIVE VENTILATION FEATURES

5.2.4.1 Safety Function

The passive ventilation features provide an abundant source of outdoor air and roof-level exhaust outlets for natural circulation flow of helium and air from a potential inadvertent leak in the helium compressor or associated piping.

5.2.4.2 System Description

The helium compressors operate continuously and lose considerable heat to the air of the compressor room, so the room is provided with ventilation features that help maintain habitable temperatures. Side vent panels with area in excess of about 300 ft^2 are built into the compressor room north and south walls to allow relatively cool outdoor air to enter the building. Fan assisted ceiling vents (free area about 40 ft^2) exhaust warm air to the outdoors.

5.2.4.3 System Evaluation

The helium in the compressor room is not cryogenic. Although the passive ventilation features are provided for the purpose of room air temperature comfort, they would be beneficial in the event of a helium leak from compressor piping. Calculations[5-6] show that inlet and outlet vent areas exceeding 33 ft^2 each provide adequate passive natural circulation capability without crediting the fans that assist the ceiling vents. The ceiling vents have total area of about 40 ft^2 and the wall panels have air inlet area exceeding 300 ft^2.

5.2.4.4 Assurance of Continued Operability

The ventilation features are passive and are maintained by configuration control.

5.3 REFERENCES

5-1 *SNS Accelerator Safety Envelope (ASE): for Full Power Operations of the Front End, Linac, Ring, Transport Lines, Beam Dumps, and Target,* SNS 102030103-ES0016-R05, May 31, 2007.

5-2 *Accelerator Facility Safety Implementation Guide for DOE O 420.2B, Safety of Accelerator Facilities*, Office of Science, U. S. Department of Energy, Washington, DC, January 2005.

5-3 *Safety of Accelerator Facilities*, DOE Order 420.2B, Office of Science, U.S. Department of Energy, Washington, DC, July 2004.

5-4 Title 10, *Energy*, Part 835, “Occupational Radiation Protection,” 10 CFR 835, U.S. Department of Energy, Washington, DC.

5-5 *2006 TLVs and BEIs based on the Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents*, American Conference of Governmental Industrial Hygienists, ACGIH Worldwide Signature Publications, 1330 Kemper Meadow Drive, Cincinnati, Ohio 45240).

5-6 J. Jankovic, *CHL Facility Oxygen Deficiency Hazard Analysis and SIL Level Determination*, SNS Document No. 102030103-CA0002-R00, December 2002.

6.0 INTERFACE BETWEEN PROTON AND NEUTRON FACILITIES

This SAD addresses the safety of SNS proton facilities, which begin at the front end and extend to the terminus of the ring-to-target--- beam tube in the target building, at the upstream side of the window that allows protons to enter the core vessel that houses the target. The SAD for Neutron facilities[6-1] addresses the SNS target facility and neutron scattering instruments. This section provides a brief summary of interfaces between the proton and neutron facilities.

Most of the SNS facilities and equipment are part of the proton facilities. This includes not only the major accelerator segments such as the Front End, LINAC, Ring, and Transport systems but also several essential support buildings such as the Klystron building and the HEBT, Ring, and RTBT support buildings. Infrastructure buildings such as shops, labs, the office building, and utility buildings are mentioned in Chapter 3 but they pose only standard industrial hazards that are addressed by existing ORNL SMBS standards and requirements. Thus, the safety of infrastructure buildings is not evaluated in Chapter 4. The activities of the neutron facilities take place primarily in the target building and its attached satellite buildings.

The purpose of this section is to explain the physical and operational interfaces between the proton and neutron facilities

6.1 DEFINITION OF PROTON AND NEUTRON FACILITIES

The neutron facilities occupy the target building and attached instrument satellite buildings except for the part of the RTBT tunnel that extends into the target building. The RTBT proton beam tunnel is part of the proton facilities. Other facilities on site are considered part of the proton facilities with the following exception: as discussed below, in Section 6.2, parts of the TPS are located in proton facilities.

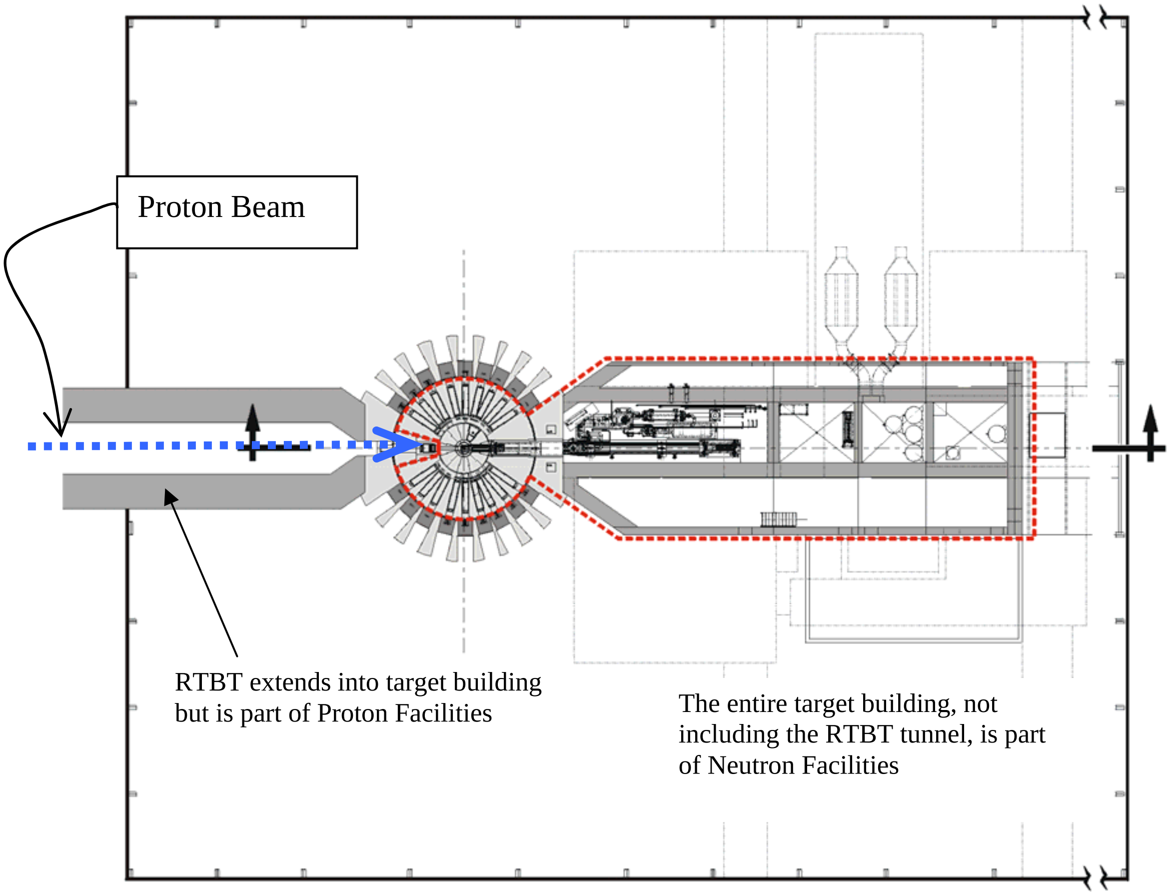


Figure 6.1-1 Target Building Horizontal Section through Proton Beam Line

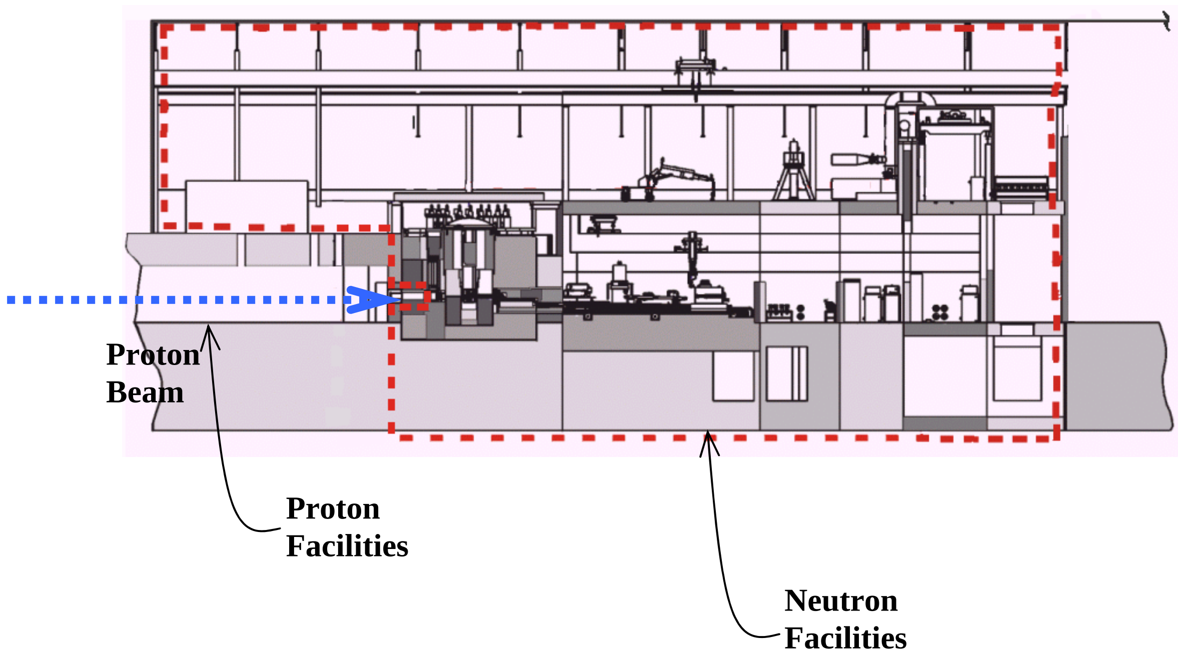


Figure 6.1-2 Target Building Vertical Section through Proton Beam Line

6.2 PHYSICAL INTERFACES BETWEEN PROTON AND NEUTRON FACILITIES

Proton and neutron facilities are separated by distance and/or solid walls. The accelerator proton beam tube passes into the monolith up to the point of connection to the proton beam window, which is defined as part of the neutron facilities. The TPS instrumentation and control cables reach into the proton facilities to connect with vital TPS parts as follows:

- The TPS owns breakers in the Front End Building that it de-energizes to cut off the proton beam when the Target is not appropriately configured to accept proton beam.
- The TPS senses the status of ac and dc power interruption devices that feed the RTBT Dipole magnet RTBT.DH13 in the Ring Service Building. The TPS logic will allow Operations personnel to place the TPS in bypass mode when it senses that both ac and dc power are not provided to RTBT.DH13. When the TPS is in bypass mode it does not cut off the proton beam in response to either low mercury pump developed head or low mercury pump power.
- The TPS and other neutron facility control, information, and/or alarm functions are displayed in the neutron facility part of the central control room in the CLO building.

It is essential that the integrity of the TPS including the above-defined components be maintained. Design features are provided to facilitate maintaining the required configuration control and integrity. For example, the TPS cutoff breakers in the Front End are located in dedicated, clearly identified, locked cabinets. The TPS is designed and must continue to be maintained throughout facility life to applicable design standards. No work will be performed on any part of the TPS without prior configuration control review and approvals (see the Final Safety Assessment Document for Neutron Facilities section on Credited Engineered Controls).[6-1]

6.3 FUNCTIONAL INTERFACES

6.3.1 INFRASTRUCTURE

Proton Facilities and Neutron Facilities share infrastructure services and resources. Table 6.3.1-1 tabulates some examples. Changes in usage or status of shared infrastructure services and resources that could affect either the Proton or Neutron Facilities are coordinated by SNS management. Both Proton and Neutron facilities depend on ORNL laboratory services, such as the ORNL Fire Department.

Table 6.3.1-1

Examples of Shared Infrastructure Services or Services Provided by Proton Facilities to Neutron Facilities

Service	Purpose	Interface Point
Electrical power	Supply power to active functions	Breakers
Tower cooling water	Provide the heat sink for water-based cooling systems	Piping connections to heat exchangers
Chilled water	Provide lower temperature water for certain functions, e.g., air conditioning	Piping connections to heat exchangers
Ventilation routing	Direct potentially contaminated target building discharge air to the SNS 80-ft stack	Discharge of primary confinement system, secondary confinement exhaust system, and hot off-gas system blowers
Emergency electrical power	Ensure continuity of power to the more important systems	Connections to safety-related systems

Note: None of the above features or services are considered Credited Engineered Controls.

6.3.2 FUNCTIONAL INTERFACES THAT HELP ENSURE SAFETY

This section highlights functional interfaces between proton and neutron facilities that involve credited engineered controls or that otherwise help ensure safety. Table 6.3.2-1 identifies equipment or systems involved, the actions taken and the applicable phases of operations.

Table 6.3.2-1

Functional Interfaces That Help Ensure Safety

Equipment Involved	Requirement	Applicability
Proton beam power control—normal full beam power	Proton beam power is controlled such that total power on the target, averaged over any 24 h, shall not exceed 2 MW.	Safety Envelope, Operations
TPS and power supply connected to RTBT. DH13	The TPS prevents proton beam operation when the target mercury loop is not functional. The TPS bypass mode is selected by operators to monitor power supplies to RTBT.DH13 and safely allow LINAC or ring tuning operations when the target loop is not ready to receive beam.	Safety Envelope, Configuration Control, maintenance, operations
Target Plug	The target PPS monitors the output of a position switch that indicates when the target plug is not inserted into the monolith so that the PPS can prevent beam-to-target when the target plug is not inserted.	Safety Envelope, Configuration Control, maintenance, operations
PPS, Target PPS	The PPS cuts off the proton beam at the front end upon receipt of the beam cutoff request signal from the target PPS.	Safety Envelope, Configuration Control
Power supply to RTBT DH13	A key switch with removable key is provided and maintained to allow target personnel to perform manual lockout when the target plug is not in place.	Configuration Control, Operations

6.4 OPERATIONAL INTERFACES

The physical and functional dependencies of the SNS have not led to operational safety interface issues between the operations of proton and neutron facilities. An integrated centralized control room is provided in the CLO building for integrated operations. The SNS Conduct of Operations program is implemented with training and procedures that ensure active coordination between the proton and neutron operations. The SNS review committees such as the Radiation Safety Committee provide independent review in the case of hazards evaluation to help ensure that interface issues are identified, evaluated, and resolved.

6.5 REFERENCES

6-1 *Spallation Neutron Source Final Safety Assessment Document for Neutron Facilities,* 102030102-ES0016.

7.0 QUALITY ASSURANCE

Quality assurance (QA) is an integral part of the design, procurement, fabrication, construction, commissioning, and operations of the Spallation Neutron Source (SNS) facility. The SNS quality program uses a graded approach to administer the appropriate application of quality practices. Special attention is given to items and services that affect the safety and operational reliability of the facilities. The SNS Operations Manager is responsible for development, implementation, assessment, and improvement of the Spallation Neutron Source Quality Manual.[7-1] The Manual defines the QA processes as well as the responsibilities for them and implements QA criteria and suspect/counterfeit item (S/CI) prevention requirements of Department of Energy (DOE) Order 414.1C.[7-2] The SNS quality program also uses ANSI/ISO/ASQ Q 9001-2000, Quality Management System—Requirements, as the appropriate voluntary national or international consensus standard, where practicable and consistent with contractual or regulatory requirements.

The SNS quality program is implemented through the use of QA/quality control (QC) procedures and guidelines and is deployed into other management systems such as the Operations Procedures Manual, system and equipment test plans, a document control center, and action tracking systems.

From facility design through commissioning, the SNS Project Quality program also utilized the existing quality systems within the SNS partner national laboratories relative to their contributions to the SNS Project. The SNS Project Office QA group maintained an oversight role of the partner laboratories and the architect engineer-construction manager quality systems used for SNS work, including formal assessments. The Project Office QA group provided guidance and support to the partner laboratories to maintain common and effective quality practices throughout the entire SNS Project.

A formal equipment and activity acceptance system was deployed throughout the SNS Project and has continued to be used. This acceptance system required the creation of a written and responsible verification strategy for items and activities that involve quality and safety issues, using documented acceptance checklists. The SNS QA group monitors the acceptance of completed components, their installation, and use throughout the facility life cycle. Equipment within the SNS facility is under Configuration Control to ensure that design changes or temporary modifications do not negatively impact their contribution to facility safety.

The SNS QA program includes appropriate attention to software QA. Two types of software QA are considered: software used in real-time applications in CECs, and software used to calculate safety related design information.

Real-time safety related applications. The CECs that are interlock type systems are the Personal Protection System (PPS, throughout the accelerator from front end ion source to the neutron instruments in the target building), the Target Protection System (TPS), and the Transfer Bay Access Control Interlock. The TPS and Transfer Bay Access are relay or analog-logic based systems and controlled under the hardware configuration control program. The PPS is a combination of hardware equipment status contacts and Allen-Bradley PLC controllers.

The PPS configuration has been controlled by reviewed and approved system drawings and a detailed, signed-off testing/commissioning procedure that verifies proper system operation. It has been modified to include new items of equipment as they have been readied for commissioning/operation.

The testing/commissioning procedure is reviewed by the systems engineer, the appropriate controls engineer, and operations. The test data is reviewed and approved by the same authorities that approved the testing and commissioning procedure prior to placing the PPS into service.

The revised PLC software is assigned a new version number identifier and it is placed into a centralized repository/database recall the Concurrent Version System (CVS). The CVS is a commercially obtained program that retains the various versions of software including the explanation of the differences and reasons why between software versions.

Codes for Calculation of Safety Related Design Information. The radiological shielding analysis reports were prepared in accordance with established SNS procedures that require the use of appropriate calculational methodologies. The codes used for calculations are obtained from recognized code repositories such as RSIC or INEL that maintain the configuration management of these codes. The shielding design inputs to these codes are under configuration management at SNS, uniquely identified, and are stored in the CVS. The shielding design analysis reports provide the traceability to the specific codes used and describe the details of the models used in performing the calculations. The results of the analyses have been validated through radiation surveys of the installed shielding during facility startup at initially low levels of power and revalidated, as needed, in conjunction with major power increases or facility design modifications.

7.1 REFERENCES

7.1 *Spallation Neutron Source Quality Manual*, SNS-QA-P01, 102040000-QA0001R05, Oak Ridge National Laboratory, Oak Ridge, TN, May 2007, R05.

7.2 Quality Assurance, DOE Order 414.1C, Office of Environment, Safety, and Health, U.S. Department of Energy, Washington, DC, June 2005.

A.0 APPENDIX A: FREQUENCY AND PROBABILITY GUIDELINES FOR HAZARD ANALYSIS (REFERS TO SECTION 4.1.1)

Appendix A: Frequency and Probability Guidelines for Hazard Analysis (refers to Section 4.1.1)

Initiating Events Category

Assigning frequency to one of the three major categories is judgment-based, aided as practicable with operating data and considering factors such as preventive maintenance (PM), which can affect failure frequencies. The frequency estimation does not have to be precise because each category encompasses two orders of magnitude.

Rationale 1: Categories based on expert opinion or common knowledge of rate of approximate frequency of occurrence:

- Anticipated events are those that occur at least once in the life of any given accelerator. Frequency is in excess of 10^{-2}/y.
- Unlikely events are those that may not have occurred at any given accelerator but that have probably occurred at least once in accelerators of the free world. Frequency is between 10^{-2}/y and 10^{-4}/y.
- Extremely unlikely events are events thought to be possible even though they may never have happened at any accelerator facility. They must, however, be physically possible and credible events.
- Beyond extremely unlikely events are, in the professional judgment of responsible engineers and scientists, not credible events. Similar events must never have occurred in an accelerator facility (or else they would be in a higher frequency category).

Rationale 2: Frequency categories based on known equipment failure rate data. The following are examples based on data taken from Tables 3, 4, and 5 of the *JNAL ES&H Manual* (No. 6500-T3 beginning at page 8 of 14):

- Power supply failure: $3(10)^{-6}$/h or 0.015 per 5000-h operating year. If any one of ten power supplies causes the same fault, then the frequency is 0.15/y, an Anticipated Event.

- Welds leak at 10^{-9}/h. If each weld is in a stressed condition for 5000 h/y and there are ten welds of concern, then the approximate event frequency is $5(10)^{-5}$/y, an Extremely Unlikely Event. If the number of welds that could unleash the hazard of interest is 100, then the frequency is $5(10)^{-4}$/y, an Unlikely Event.

Mitigating Actions Category

To understand effectiveness of mitigating actions, either administrative or automatic, it is necessary to assign an approximate conditional probability of success in the given circumstance. Given that the hazard-related initiating event has occurred, what is the likelihood of success for the mitigating action. Here are some example guidelines:

Automatic Action, Safety Instrumented System:

Between 0.99 and 0.999 for a SIL-2 (Safety Integrity Level 2) system, and between 0.9 and 0.99 for a SIL-1 system.

High-Integrity Non-Safety System:

Given the financial consequences involved, action of the MPS is designed to provide success probability of between 0.9 and 0.99 for threats that it is designed to counter.

Personal Self-Protective Actions:

If the worker is specifically trained to evacuate on a given signal (ODH, radiation alarm, etc.), then it is highly likely (probability > 0.99) that the worker would evacuate within about 30 seconds.

If diagnoses and deduction is necessary (even for a trained worker), the worker may still evacuate with high certainty but only after a sufficient delay, e.g., two to five minutes.

Evacuation is highly likely even without specific training for unambiguous trouble signs such as obvious smoke or flames or severe earthquake shaking.

Even a loud, obvious alarm cannot be assumed to elicit quick evacuation without training. For example, personnel (e.g., riggers) in the building for a pickup or delivery cannot be assumed to evacuate without being told. In an incident that occurred several years ago, riggers covered their ears and stayed inside the building until specifically instructed to evacuate by one of the building personnel. Similarly, only ODH-trained workers are assumed to evacuate following an ODH alarm.

Other Administrative Actions:

Must be evaluated on a case-by-case basis considering appropriate training and frequency of training. Administrative actions credited in an SNS hazard analysis must be consistent with the experience of SNS personnel at other DOE accelerator facilities. Actions noted in the hazard analysis must be only those expected to come under strict management control and surveillance at a well-managed accelerator facility.

B.0 APPENDIX B: SHIELDING ANALYSIS METHODOLOGY (REFERS TO SECTION 4.2.1.1.2)

Appendix B: Shielding Analysis Methodology (refers to Section 4.2.1.1.2)

Shielding calculations at the SNS utilize a number of techniques and programs to complete the required calculations in the most efficient manner. The majority of the programs are distributed through national radiation shielding centers such as the Radiation Safety Information Computational Center[B-1]. A listing of all major programs used in the SNS neutronic design is given in Table B-1. All of the codes or code systems listed in Table B-1 have been rigorously tested and benchmarked in applications similar to the design and analysis of the SNS. Furthermore, a series of experiments have been conducted at BNL and LANL to simulate the SNS Target environment and the applicable codes have been used to benchmark the calculational methodology through comparisons to the experimental data. Some techniques required the development of cross section libraries and programs allowing techniques to be used together, called coupling codes. All locally developed programs and data are documented in detail in the SNS document control center. This appendix will present in general the programs used to complete shielding calculations for the SNS and will provide references in which specific details can be found.

Many calculations are completed using the Monte Carlo method utilizing MCNPX[B-2]. The Monte Carlo method allows arbitrarily complex geometry models and MCNPX provides multi-particle transport accurately up to several GeV. These qualities make MCNPX uniquely applicable to many radiation transport and shielding problems at the SNS. One major drawback of the Monte Carlo method is the amount of time required to complete the analysis. This issue was addressed at the SNS by the implementation of parallel processing with MCNPX via PVM[B-3] by Gallmeier[B-4]. This improvement was later formalized in MCNPX and expanded to other message passing interfaces to form the basis of the current MCNPX parallel processing capability. MCNPX is typically used to generate source terms and to transport particles through several meters of shielding (approximately 5 m) without a beam extraction line.

For shields thicker than ~5 m without beam extraction lines allowing significant penetration, such as the accelerator tunnel shielding, the discrete ordinates method is much faster and can yield accurate answers to transport problems. At the SNS, the DOORS system[B-5], including the one-dimensional code ANISN, the two-dimensional code DORT, and the three-dimensional code TORT, are used for these analyses. Because MCNPX is used to generate the source term, a method must be implemented to couple the Monte Carlo source terms with the discrete ordinates transport codes. This process was completed by Gallmeier and Pevey[B-6, B-7]. During this process, it became clear to the authors that it would also be possible to couple several different two-dimensional transport calculations on translated or rotated axes, avoiding difficult and memory consuming three-dimensional calculations. One application of this technique is the analysis of a labyrinth used to shield the entrance to the accelerator tunnel. The coupling code for this technique was written by Lillie[B-8].

Discrete ordinates calculations, or any transport calculation for that matter, are only as good as the cross section database used for the analysis. At the SNS the incident protons, at 1 GeV, will be capable of producing neutrons up to 1 GeV in energy. In addition, energy and power upgrades have been discussed since early in the project. With this in mind, a new transport cross section library, with the maximum energy extended to 2 GeV, was constructed by Lillie and Gallmeier[B-9]. This cross section library is used for all discrete ordinates calculations at the SNS.

Activation analysis is usually included in the shielding discussion, since activated components typically require some shielding for maintenance or disposal operations. Two activation systems are used at the SNS. The first, based on the ORIHET system, is the Activation Analysis System[B-10]. The second, involving CINDER'90[B-11], is not as easy to use and is not currently released to the public, but has proven to reliably predict dose rates and decay heat when compared with experimental data. The SNS neutronics team is working with the CINDER'90 authors to have the code publicly released and to finish the manual. Comparisons with the Activation Analysis System and CINDER'90[B-12] have shown the codes to agree reasonably well, although CINDER'90 includes data for more metastable states leading to some disagreement at short times.

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B-10 Greg S. McNeilly, The Activation Analysis System (AAS), SNS-101040200-TR0003-R00, September 2000.

B-11 W. B. Wilson and T. R. England, A Manual for CINDER'90 Version C00D and Associated Codes and Data, LA-UR-00-Draft, April 2001.

B-12 P. D. Ferguson, I. Remec, F. X. Gallmeier, and W. B. Wilson, Transmutation Studies for Tungsten and Mercury Targets with the CINDER'90 and ORIHET'95 Codes,

Table B-1		
List of Codes and Principal Applications to the Neutronic and Shielding Analysis of the SNS		
Code Name	**Analysis Type**	**Principal Application**
CALOR	Complete Radiation Transport Code System (All Energies)	Neutronics, Energy Deposition, Material Damage and Activation, Shielding
HETC	High Energy (E>20 MeV) Hadron Transport	Neutronics, Energy Deposition, Material Damage and Activation, Shielding
SPECT	High Energy Hadron Transport Analysis	Neutronics, Energy Deposition, Material Damage and Activation, Shielding
MCNP	Low Energy (E<20 MeV) Neutron, Photon, and Electron Transport	Neutronics, Energy Deposition, Material Damage and Activation, Shielding
MCNPX	Complete Radiation Transport Code System (All Energies)	Neutronics, Energy Deposition, Material Damage and Activation, Shielding
LAHET	High Energy (E>20 MeV) Hadron Transport and Analysis	Neutronics, Energy Deposition, Material Damage and Activation, Shielding
MORSE	Low Energy Neutron and Photon Transport	Neutronics, Energy Deposition, Shielding
MICAP	Low Energy Neutron and Photon Transport	Energy Deposition, Material Damage and Activation
EGS4	Electron, Positron, and Photon Transport	Energy Deposition, Shielding
ORIHET95	Depletion and Isotope Production and Decay Heat Analysis	Activation, Decay Heat, Radionuclide Inventory
CINDER'90	Depletion and Isotope Production and Decay Heat Analysis	Activation, Decay Heat, Radionuclide Inventory
ANISN	1-D Low Energy Neutron and Photon Transport	Energy Deposition, Material Damage and Activation, Shielding
DORT	2-D Low Energy Neutron and Photon Transport	Energy Deposition, Material Damage and Activation, Shielding
TORT	3-D Low Energy Neutron and Photon Transport	Energy Deposition, Material Damage and Activation, Shielding
CASL	3-D Semi-Empirical Shield Analysis	Shielding
HILO	Multi-Group Cross Section Library to Extend ANISN/DORT/TORT Energy Range up to 2 GeV	Energy Deposition, Material Damage and Activation, Shielding

C.0 APPENDIX C: AIRBORNE RADIOACTIVE MATERIAL HAZARDS FOR THE SNS RING INJECTION BEAM DUMPS (REFERS TO SECTION 4.3.3)

Appendix C: Airborne Radioactive Material Hazards for the SNS Beam Dumps (refers to Section 4.3.2)

Since the SNS beam dumps constitute an integral part of the SNS accelerator they come under the accelerator safety order (DOE O 420.2B) and its guidance document.

To allow consideration of airborne hazard potential with the Ring Injection Dump, the consequences of an injection dump coolant spill are analyzed.

The rationale for concentrating on the injection dump is that it has, by far, the highest radionuclide inventory. SNS design parameters for the beam dumps (see Section 3.2.1.5) specify design beam power of 7.5 kW with a 10% duty factor for the LINAC and Ring extraction dumps, in contrast to the 150 kW design beam power with 100% duty factor for the injection dump. The LINAC and Ring extraction dumps operate at power < 4% for a fewer number of hours relative to the injection dump (500 h/y instead of the 5000 h/y). The LINAC and Ring extraction dumps log no more than 0.4% as much-integrated irradiation as the injection dump. The two 7.5 kW dumps, therefore, build up only 0.4% as much long-lived spallation products as the injection dump. The HEBT arc "off-momentum" dump receives some beam continuously but at the level of ~ 2 kW.

Airborne radioactivity concentrations following a water spill accident were predicted[C-1] for an assumed spill in the injection dump utility vault (concrete building surrounding the active components of the dump's cooling and cooling water purification system). Conservative assumptions were made regarding evaporation of water, its radioactive contaminants, and their accumulation in the atmosphere of the dump. The result showed that the total concentration of radioactivity in the vault's air could reach 12 times the composite level allowed under routine occupational conditions (i.e., 12 times the composite Derived Air Concentration for the radionuclides involved per 10 CFR 835). This is obviously not a significant accident concern even with static air because of limited occupancy. Moreover, the vault is actually a ventilated space (exhausted to the main ventilation stack), so the attainable concentration would be considerably less than 12 times the routine occupational limit reported above. This is not indicative of a situation that needs further detailed evaluation or that would indicate the needed for credited controls.

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C-1 G.B. Stapleton and R.M. Harrington, *Injection Dump Potential Airborne Release Concentrations*, 102030103-ES0004-R00, Spallation Neutron Source, Oak Ridge, TN, August 2000.

D.0 APPENDIX D: SAFETY FOR CRYOGENIC OPERATIONS AT SNS (REFERS TO SECTION 4.4.2)

Appendix D: Safety for Cryogenic Operations at SNS

Background

Cryogenic fluids are designated as those with normal boiling point temperatures (T_{NBP}) at or below 123 K at one atmosphere. There are several categories of hazards associated with cryogenic systems: brittleness of structural material, overpressurization transients, exposure to extreme cold, and oxygen enrichment/ displacement. Some normal operations may be inherently hazardous. Other hazards can occur as the result of an inadvertent fluid release. Figures D-1a and D-1b show uniform oxygen depletion as a function of the release and compartment volumes for helium and nitrogen.

SNS Cryogenic Safety Policy

Cryogenic safety is important in avoiding: (1) injury to operating personnel and the general public; (2) financial losses; and (3) negative public reaction. The goal of cryogenic safety at the SNS is to have safe systems that are operated safely. Hazard evaluation (system hazard analysis and JHA) in both phases of the process achieves safe system design and operation.

Cryogenic Areas and Cryogenic Work are defined below. Activities in Cryogenic Areas and Cryogenic Work shall meet the minimum requirements of Table D-1, Basic Safety Requirements for Cryogenic Areas/Work. Figure D-2 illustrates the signage typically posted outside SNS cryogenic areas. Figure D-3 depicts oxygen monitoring equipment utilized with SNS cryogenic areas.

Any SNS area containing a complex cryogenic system shall be screened in accordance with Figure D-4 to determine the hazard analysis requirements and to determine the need for additional ODH analyses (Figure D-5). Any work on a complex cryogenic system shall be screened per the process depicted on Figure D-6 to determine the need for safety requirements in addition to those of Table D-1.

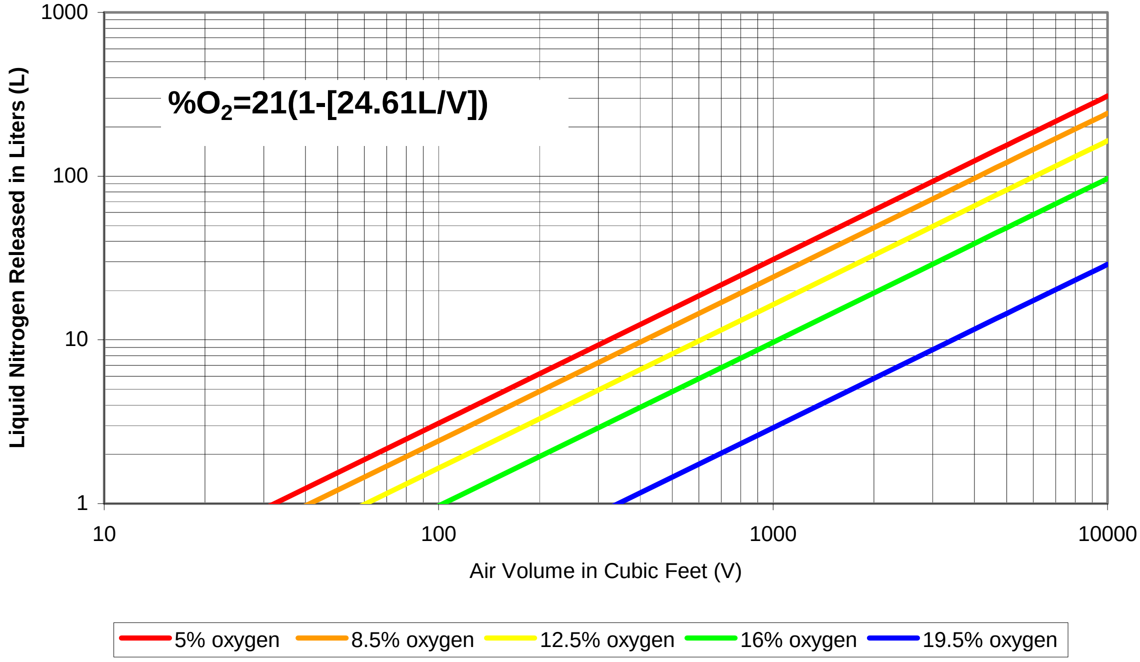
The frequency of system failure is important in hazard analysis. Conservative failure rate estimates for identified failure modes shall be employed as an aid in establishing the required Credited Engineered Controls, operational safety requirements, and any SIS (Figure D-8). Failure rate estimates will not typically be used for Cryogenic Work hazard evaluations in establishing PPE, operational safety requirements, and Credited Engineered Controls that depend on the nature of the activity since it is assumed that contact with the cryogen is likely (Figure D-6).

Scope and General Applicability

Cryogenic safety, as used herein, applies to personnel safety and requires application of appropriate hazard analysis methods when the complexity of the system extends beyond the use of portable dewars employed in standard practice or dewar storage volume is large enough to deplete oxygen concentration breathable by workers to below 19.5%. These methods provide the input by which elements of the SIS, establishment of operational safety requirements, PPE, and other features are specified to mitigate cryogenic hazards. Credited Engineered Controls and SIS designations may be required to mitigate oxygen deficiency concerns whenever estimates of potential releases of cryogens from complex systems or storage quantities are sufficient to displace the oxygen concentration below 16% (partial pressure of O_2 121.6 mm Hg). Figures D-1a and D-1b show uniform oxygen depletion as a function of the release and compartment volumes for helium and nitrogen.

Oxygen deficiency is defined as 19.5% (partial pressure of $O_2 < 148$ mm Hg) for purposes of specifying safe working conditions and the selection of appropriate PPE. Other cryogenic hazards will be considered whenever personnel may come in contact with the systems/fluids. Safe cryogenic system design is dealt with elsewhere, but Credited Engineered Controls of cryogenic systems design are designated through this process, including the specification of SISs.

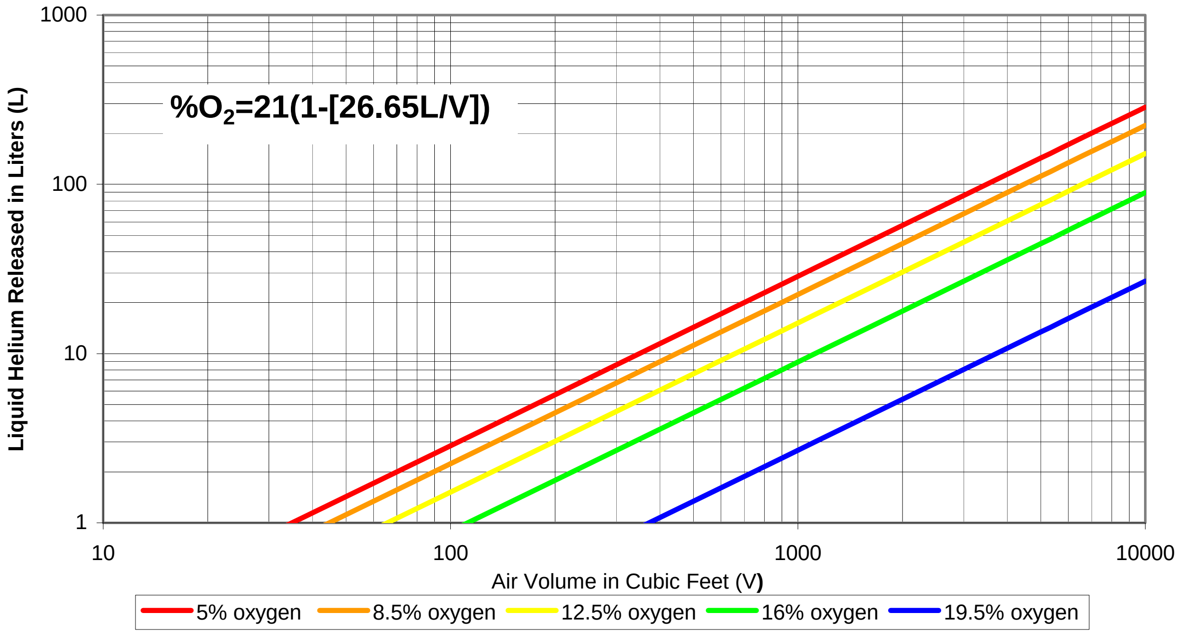
Liquid helium and nitrogen will be in common use at SNS; however, all cryogenic fluids fall under the scope of this document. Areas containing cryogenic fluids served by complex systems or storage in sufficient quantities to lower the oxygen concentration to less than 19.5% in the event of a release and where people enter and work are designated as “Cryogenic Areas.” Work on cryogenic systems with potential for fluid release is designated as “Cryogenic Work.” Minimum safety considerations for these designations are specified in Table D-1.



Typical impact of oxygen concentrations indicated:

- Above 19.5% — no concern
- Above 16% — no escape impairment
- Between 8.5 and 16% — escape time > 5 minutes
- Between 5 and 8.5% — escape time < 5 minutes
- At or below 5% — immediate incapacitation

Figure D-1a Oxygen Concentration as a Function of LN2 Volume



Typical impact of oxygen concentrations indicated:

- Above 19.5% — no concern
- Above 16% — no escape impairment
- Between 8.5 and 16% — escape time > 5 minutes
- Between 5 and 8.5% — escape time < 5 minutes
- At or below 5% — immediate incapacitation

Figure D-1b Oxygen Concentration as a Function LHe Volume

Table D-1		
Basic Safety Requirements for Cryogenic Areas/Work		
Requirements	**Cryogenic Classification[1]**	
	Cryogenic Area	**Cryogenic Work**
Safety/Environmental Protections		
Restricted Access	Oxygen Deficiency Hazards Only[2]	X
Fixed Point Oxygen Monitors		As provided for the cryogenic area in which the work occurs
Penetration Sealing		
General Mechanical Ventilation		
Permanent Cryogenic Warning Signs		
Local Exhaust/Supply Ventilation	Not applicable.	Per JHA/SOP
Personnel Safety Qualifications		
Initial Cryogenic Safety Training	X	X
Respirator Qualified[3]	Per JHA or SOP	
Activity-Specific Safety Training	X	X
Administrative Protections		
Cryogenic Job Hazard Analysis	X	X
SOP	For Routine Activities (removes requirement for additional JHAs)	
Buddy System[4]	Per JHA or SOP	
Unexposed Observer (attendant)		
Pre-Entry Visitor Briefing	X	X
Visitor Escort	Per JHA or SOP	X
Emergency Rescue on Standby	Not Applicable	Per JHA or SOP
Personal Protective Equipment		
Personal Oxygen Monitor	Per JHA or SOP	
Atmosphere Supplying Respirator		
Eye Protection		
Gloves		
Clothing/Shoes		
Head Protection		

[1]A Cryogenic Area is any area (or entry into such area) containing cryogenic fluids in a quantity sufficient to produce a hazardous condition (oxygen deficiency below 19.5% [partial pressure of O_2 < 148 mm Hg], frost bite, hypothermia, oxygen enrichment, embrittlement, overpressurization) during normal operations or in the event of an accident. Cryogenic work is specific work on cryogenic systems with the potential to produce a hazardous condition.

[2]Credited Engineered Controls may be invoked when the oxygen level could decrease below 16% (partial pressure of O_2 < 121.6 mm Hg).

[3]Medical approval for fitness for respirator use meets requirements for medical suitability to enter Cryogenic Areas and to perform Cryogenic Work.

[4]Consider specifying an attendant who can summon aid whenever the potential consequence could limit the ability to self-rescue.

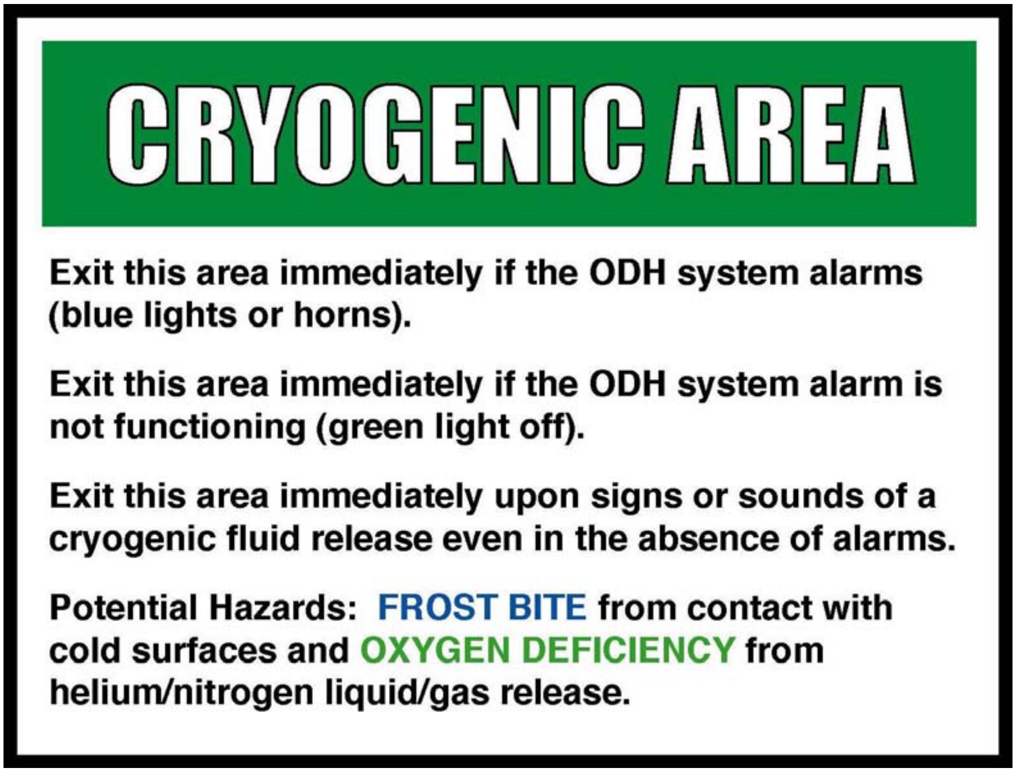
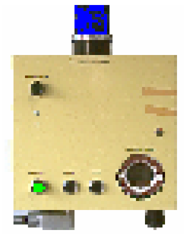


Figure D-2 Typical Posting outside Entrances to SNS Cryogenic Areas

OXYGEN MONITORING



• Oxygen-monitoring equipment and associated visual and audible alarms have been placed at the entrances to cryogenic areas, as well as in strategic locations within the cryogenic areas.

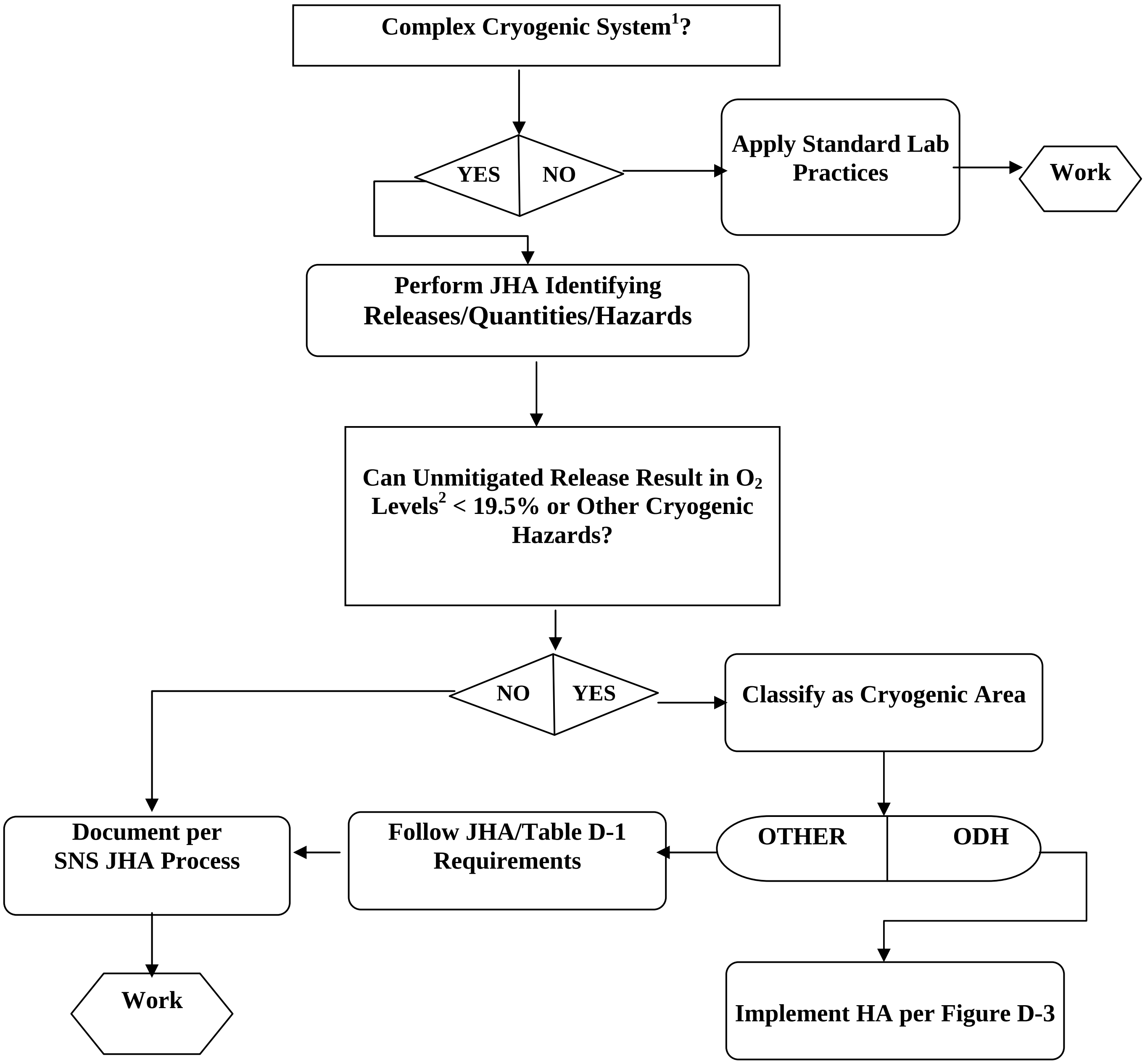
• A **green** systems status light on the visual alarm box means the equipment is functional.

• A flashing **blue** light on the visual alarm box means the oxygen level is below 19.5%. If inside, **evacuate the area immediately**. If outside, **do not enter**.

• An audible tone also sounds in the area when the oxygen level drops below 19.5%. All personnel, regardless of their activity, must **immediately evacuate**.

• A cryogenic **area must not be occupied or entered** without personnel protective devices or oxygen monitoring equipment in any case **when the system status light is not green** or the blue light is flashing.

Figure D-3 Illustration of Typical Oxygen Monitoring Equipment at SNS Cryogenic Areas



[1]A complex cryogenic system is one that goes beyond the use of portable dewars employed in standard practice.

[2]At a minimum, consider two cases: (1) full inventory is released with no personnel present, complete mixing occurs, personnel subsequently re-enter and (2) inventory is being discharged while personnel are present.

Figure D-4 Determining Cryogenic Areas and Associated Safety Requirements

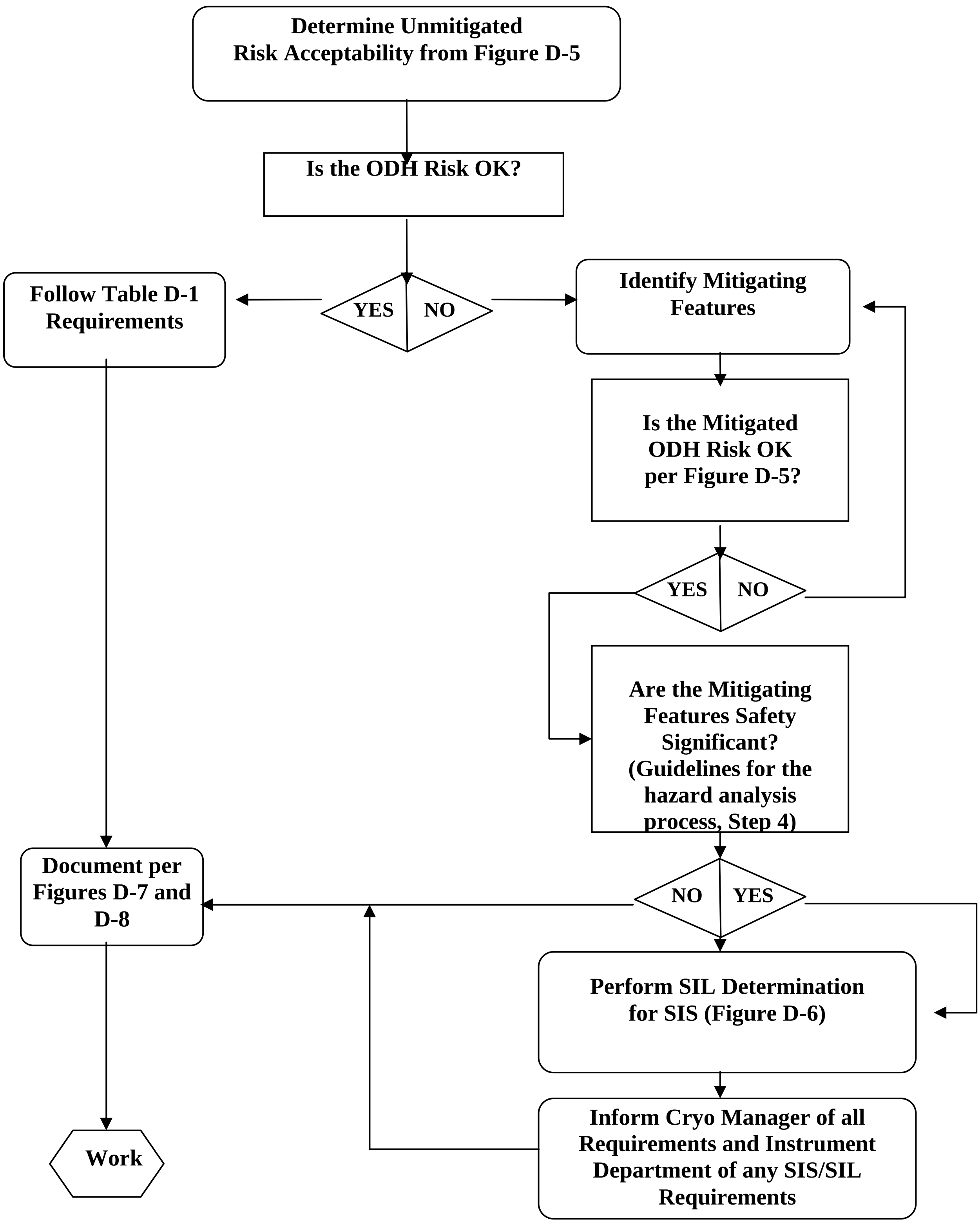
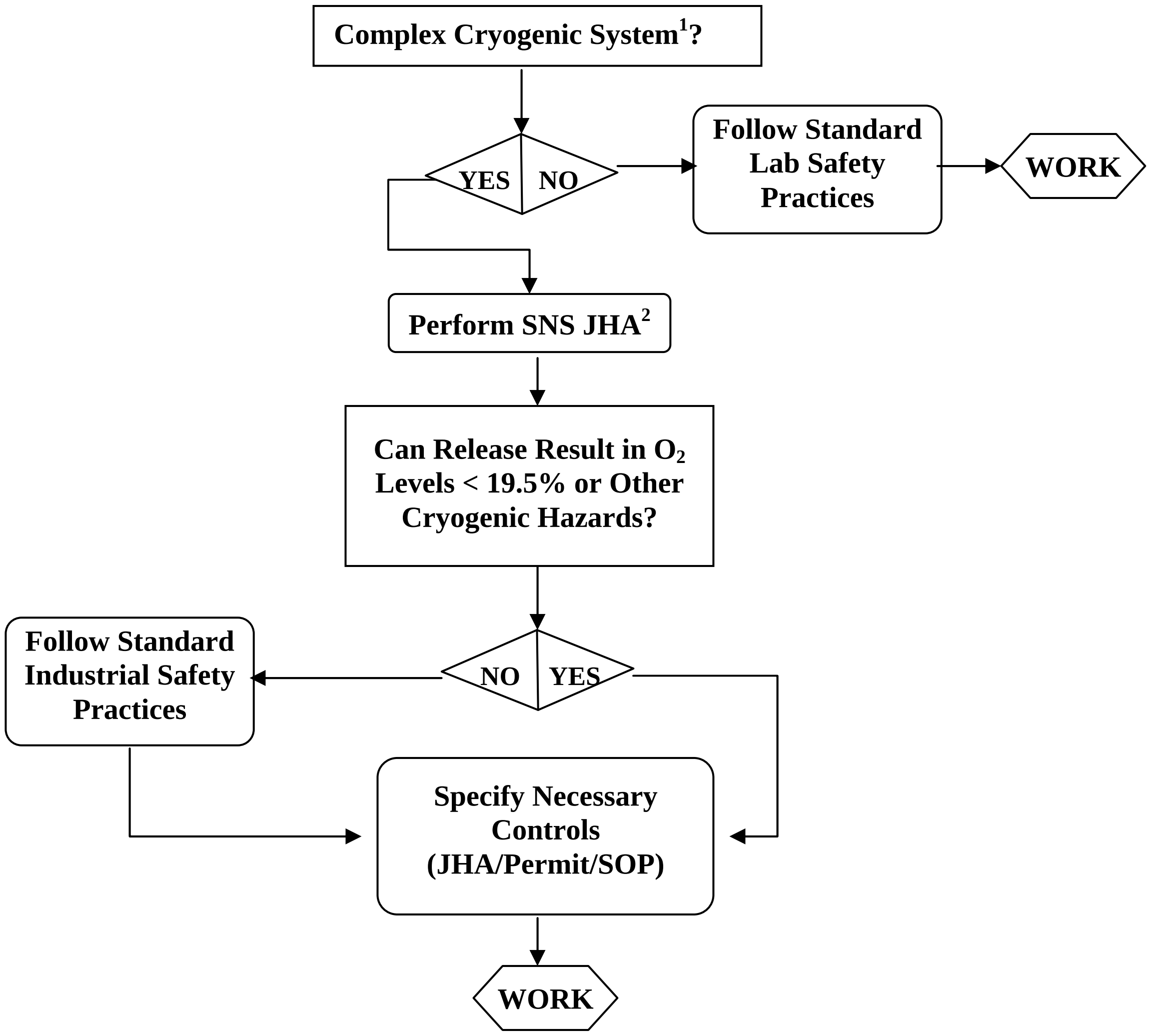


Figure D-5 Oxygen Deficiency Hazard Analysis to Establish Credited Engineered Controls and SIS Requirements



[1]A complex cryogenic system is one that goes beyond the use of portable dewars employed in standard practice.

[2]Inventory is being discharged while personnel are present. Consider two cases: (1) personnel are in close proximity to the release and (2) personnel are distant from the release point.

Figure D-6 Cryogenic System Work

Guidelines for the Hazard Analysis Process

A facility owner can make rational risk acceptance decisions only after sufficient study of the risks to be incurred. Hazard analysis is the risk assessment process followed for most DOE facilities. It is well suited to helping understand risk because it requires the facility owner to understand both the likelihood and consequences of hazards. A hazard analysis comprises the following steps: (1) hazard identification and screening; (2) assessment of the potential consequences of unmitigated risk; (3) identification of relevant and effective mitigation measures; and (4) assessment of mitigated risk. At this point in the hazard analysis, it is possible to understand the risk and to make an informed “risk acceptance” decision. It is highly desirable to show that SNS facility risks are in the “extremely low” category (see Figure D-7 below). The following steps and decision criteria should be followed in the hazard analysis process:

1. Hazard identification produces a comprehensive list of hazards present in a process or facility, and the screening phase removes all hazards that are below a threshold of concern or that are covered by recognized industrial codes and standard(s). The hazards that are “screened out” do not need to be studied in a hazard analysis because their risks are already considered to be well understood and acceptable.
2. For each hazard retained for hazard analysis, the unmitigated risk is first evaluated in terms of frequency and consequence. This places it on the risk matrix (see Figure D-7).
    a. The unmitigated risk does not include any safety or control systems or administrative controls.
    b. Assigned frequencies are based on engineering judgment or operating experience (see Table D-2 for examples).
    c. Assigned consequence can be qualitative but must be conservative.
    d. If the risk is acceptable, i.e., low or, preferably, extremely low, the process can stop at this point. Otherwise, proceed to Step 3 to evaluate mitigation.
3. Now the risk is re-evaluated considering all the mitigating factors in place that would either reduce the consequence or make the challenge less frequent. This should move the location on the risk matrix based on assumed conditional probabilities of failure for the mitigating systems (see Table D-3 for assignment of conditional probabilities to failure of mitigating systems or actions).

a. At this point the risk should be low or extremely low, preferably extremely low, since it is necessary to prove that SNS only has the potential for minor onsite consequences.

b. Now all that remains is the designation of Credited Engineered Controls or credited administrative controls, so proceed to Step 4 (see Figure D-8).

4. The purpose of the Credited Engineered Control designation is to highlight a minimum number of equipment items and/or administrative controls needed to ensure safety.

   a. The number of Credited Engineered Controls needs to be held to a minimum so the designated equipment can be treated specially and can be considered for incorporation into the Safety Envelope.

   b. If the unmitigated consequence is fatal or can cause permanent disability for one or more persons, then a Credited Engineered Control designation should be made. Equipment is selected in favor of administrative control if at all practical.

Consequence Severity					
	High $O_2 < 5\%$ **Death or Permanent Disability**	-Low- Marginally Acceptable	-Medium- Not Acceptable	-High- Not Acceptable	-High- Not Acceptable
	Medium $5\% \le \%O_2 < 12.5\%$ **Serious Injury**	-Extremely Low- OK	-Low- Marginally Acceptable	-Medium- Not Acceptable	-High- Not Acceptable
	Low $12.5\% \le \%O_2 < 16\%$ **Minor Injury**	-Extremely Low- OK	-Extremely Low- OK	-Low- Marginally Acceptable	-Low- Marginally Acceptable
	Extremely Low $O_2 \ge 16\%$ **No Injury**	-Extremely Low- OK	-Extremely Low- OK	-Extremely Low- OK	-Extremely Low- OK
		Extremely Unlikely ($<10^{-4}$/y)	**Unlikely** (between 10^{-4}/y and 10^{-2}/y)	**Medium** (between 10^{-2}y and 10^{-1}/y)	**High** (above 10^{-1}/y)
Accident Frequency					

Figure D-7 Oxygen Deficiency Risk Matrix

Table D-2
Guidelines for Selecting Frequency Category for Initiating Events for the Risk Matrix (see Figure D-7)
Assigning frequency to one of the probability categories is based on judgment, aided as practical with operating data.* Rationale 1: Categories based on expert opinion or common knowledge of rate of approximate frequency of occurrence. - Anticipated-events are those that occur at least once in the life of any given system. Frequency is in excess of once per 100 exposure years (An exposure year is assumed to be composed of 5000 exposure hours). - Unlikely events are those that may not have occurred at any similar facility but have probably occurred at least once in similar facilities of the free world. Frequency is between 100 to 10,000 exposure years. - Extremely unlikely events are events thought to be possible that may never have happened at any similar facility. They must be physically possible and credible events. They may or may not have ever actually occurred at a similar facility. - Beyond extremely unlikely events are, in the professional judgment of responsible engineers and scientists, not credible events. Similar events must never have occurred in a similar facility (or else they would be in a higher frequency category). Rationale 2: Frequency categories based on known equipment failure rate data. The following are examples based on data taken from Tables 3, 4, and 5 of the JNAL ES&H Manual (No. 6500-T3 beginning at page 8 of 14). - Power supply failure: 3E-6/h or 0.015 per 5000-h operating year. If ten power supplies can cause the same fault, then the frequency is 1.5E-1/y an Anticipated-High Event. - Welds leak at 1E-9/y. If each weld is in a stressed condition for 5000-h per year, and there are ten welds whose failure could invoke a given hazard, then the approximate event frequency is 5E-5/y, an Extremely Unlikely Event. If the number of welds that can leak is 100, then the frequency increased to 5E-4 and moves into the Unlikely Event category. Rationale 3: Where assessments address risk of personnel injury, it is appropriate to multiply (logical "and") probabilities for occupancy time with system failure probabilities.

* Caveat: The frequency of system failure is important in hazard analysis. Conservative failure rate estimates for identified failure modes shall be employed as an aid in establishing the required Credited Engineered Controls, operational safety requirements, and any SIS (Figure D-8). BNL, Fermilab, and JLab maintain updated failure rates on cryogenic equipment derived from their collective operating experience. Failure rate estimates will not typically be used for Cryogenic Work hazard evaluations in establishing PPE, operational safety requirements, and Credited Engineered Controls that depend on the nature of the activity since it is assumed that contact with the cryogen is likely (Figure D-6).

Table D-3

Guidelines for Assigning Success Probability to Mitigating Actions for the Risk Matrix (see Figure D-7)

To understand effectiveness of mitigating action, either administrative or automatic, it is necessary to assign an approximate conditional probability of success in the given circumstance. Given that the hazard-related initiating event has occurred, what is the likelihood of success for the mitigating action.

Here are some example guidelines:

- Automatic action, safety-instrumented system: Between 0.99 and 0.999 for a SIL-2 (Safety Integrity Level 2) system and between 0.9 and 0.99 for a SIL-1 system.
- High-integrity, non-safety system: Given the financial consequences involved, action of the MPS will be designed to provide success probability of between 0.9 and 0.99 for threats it is designed to counter.

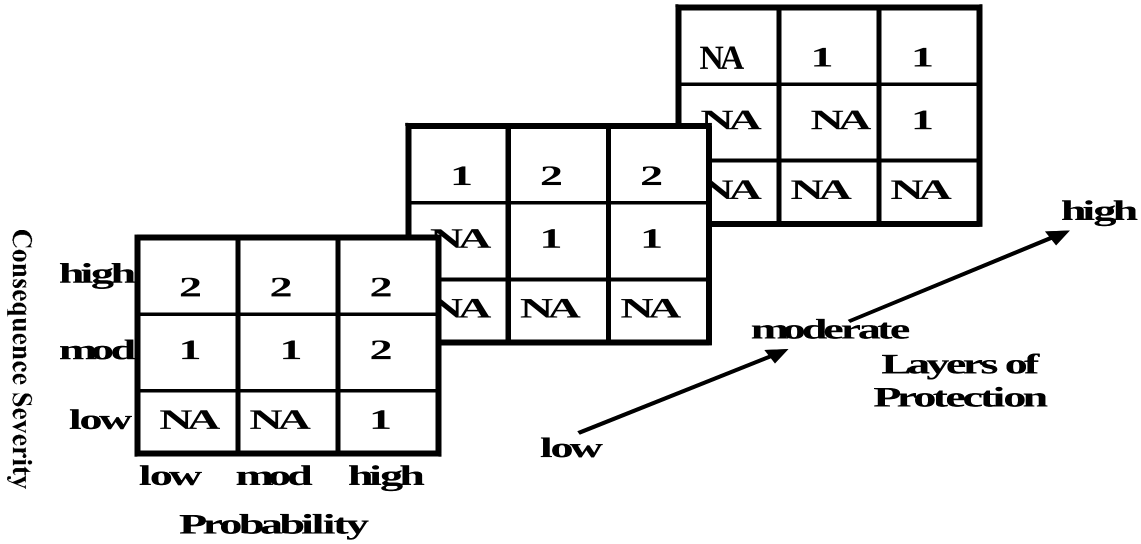
Personal self-protective actions:

- If the worker is specifically trained to evacuate on a given signal (ODH alarm, moisture cloud, etc.), then it is highly likely (probability > 0.99) that the worker will begin evacuating within a second.
- If some diagnoses and/or thought are necessary (even for a trained worker), the worker may still evacuate with high certainty but only after a sufficient delay, e.g., one to two minutes.
- Evacuation is highly likely even without specific training for unambiguous trouble signs such as obvious smoke or flames or severe earthquake shaking.

Even a loud, obvious alarm cannot be assumed to elicit quick evacuation without training. For example, riggers who are in the building for a pickup or delivery cannot be assumed to evacuate without being told. In an incident that occurred several years ago, riggers in a DOE facility covered their ears and stayed inside the building until specifically instructed to evacuate by one of the building personnel. Similarly, only ODH-trained workers can be assumed to evacuate following an ODH alarm.

- Other Administrative Actions:

  Must be evaluated on a case-by-case basis. Administrative actions credited in an SNS hazard analysis must be consistent with the experience of SNS personnel at other DOE accelerator facilities. Actions noted in the hazard analysis must be only those that can be expected to come under strict management control and surveillance at a well-managed accelerator facility.



Consequence Severity (Conservative Minimum Oxygen Concentration as $\%O_2$)

Extremely Low	$\%O_2 \geq 16\%$
Low	$12.5\% \leq \%O_2 < 16\%$
Moderate	$5\% \leq \%O_2 < 12.5\%$
High	$\%O_2 < 5\%$

Likelihood of Occurrence for initiating events (Conservative Accidental Release as failure rate/y, "f")

Extremely Unlikely	f < 1E-4/y
Low	1E-4/y ≤ f < 1E-2/y
Moderate	1E-2/y ≤ f < 1E-1/y
High	f > 1E-1/y

Effectiveness of Protection Layers (n) *not dependent on personnel actions whose effectiveness cannot be verified*

Low	n = one or less protective systems in place
Moderate	n = two protective systems in place
High	n = more than two protective systems in place

Figure D-8 Establishing Safety System Requirements (Numbers in boxes are safety integrity levels [SILs)].)

Other Cryogenic Hazards

Apart from the potential for oxygen deficiency, cryogenic fluids present a risk of cold injury; namely hypothermia and frostbite. Fatal exposures to cold among workers have almost always resulted from accidental exposures involving failure to escape from low environmental air temperatures.[D-1] Temperature measurements taken during experimental releases of liquid helium at Jlab, BNL, and Fermilab in or near the helium cloud found ambient temperatures as low as -40 to -150 °C. Exposed surfaces conducting cryogenic fluids may be much colder.

Hypothermia: Hypothermia is an abnormal lowering of the core body temperature (37.6 °C). The threshold for hypothermia has been established as a decrease in core body temperature to 36 °C. Pain or stiffening of the extremities may be the first early warning of danger to cold stress. A core body temperature drop of 2.6 °C (35 °C) is outwardly manifested by maximum shivering and has been classified as clinical hypothermia. Shivering must be taken as a sign of danger to workers, and exposure to cold should be immediately terminated. Severe hypothermia results from a core body temperature below 33 °C, and resuscitative measures are usually necessary for recovery. At SNS, unimpaired evacuation involves short times and distances. Therefore, it has been determined that hypothermia is not a credible event for purposes of hazard analysis.

Frostbite: Frostbite literally means freezing of the tissue and can occur from contact with surfaces or cold ambient temperatures below the freezing point of water. Theoretically, contact frostbite becomes a concern when surface temperatures are ≤ -7 °C or ambient temperatures are ≤ -17.5 °C. At cryogenic temperatures (< -150 °C) frostbite is a credible event for any area of the SNS where cryogenic fluids are found, either through splash, direct contact with the liquid, or cold surfaces (including air) that has lost heat to the cryogen. For very small splashes, there is some limited protection due to the low latent heat and the formation of a protective layer of gas that prevents efficient wetting of the skin.[D-2] Standard industrial practice in the form of administrative controls and PPE requirements will be adopted by SNS to allow work with cryogenic fluids to take place safely.

Protection From Hypothermia and Frostbite: The American Conference of Governmental Industrial Hygienist's have proposed a series of recommendations to control cold stress in their Threshold Limit Values™ documentation. The SNS intends to implement these recommendations as part of a program to prevent the nonfatal aspects of hypothermia and injuries resulting from the freezing of exposed skin and

Table D-4

Cooling Power of Wind on Exposed Flesh Expressed as Equivalent Temperature (under calm conditions)*

Estimated Wind Speed (in mph)	Actual Temperature Reading (°F)											
	50	40	30	20	10	0	-10	-20	-30	-40	-50	-60
	Equivalent Chill Temperature (°F)											
calm	50	40	30	20	10	0	-10	-20	-30	-40	-50	-60
5	48	37	27	16	6	-5	-15	-26	-36	-47	-57	-68
10	40	28	16	4	-9	-24	-33	-46	-58	-70	-83	-95
15	36	22	9	-5	-18	-32	-45	-58	-72	-85	-99	-112
20	32	18	4	-10	-25	-39	-53	-67	-82	-96	-110	-121
25	30	16	0	-15	-29	-44	-59	-74	-88	-104	-118	-133
30	28	13	-2	-18	-33	-48	-63	-79	-94	-109	-125	-140
35	27	11	-4	-20	-35	-51	-67	-82	-98	-113	-129	-145
40	26	10	-6	-21	-37	-53	-69	-85	-100	-116	-132	-148
(Wind speeds greater than 40 mph have little additional effect.)	*LITTLE DANGER* In < hr with dry skin. Maximum danger of false sense of security				*INCREASING DANGER* Danger from freezing of exposed flesh within one minute.				*GREAT DANGER* Flesh may freeze within 30 seconds.			
	Trenchfoot and immersion foot may occur at any point on this chart.											

* Developed by U.S. Army Research Institute of Environmental Medicine, Natick, MA.

body extremities. Table D-4 provides levels of concern for various temperature/air movement conditions. The "documentation" provides specific and detailed recommendations to be followed for given environmental conditions and will not be reproduced here.

Oxygen Enrichment: The fire hazard in an oxygen-enriched environment is usually significantly greater than in ordinary air. In general, the greater the oxygen concentration, the lower the minimum ignition energy, the faster the flame spread, and the greater the range between the lower and upper flammable limit (usually the UFL is increased with little effect on the LFL). Some materials not considered flammable in air become flammable in an oxygen-enriched environment. For example, dibromodifluoromethane is nonflammable in air. In oxygen, this halogenated hydrocarbon becomes flammable (LFL = 29%, UFL = 80%).[D-3]

Atmospheric air (oxygen and nitrogen) that comes in contact with a surface below the boiling point of nitrogen may condense into a liquid. Frozen water vapor forming a frost usually acts as an insulator preventing air condensation. However, when air does condense, the condensate that may drip off the surface could contain a disproportionate amount of oxygen owing to its higher boiling point. The oxygen content may be increased to as much as 40%.[D-4] **Therefore, liquid condensate, as well as ice crystals, shall be procedurally handled as oxygen enriched, i.e., allowed to dissipate into the air while keeping combustibles and ignition sources segregated.** Currently, operating experience in the other accelerator laboratories has not indicated that this is a credible event.

PPE to be worn when working with cryogens:

- Eyes — Safety glasses with shields at all times
- Face — Full-face shield where pressure releases are possible
- Hands — Loose fitting gloves that can be easily removed, not fitted with gauntlets in which liquids can collect (leather or cryogenic specialty fabric)
- Clothing — Long trousers without cuffs to be worn outside shoes (the less porous the fabric the better); no open or fabric shoes
- Fabrics — Close weave best

Caution: Ice on cryogenic surfaces requires the assumption of oxygen enrichment. Clothing that has been in contact with melting ice should be considered to be oxygen enriched—no ignition sources for 30 minutes minimum after initial contact.

SNS ES&H Calculation Note Cover Sheet

<table>
<tr><td rowspan="2">Title:</td><td>Document Number:</td></tr>
<tr><td>Sheet 1 of __________</td></tr>
<tr><td colspan="2">Computer programs used, if any, including version number and V&V status:</td></tr>
<tr><td colspan="2">Purpose and Objective:</td></tr>
<tr><td colspan="2">Conclusions:</td></tr>
</table>

<table>
<tr><td colspan="2">Revisions</td></tr>
<tr><td>Revision Number</td><td>Revision Description</td></tr>
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<tr><td colspan="5">Sign-Off</td></tr>
<tr><td>Revision Number</td><td>Originator (Print) Sign/Date</td><td>Verification/ Checking Method</td><td>Verifier/Checker (Print) Sign/Date</td><td>Manager (Print) Sign/Date</td></tr>
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Figure D-9 Example SNS ES&H Calculation Note Cover Sheet

FACILITY NAME:________________________________ NUMBER:_________________________
SYSTEM:_______________________________________
SUB-SYSTEM:___________________________________
HAZARD:______________________________________

Event Possible Consequences and Hazards:				
Potential Initiators:				
Risk Assessment Prior to Mitigation				
Severity:	High ( )	Medium ( )	Low ( )	Extremely Low ( )
Probability:	Anticipated-High ( )	Anticipated-Medium ( )	Unlikely ( )	Extremely Unlikely ( )
Risk Category:	High Risk (Unacceptable) ( )	Medium Risk (Unacceptable) ( )	Low Risk (Marginally Acceptable) ( )	Extremely Low (OK) ( )
Hazard Mitigation				
Risk Assessment After Mitigation				
Severity:	High ( )	Medium ( )	Low ( )	No Hazard ( )
Probability:	Anticipated-High ( )	Anticipated-Medium ( )	Unlikely ( )	Extremely Unlikely ( )
Risk Category:	High Risk (Unacceptable) ( )	Medium Risk (Unacceptable) ( )	Low Risk (Marginally Acceptable) ( )	Extremely Low (OK) ( )
Credited Engineered Controls and SILs				

Figure D-10 Example Hazard Analysis Results Summary Form

Suggested Methods of Estimating Oxygen Concentration

The analyst must choose between simplified hand-calculation methods (Items 1 and 2 below) or more sophisticated computer modeling (Item 3), depending on the complexity of the geometry involved.

Note: Ventilation is not considered in the hazard analysis phase of a risk evaluation and does not appear as a term in any of the following equations.

1. Single-zone first approximation model for determining oxygen levels in the enclosure of interest (simple volume-to-volume mix):

$$\%O_2 = 21\left(1 - Gt/V\right)$$

t = release time
G = gas release rate
V = volume into which gas is released

2. Two-zone ventilation model for determining oxygen levels (w/o dilution ventilation):

Near Field: $C_{nf}(t) = .21e^{-\frac{G}{V}t}$, for a freely expanding gas front, the oxygen concentration can be approximated as 7.7%.

Far Field: $$C_{ff}(t) = .368\left(\frac{\frac{21G}{V_{ff}}}{G - \frac{V_{ff}}{t}}\right) + .21\left(1 - \frac{\frac{G}{V_{ff}}}{G - \frac{V_{ff}}{t}}\right)e^{-\frac{G}{V_{ff}}t}$$

3. Computational fluid dynamics (CFD) modeling (see Figure D-11 below for an example):

300 g/s Release Midway Through Tunnel – 2D CFX Simulation

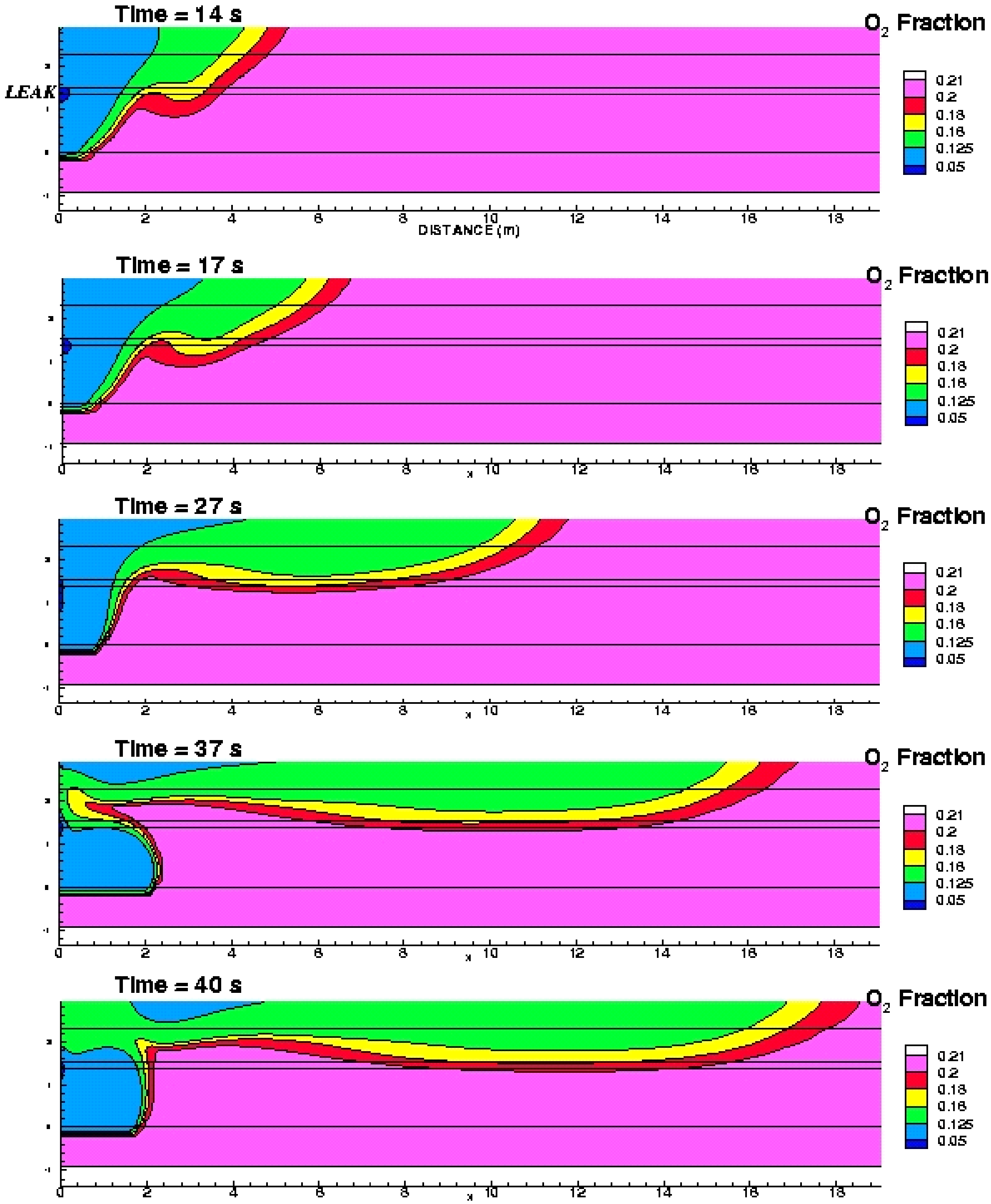
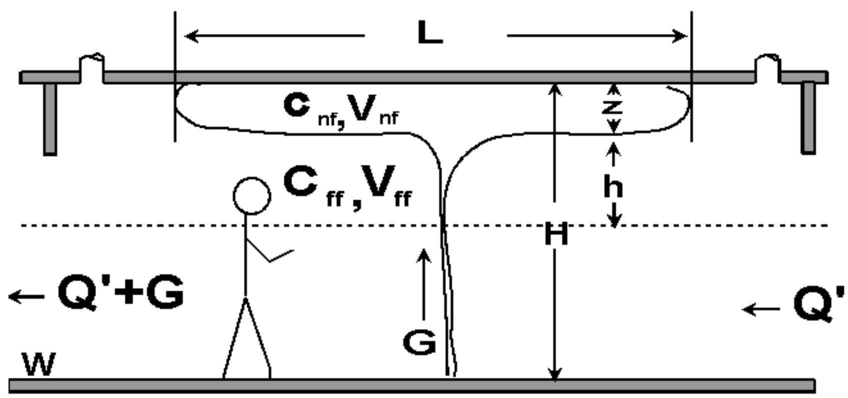


Figure D-11 CFD Modeling of Helium Release in the LINAC

Simple Modeling Approach

Considering the results of the CFD modeling presented in Figure D-11 above, a conceptualized two-zone ventilation model can be used for estimating potential oxygen levels resulting from a cryogenic fluid release as follows:

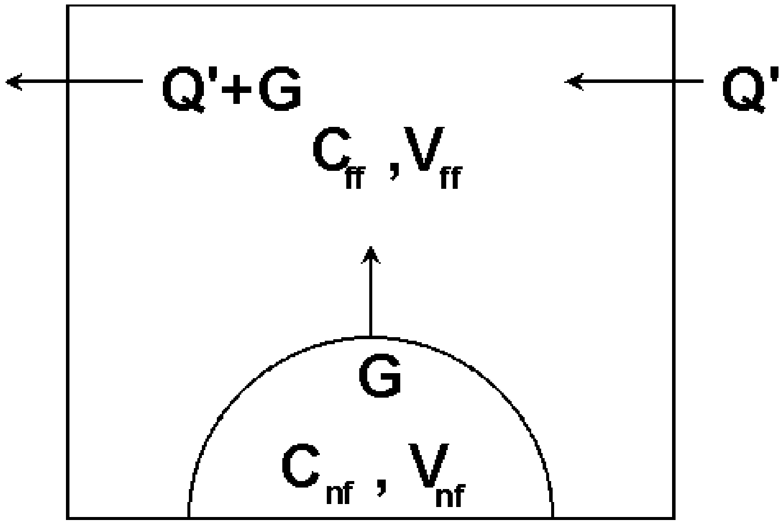
Model for Determining Oxygen Levels in the SNS Tunnel or Similar Structure



Q'	=	effective tunnel fresh air ventilation rate, ft^3/min. (if ventilation is considered as a control, this should be set to zero)
G	=	asphyxiating gas generation rate, ft^3/min.
C_{nf}	=	O_2 concentration in the near field at time "*t*," %
C_{ff}	=	O_2 concentration in the far field at time "*t*," %
V_{nf}	=	volume in the near field = *LWZ*, ft^3
V_{ff}	=	volume in the far field = *LW* (*H*-5-*Z*), ft^3
*L**	=	length of the near field and far field, ft
H	=	height of the tunnel, ft
H	=	height of the far field = *H*-5-*Z*, ft
Z	=	ceiling jet flow thickness, 0.12 x the distance from the release point to the ceiling, ft
W	=	tunnel width, ft
dL/dt	=	plume front velocity = (0.5*G*/*WZ*)+(*Q*/*HW*), ft/min.

*Length "*L*" is usually taken as 150 ft, the distance a person can travel in 15 seconds while holding breath.

Model for Determining Oxygen Levels in SNS Areas without Tunnel-Like Geometry



Q'	=	effective fresh air ventilation rate in the structure, ft^3/min. (if ventilation is considered as a control, this should be set to zero)
G	=	asphyxiating gas generation rate, ft^3/min.
C_{nf}	=	O_2 concentration in the near field in time "*t*," %
C_{ff}	=	O_2 concentration in the far field in time "*t*," %
V_{ff}	=	volume in the far field = structure geometry, ft^3
V_{nf}	=	volume in the near field = $\varphi \pi R^3$ = approximated by a sphere of 75 ft radius, the distance a person can travel in 15 seconds while holding breath
φ	=	4/3 for a point source (sphere), 2/3 for a near-floor release (hemisphere), 1/3 for a floor/wall juncture release, and 1/6 for a corner release
dR/dt	=	plume front velocity = $.228\,(1/\varphi)^{1/3}(.25G)^{-2/3}G$, ft/min.

Coupled Mass Balance Equations for the Two-Zone Model with Ventilation Flow

Near Field: $$V_{nf}\frac{dC_{nf}}{dt} = G - GC_{nf}$$

Solution: $$C_{nf}(t) = .21e^{-\frac{G}{Vnf}t}$$

Far Field: $$V_{ff}\frac{dC_{ff}}{dt} = .21Q' + .21Ge^{-\frac{G}{Vnf}t} - (Q' + G)C_{ff}$$

Solution:

$$C_{ff}(t) = \frac{.21Q'}{Q'+G} + [\frac{.21G}{Q'+G-\frac{G}{V_{nf}}V_{ff}}]e^{-\frac{G}{V_{nf}}t} +$$

$$.21[1-\frac{Q'}{Q'+G}-\frac{G}{Q'+G-\frac{G}{V_{nf}}V_{ff}}]e^{-\frac{Q'+G}{V_{ff}}t}$$

Determine the model input parameters for the credible release (*G, Q, Q'*) (if ventilation is considered as a control, *Q'* should be set to zero).

1. Dimensions of the enclosing area, likely position of worker(s), distances to exits
2. Determine V_{nf} and V_{ff}
3. Calculate C_{nf} and C_{ff}

Source Term Characterization (*G*):

Any reasonable approach may be used. The following is an example of one method.

General simplifying/conservative assumptions:

- Tanks are full
- Liquid is saturated
- Release flow will be two-phase choked
- Gases are treated as perfect
- Flashing occurs rapidly and is adiabatic
- Tank pressure controls and natural flashing of liquid will keep tank/line pressures constant

Other considerations:

Small line breaks and relief valve discharges are likely events. Cracks in lines or tanks are the more likely form of containment release, but these consequences are bounded by a guillotine break of the largest line in the immediate system. Indoors, a large rupture of a tank is not considered credible due to the rugged nature of the tank used in cryogenic systems. Outdoors, a large rupture is credible from high-wind driven flying missiles, but the high winds would rapidly disperse the released gas.

Vessel Release Rate

$$Q_m = \frac{\Delta H_\upsilon A}{V_{fg}} \sqrt{\frac{g_c}{c_p T}}$$

where,	Q_m	=	mass flow, lbm/s
	ΔH_v	=	h_{fg} = latent heat of vaporization at storage conditions, BTU/lbm
	A	=	flow area, ft^2
	V_{fg}	=	$1/\rho_v - 1/\rho_l$, ft^3/lbm
	g_c	=	32.2 lbm ft/(lbf)(s^2)
	c_p	=	C_{pl}, BTU/lbm °F
	T	=	T_s, °R.

Flash Fraction

$$f = 1 - e^{-[c_{pl}(T_s - T_b)/\Delta H_v]}$$

where,	f	=	fraction of liquid vaporized
	c_{pl}	=	average liquid specific heat between storage/expanded conditions, BTU/lbm °F
	T_s	=	storage temperature, °F
	T_b	=	final boiling point temperature, °F
	ΔH_v	=	average latent heat of vaporization over the temperature range, BTU/lbm.

Shaw and Brisco Model for a Boiling Liquid Spill on Land

$$m_p = \pi^{1.5}[\frac{XK_s(T_g - T_b)}{\Delta H_v\sqrt{\pi\alpha_s}}](2gV_p)^{0.5}t$$

where,	m_p	=	evaporation rate, kg/s
	X	=	surface roughness factor, 1 for concrete
	K_s	=	surface thermal conductivity, .94W/m K for concrete
	T_g	=	surface temperature, °K
	T_b	=	boiling point of liquid at atmospheric pressure, K
	ΔH_v	=	latent heat at boiling point temperature, J/kg
	α_s	=	thermal diffusivity, concrete = 7.9E-7 m^2/s
	V_p	=	volumetric release rate of liquid into the pool, m^3/s.

Pool Radius Calculation

$$r = \sqrt{\frac{2}{3}}[\frac{8gV_p}{\pi}]^{0.25}t^{0.75}$$

where r is the time-dependent radius.

To find the time when the evaporation rate equals the spill rate, set

$Q_m(1-f) = m_p$ to solve for t and substitute the result into the equation for radius to obtain the maximum pool size.

REFERENCES

D-1 *Documentation of the Threshold Limit Values*, American Conference of Governmental Industrial Hygienists.

D-2 *Cryogenic Safety*, Proceedings of the 1959 Safety Conference, Allentown, Pennsylvania, July 1959.

D-3 *Fire Protection Handbook*, 17th ed., National Fire Protection Association, Quincy, Massachusetts, 1991.

D-4 *Handbook of Compressed Gases*, 2nd ed., Van Nostrand Reinhold Company, New York, 1981.

E.0 APPENDIX E: SNS SITE AND BUILDING FIRE HAZARDS ANALYSIS (REFERS TO SECTION 4.2.12)

Appendix E: SNS Site and Building Fire Hazards Analysis (refers to Section 4.2.12)

The FHAs completed for the SNS site and buildings, including the most recent revision dates, are listed below. Copies of these documents are accessible in the SNS ProjectWise document storage and retrieval system:

- Fire Hazard Analysis for the SNS Accelerator Facilities, Buildings 8100, 8200, 8300, 8340, 8310, 8320, 8330, 8350, 8520, 8540, 8550, 8918, 8413, 8423 and 8915, Rev. 0, 12/29/2008, SNS 108030000-ES0002-R00

- Fire Hazard Analysis for the SNS Target Building, Buildings 8700, 8702, 8705, 8707, 8711, & 8760 at the SNS, Rev 0, 12/31/2008, SNS 108030700-ES0008-R00

- Fire Protection Engineering Assessment for SNS Central Laboratory and Office Building 8600, 9/27/2010

- Fire Protection Engineering Assessment for the Site Utilities Buildings (8910, 8911, 8912, 8913, 8914, 8915, and 8950) at the SNS, Rev. 0, 3/26/2009, SNS108031100-FP0008-R02

- Fire Protection Engineering Assessment of the Receiving Acceptance Testing Storage (RATS) Building (8920) at the SNS, Rev. 2, 12/23/2008, SNS 108021200-ES0001-R02

F.0 APPENDIX F: LINAC ODH ANALYSIS (REFERS TO SECTION 4.4.2)

Note: The calculation (102030103-CA0001-R00) shown in this appendix has not been revised since 2002.

Appendix F: LINAC ODH Analysis (refers to Section 4.4.2)

Title: ODH Analysis for the LINAC and Associated Structures	**Document Number: 102030103-CA0001-R00** **Sheet 1 of 19**

Computer programs used, if any, including version number and V&V status:

2D CFX Simulations (M. Wendel) used for qualitative evaluations of helium behavior in tunnel.

Purpose and objective:

To determine the need for safety-related systems/controls to mitigate hazard related to potential for accidental release of helium in the SCL Tunnel.

Conclusion:

In the event of a cryogenic release from the supply system during off hours, sufficient helium can be released to reduce the oxygen concentrations in the LINAC, Front End, Klystron, HEBT, Ring, and RTBT to hazardous levels. Without providing some form of warning and control, unsuspecting staff returning to work could enter these facilities and be at risk of asphyxiation. Safety Significant initiation of the smoke removal fans by oxygen sensor signals provides adequate mitigation (SIL-1 level designated for this function based on estimated frequency of the event and the presence of non-safety-related layers of defense).

Revisions

Revision Number	**Revision Description**

Sign-Off

Revision Number	**Originator (Print) Sign/Date**	**Verification/ Checking Method**	**Verifier/Checker (Print) Sign/Date**	**Manager (Print) Sign/Date**
Original (Rev. 0)	**/s/ John Jankovic, 8/13/2002**	**Hand calculations, engr judgement**	**/s/R. M. Harrington 8/17/2002**	**/s/F.C. Kornegay, 8/19/2002**

ODH Analysis for the LINAC, Front End, HEBT, Ring/RTBT, and Klystron Building

Section 1A: Summary of Hazard Analysis Results—Most Limiting Case				
Event: Delay in detection allows the LINAC and attached structures to be flooded with helium in sufficient quantities to produce lethal conditions in some areas.				
Possible Consequences and Hazards: Brittleness fracture, valve failure				
Potential Initiators: During off hours, a LHe transfer line ruptures releasing helium into the LINAC at 150 g/s. This leak is undetected for 4 h.				
Risk Assessment Prior to Mitigation:				
Severity:	High (**X**)	Medium ( )	Low ( )	Extremely Low ( )
Probability:	Anticipated-High ( )	Anticipated-Medium (**X**)	Unlikely ( )	Extremely Unlikely ( )
Risk Category:	High Risk (Unacceptable) (**X**)	Medium Risk (Unacceptable) ( )	Low Risk (Marginally Acceptable) ( )	Extremely Low (OK) ( )
Hazard Mitigation	1. Oxygen sensors with corresponding visual and audible alarms installed in strategic positions 2. Cryogenic system alarms provided 3. Exhaust ventilation triggered by oxygen sensors placed at strategic points 4. Personnel trained to meaning of alarm notifications			
Risk Assessment After Mitigation:				
Severity:	High ( )	Medium ( )	Low ( )	Extremely Low (**X**)
Probability:	Anticipated-High ( )	Anticipated-Medium (**X**)	Unlikely ( )	Extremely Unlikely ( )
Risk Category:	High Risk (Unacceptable) ( )	Medium Risk (Unacceptable) ( )	Low Risk (Marginally Acceptable) ( )	Extremely Low (OK) (**X**)
Safety Significant Systems and SILs	Automatic initiation of LINAC smoke exhaust fans is Safety Significant. The safety function is to confine oxygen-deficient conditions to the vicinity of the SCL in the event of a long-term (150 g/s) release to the LINAC Tunnel. Instrumentation involved in the automatic initiation is designated as SIL-1.			

Source Terms

The SNS Cryogenic Safety Policy (see Appendix D) requires a hazard analysis for any complex cryogenic system capable of releasing sufficient helium to reduce the ambient oxygen to less than 16%. The hazard analysis considers both long- and short-term duration releases of helium to the SCL Tunnel.

1. Refrigerator-supplied (long-duration) release source term:

   The He release rate is limited by the capacity of the refrigerator and is maximally 150 g/s (data provided by SNS cryogenic engineering). This value is believed to bound any line leak, including a guillotine break.

   Storage conditions: 3 atm, 4.6 K

   Conditions at release point: 1 atm, 294 K

   Liquid/gas ratio (liquid at storage conditions, gas at 70 °F (294 K) and 1 atm v/v) is given by:

   ρ LHe at 4.6 K and 3 atm = 141.92 g/L

   ρ Ghe at 70 °F and 1 atm = 0.1656 g/L

   $$expansion\ \ ratio = \frac{141.92\ \ \mathrm{kg/m^3}}{0.1656\ \ \mathrm{kg/m^3}} = 857:1.$$

   Line Diameter/Area: 3/4" (0.0031 ft^2) to 1.5" (0.012 ft^2)

   Assumptions: Liquid He is at its saturated vapor pressure, choked, two-phase flow discharge, guillotine line break or puncture.

   Mass flow rate is approximated by:

   $$Q_m = \frac{\Delta H_v A}{V_{f_g}} \sqrt{\frac{g_c}{C_p T}}$$ (*Chemical Process Safety*, Prentice Hall, 1990, page 115)

   $$Q_m = \frac{(10.27\ \mathrm{BTU/lbm})(0.0031\mathrm{ft}^2)}{15.717\ \mathrm{ft^3/lbm}} \sqrt{\frac{(32.2\ \mathrm{lbm\cdot lbf^{-1}\cdot s^{-2}})(778\ \mathrm{ft\cdot lbf\cdot BTU^{-1}})}{(1.24\ \mathrm{BTU\cdot lbm^{-1}})(8.3^\circ\ \mathrm{R})}}$$

   $Q_m = 0.1\ \mathrm{lbm\cdot s^{-1}} = 45\ \mathrm{g\cdot s^{-1}}$ for a 3/4" diameter hole

   $Q_m = 0.393\ \mathrm{lbm\cdot s^{-1}} = 179\ \mathrm{g\cdot s^{-1}}$ for a 1.5"diameter hole.

A ¾ to 1.5" diameter opening is one that could result from a sheared line or vessel puncture. Therefore, modeling for risk analysis using 150 g/s is consistent with the discharge rate suggested by SNS cryogenic engineering.

Maximum volumetric release rate is given by:

$$\left(\frac{150\text{ g}}{\text{s}}\right)\left(\frac{\text{L}}{141.92\text{ g}}\right)\left(\frac{60\text{ s}}{\text{min}}\right)\left(\frac{\text{ft}^3}{28.3\text{ L}}\right)(857) \approx 1920\text{ ft}^3/\text{min}.$$

Maximum release duration:

The maximum release duration was established as 4 h during an ODH meeting held on 03/08/02. In attendance were George Dodson, Mario Giannella, Mike Harrington, Paul Wright, Sam McKenzie, Ron Cornwell, and John Jankovic.

2. Cryomodule-supplied (short-duration) release source term: A maximum of 1,000 L of LHe at a release rate of 4500 g/s is postulated for a release from a cryomodule pressure relief plate (by SNS cryogenic engineering).

Maximum volumetric release rate is given by:

$$\left(\frac{4500\text{ g}}{\text{s}}\right)\left(\frac{\text{L}}{141.9\text{ g}}\right)\left(\frac{60\text{ s}}{\text{min}}\right)\left(\frac{\text{ft}^3}{28.3\text{ L}}\right)(857) \approx 57{,}620\text{ ft}^3/\text{min}.$$

Volume at 70 ºF and 1 atm is given by:

$$\left(\frac{1000\text{ L}}{28.3\text{ ft}^3/\text{L}}\right)(857) \approx 30{,}283\text{ ft}^3.$$

Maximum release duration is given by:

$$\left(\frac{30283\text{ ft}^3}{57620\text{ ft}^3/\text{min}}\right)(60\text{ sec}/\text{min}) \approx 32\text{ sec}.$$

<u>LINAC/HEBT dimensions used</u>:

Lentil depth	2.5 ft
Distance between lentils	798 ft

HEBT to Front End length	1,057 ft
HEBT to Front End width	14 ft
HEBT to Front End height	10 ft
HEBT length	400 ft
HEBT width	17 ft
HEBT height	13 ft

Structure volumes used:

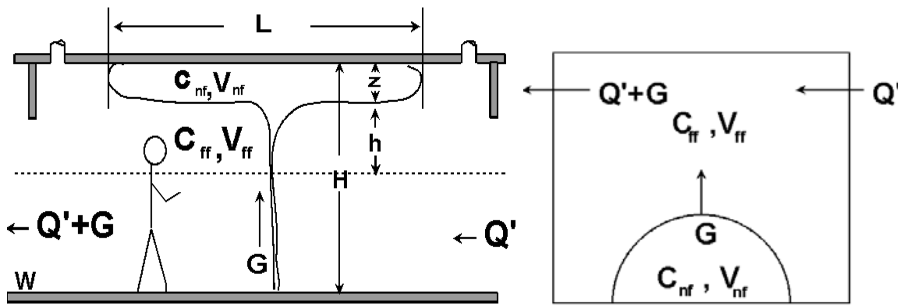
LINAC/HEBT		236,380 ft^3
Near field (volume above 7.5' level)		50,995 ft^3
Far field (volume below 7.5' level)		169,785 ft^3
Front End Building		229,367 ft^3
	Main level	192,605 ft^3
	Mezzanine	36,762 ft^3
Ring/RTBT		299,000 ft^3
	Klystron Building	1,060,719 ft^3

Oxygen calculation methodologies:

Simple dilution is given by:

(1) volume/volume dilution, $\%O_2 = 21 - 21\frac{\text{ft}^3\ \text{He}}{\text{ft}^3\ \text{Air}}$.

A two-compartment model is illustrated in Figure F-1a below:



- Helium in the **near field** can be simply represented as a ceiling jet (rises rapidly to the ceiling before spreading horizontally between the lentils, or as an expanding bubble until the helium warms sufficiently to rise).
- Areas outside the near field are considered in the **far field.**

Q'	=	effective ventilation rate, often set to zero
G	=	gas generation rate
C_{nf}	=	oxygen concentration in the near field
C_{ff}	=	oxygen concentration in the far field
V_{nf}	=	volume of the near field
V_{ff}	=	volume of the far field

Figure F-1a General Near Field/Far Field Model Depicting Gas Cloud Scenario (ceiling jet and expanding volume)

Near Field (Figure F-1a): Helium released expands outwards either as a ceiling jet or some spherical variation and flows to top where it spreads horizontally. As expansion continues air entrainment dilutes the helium.

(2) $\%O_2\ (\text{time}) = 21e^{-\frac{G}{V}t}$**,** and for $V = Gt$, which represents the expanding gas cloud (the volume of the near field),

$$\%O_2 = 21e^{-1} \approx 7.7\%$$

Far Field (Figure F-1a),

$Q = 0$:

(3)

$$C_{ff}(t) = .368\left(\frac{21G}{G - \frac{V_{ff}}{t}}\right) + 21\left(1 - \frac{G}{G - \frac{V_{ff}}{t}}\right)e^{-\frac{G}{V_{ff}}t}$$

$Q > 0$:

(4)

$$C_{ff}(t) = \frac{.21Q'}{Q'+G} + \left(\frac{.21Q'}{Q'+G-\frac{G}{V_{nf}}V_{ff}}\right)e^{-\frac{G}{V_{nf}}t} +$$

$$.21\left(1 - \frac{Q'}{Q'+G} - \frac{G}{Q'+G-\frac{G}{V_{nf}}V_{ff}}\right)e^{-\frac{Q'+G}{V_{ff}}t}$$

Application of the near field/far field models to the SNS accelerator and adjacent facilities:

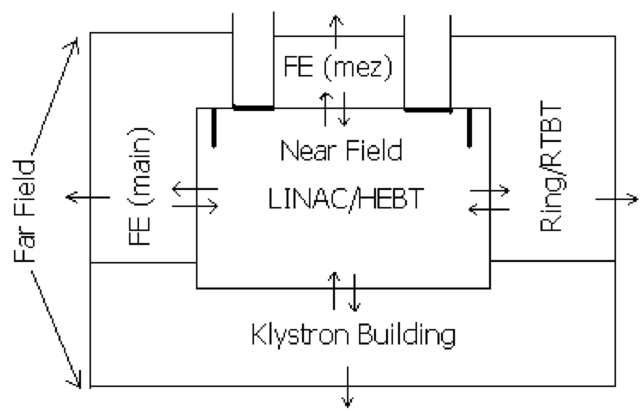
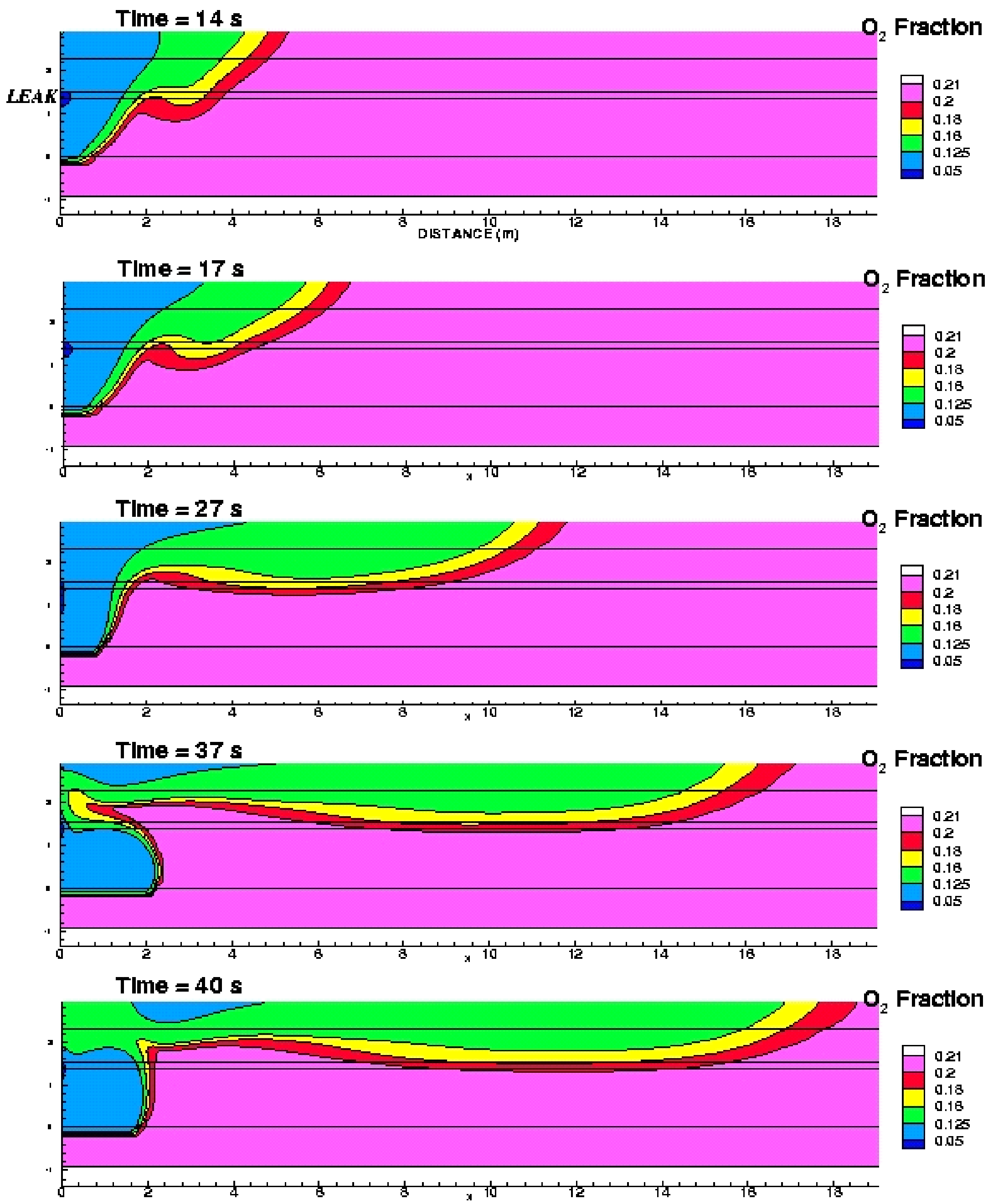


Figure F-1b Treating LINAC/HEBT as Near Field and Attached Structures as the Far Field

300 g/s Release Midway Through Tunnel – 2D CFX Simulation



CFD predictions are less restrictive than simpler model predictions in the first minute. However, conclusions are not changed.

For example, the near field prediction is 7.7%, and the CFD model indicates a gradient between 5 and 12.5% (blue area) near the source and a gradient along the ceiling above 12.5% (green, yellow, red areas).

Figure F-2 2D CFX Simulations (center of LINAC away from vents)

Assumptions for assessments based on CFD and Near Field/Far Field Model

- Helium, as it warms, rises rapidly to the ceiling minimizing horizontal spread in the bottom 3/4 of the LINAC/HEBT. As time becomes long diffusion takes place resulting in uniform mixing.
- The low-level danger zone is restricted to the area immediately above and adjacent to the pool. At a release rate of 300 g LHe/s or less, the pool radius stabilizes at about 2 m or less (see CFD modeling) and is easily detected by visual and audible means and, therefore, easily avoidable.
- No active or passive ventilation is assumed for the initial oxygen calculations within the LINAC/HEBT.
- Failure rate for the accidental release is taken from CEBAF operating experience, i.e., one release in 13 y (0.075/y - moderate).
    - Maximum time for a person to traverse the cold portion of the LINAC during a walking evacuation of the tunnel is three min. (718'/240 ft/min.).
    - Helium is assumed to pass out of the LINAC/HEBT (see Figure F-1b) into adjacent areas in four equal unrestricted amounts (Front End, Klystron, Ring/RTBT). An initial portion may be exhausted passively or actively before calculating the distribution of the helium.

LINAC Helium Release Scenarios for the Purpose of Identifying Necessary Safety Controls

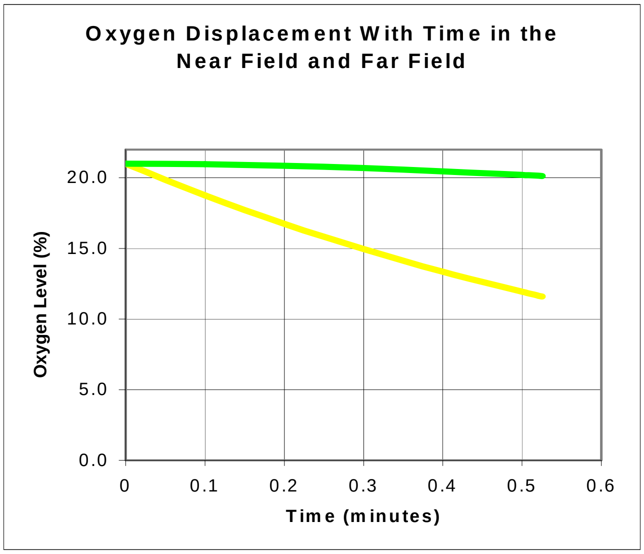
Release Scenario 1a (cryomodule release at 4500 g/s, quantity of LHE limits release to ≈ 0.5 min.):

People are present in LINAC, adjacent structures, and Control Room (i.e., not in beam permit). Smoke removal dampers are open (administrative requirement), but no passive or active venting is assumed to remove helium (according to SNS fire protection engineering, ambient environmental conditions could exist such that significant helium buoyancy would not produce a stack effect). The accidental release is assumed to be readily apparent to LINAC occupants, either because they produced the release, or there were visual or audible cues. SNS cryogenic training requires immediate evacuation and Control Room Operator notification. No sign in adjacent areas that release is occurring. The resulting oxygen concentrations are as follows:

Figure F-3: Calculating oxygen levels w/o dilution ventilation for the LINAC/HEBT assuming He does not migrate to other areas (Fig. 1a (see Figure F-1a)

Release Rate (ft^3/m)	57,620
Time (min)	0.533
Near Field Volume (ft^3)	50,995
Near Field % Oxygen (t)	11.5
Far Field Volume (ft^3)	169785
Far Field % Oxygen (t)	20.1
Ventilation Rate (ft^3/min)	0.0

	No Ventilation	
Time	NF	FF
0	21.0	21
0.1	18.8	21.0
0.2	16.8	20.9
0.3	15.0	20.7
0.4	13.4	20.5
0.5	11.9	20.2
0.525	11.6	20.1



Oxygen at equilibrium assuming all He stays in LINAC/HEBT:

21-21(30,283 ft^3 GHE/236,380 ft^3) = 18.3%

Figure F-3 Calculating Oxygen Levels without Dilution Ventilation for the LINAC/HEBT Assuming He does not Migrate to Other Areas (see Figure F-1a)

Table F-1a		
Equilibrium Oxygen Concentrations from Release Scenario 1a **Assuming the volume of He released is divided equally among all attached areas (Figure F-1b)**		
Areas Involved	**Volume (ft^3)**	**% Oxygen at t = ∞**
LINAC/HEBT	236,380	20.5
FE main level	192,605	20.3
FE Mezzanine	36,762	17.5
Klystron	1,060,719	20.9
Ring/RTBT	299,000	20.6

Conclusions for Scenario 1a:

No “immediately dangerous to life or health” conditions outside the plume area are expected.

LINAC/HEBT at during release:

No ODH with the exception of the plume area. Risk is considered “extremely low.” Cryogenic safety training mitigates risk.

Front End Building Mezzanine:

The ODH is “low marginally acceptable.” Assuming the probability of this type of release is “high,” administrative controls can be used to satisfactorily mitigate the hazard.

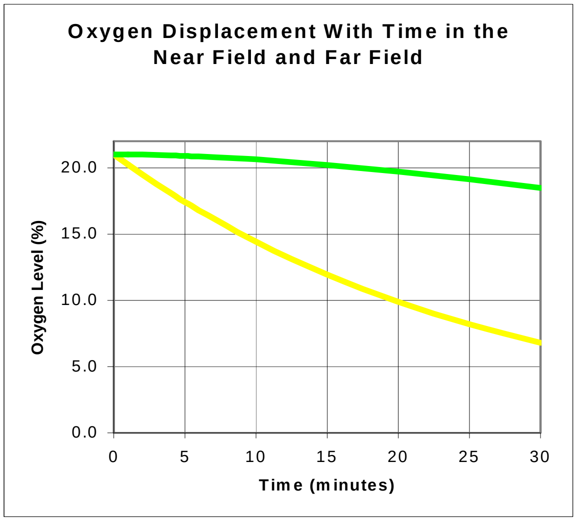
Release Scenario 1b (supply line release at 150 g/s):

People present in LINAC, adjacent structures, and Control Room (i.e., not in beam permit). Smoke removal dampers are open, but no passive or active venting is assumed to remove helium (ambient environmental conditions could exist such that significant helium buoyancy would not produce a stack effect per SNS fire protection engineer). The accidental release continues for 30 minutes before discovery and the release is terminated. There is no sign in adjacent areas that a release is occurring. Once the release is discovered, SNS cryogenic training requires immediate evacuation and Control Room Operator notification. The resulting oxygen concentrations are as shown below in Figure F-4.

Figure F-4. Calculating oxygen levels w/o dilution ventilation for the LINAC/HEBT assuming He does not migrate to other areas (see Figure F-1a)

Release Rate (ft^3/m)	1920
Time (min)	30
Near Field Volume (ft^3)	50995
Near Field % Oxygen (t)	6.8
Far Field Volume (ft^3)	169785
Far Field % Oxygen (t)	18.5
Ventilation Rate (ft^3/min)	0.0

Time	No Ventilation NF	FF
0	21.0	21
1	20.2	21.0
2	19.5	21.0
3	18.8	21.0
4	18.1	20.9
5	17.4	20.9
10	14.4	20.6
15	11.9	20.2
20	9.9	19.7
25	8.2	19.1
30	6.8	18.5



Oxygen at equilibrium assuming all He stays in the LINAC/HEBT and that release is terminated after 30 minutes:

$21-21(57600ft^3\ He/236,380ft^3) = 15.9\%$

Figure F-4 Calculating Oxygen Levels without Dilution Ventilation for the LINAC/HEBT Assuming He does not Migrate to Other Areas (see Figure F-1a)

Table F-1b		
Equilibrium Oxygen Concentrations from Release Scenario 1b **Assuming the volume of He released is divided equally all attached areas (Figure F-1b)**		
Areas Involved	**Volume (ft^3)**	**% Oxygen at t = ∞**
LINAC/HEBT	236,380	20.0
FE Main Level	192,605	19.7
FE Mezzanine	36,762	14.4
Klystron	1,060,719	20.8
Ring/RTBT	299,000	20.2

Conclusions for Scenario 1b:

No immediately dangerous to life or health conditions outside the plume area are expected.

LINAC/HEBT during release:

No ODH with the exception of the plume area. Risk is considered "extremely low." Cryogenic safety training mitigates risk.

Front End Building Mezzanine:

The ODH is "low marginally acceptable." Assuming the probability of this type of release is "high," administrative controls can be used to satisfactorily mitigate the hazard.

Release Scenario 2a (cryomodule release at 4500 g/s, quantity of LHE limits release to ≈ 0.5 min.):

Staff returning after prolonged absence. May enter LINAC or adjacent structure/not in beam permit. Smoke removal dampers open, but no passive or active venting assumed to remove helium (ambient environmental conditions could exist such that significant helium buoyancy would not produce a stack effect, SNS fire protection engineer). May be no outward sign that release has occurred in LINAC. No sign in adjacent areas that release has occurred.

Conclusions for Scenario 2a (Oxygen depletion conditions are the same as for Scenario 1a.):

No "immediately dangerous to life or health" conditions outside the plume area are expected.

<u>LINAC/HEBT at during release</u>:

No ODH with the exception of the immediate plume area. Risk is considered “extremely low.” Cryogenic safety training mitigates risk.

<u>Front End Building Mezzanine</u>:

The ODH is “low marginally acceptable” assuming the probability of this type of release is “high.” Administrative controls can be used to satisfactorily mitigate the hazard.

<u>Release Scenario 2b (supply line release at 150 g/s, large quantity of LHe available)</u>:

Staff returning after prolonged absence. May enter LINAC or adjacent structure/not in beam permit. Smoke removal dampers open, but no passive or active venting assumed to remove helium (ambient environmental conditions could exist such that significant helium buoyancy would not produce a stack effect, SNS fire protection engineer). May be no outward sign that release has occurred in LINAC. No sign in adjacent areas that release has occurred. Release is assumed to be uncontrolled for no longer than 240 minutes at 150 g/s.

Figure F-5: Calculating oxygen levels w/o dilution ventilation for the LINAC/HEBT assuming He does not migrate to other areas (see Figure F-1a)

Release Rate (ft^3/m)	1920
Time (min)	240
Near Field Volume (ft^3)	50995
Near Field % Oxygen (t)	0.0
Far Field Volume (ft^3)	169785
Far Field % Oxygen (t)	2.0
Ventilation Rate (ft^3/min)	0.0

	No Ventilation	
Time	NF	FF
0	21.0	21
5	17.4	20.9
10	14.4	20.6
15	11.9	20.2
20	9.9	19.7
30	6.8	18.5
45	3.9	16.4
60	2.2	14.3
90	0.7	10.5
120	0.2	7.6
150	0.1	5.5
190	0.0	3.5
240	0.0	2.0

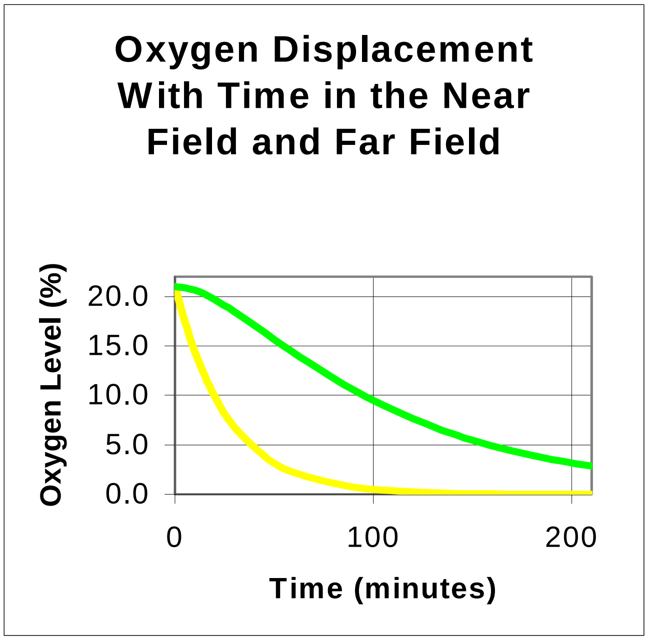


Figure F-5 Calculating Oxygen Levels without Dilution Ventilation for the LINAC/HEBT Assuming He does not Migrate to Other Areas (see Figure F-1a)

Table F-2		
Equilibrium Oxygen Concentrations from Release Scenario 2b **Assuming the volume of He released is divided equally among all attached areas (Figure F-1b)**		
Areas Involved	**Volume (ft^3)**	**% Oxygen at t = ∞**
LINAC/HEBT	236,380	0.0
FE Main Level	192,605	0.0
FE Mezzanine	36,762	0.0
Klystron	1,060,719	19.2
Ring/RTBT	299,000	0.0

Conclusions for Release Scenario 2b:

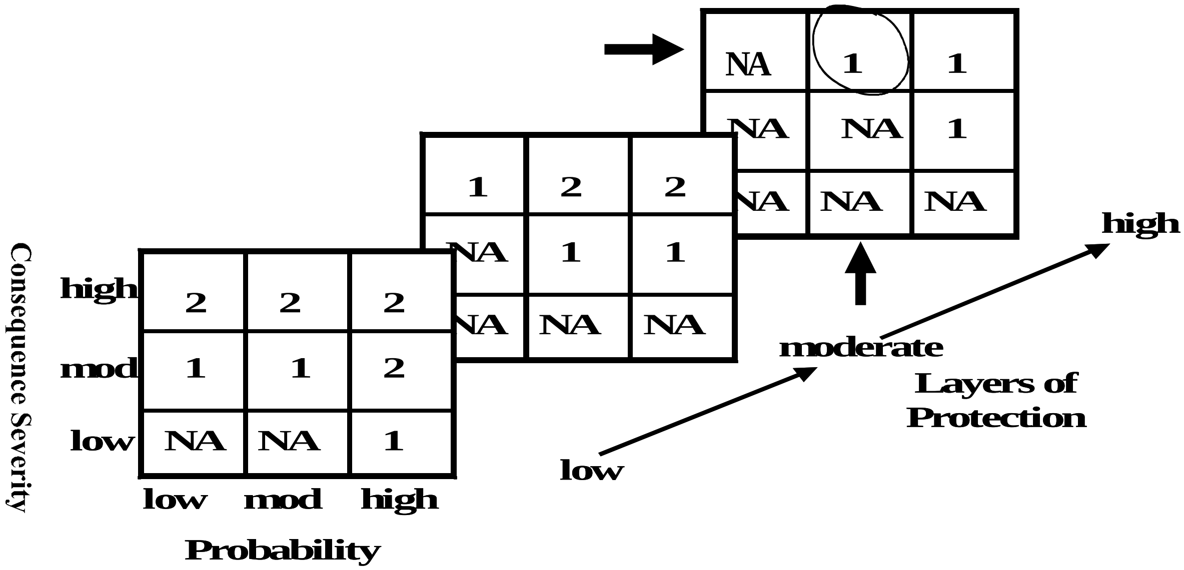
All areas with the exception of the Klystron Building are expected to be at lethal levels. The Klystron Building is marginally near the legal oxygen deficiency level. Control is required to mitigate the hazard.

Mitigation:

Assuming the smoke removal system ventilates at 30,000 cfm, and allowing a safety factor of two for imperfect mixing (50% air/50% He), triggering the ventilation system as a result of a release would contain the helium in the LINAC so adjacent areas would be unaffected.

Table F-3		
Scenario 2b Mitigation Oxygen Levels at **Equilibrium Concentrations from Release** **Scenario 2b assuming the He not exhausted is divided equally among all attached areas (Figure F-1b)**		
Areas Involved	**Volume (ft^3)**	**% Oxygen at t = ∞**
LINAC/HEBT	236,380	21
FE Main Level	192,605	21
FE Mezzanine	36,762	21
Klystron	1,060,719	21
Ring/RTBT	299,000	21

The system for detecting a release and initiating the mechanical ventilation would be Safety Significant requiring a safety integrity level of one. This determination is based on a high severity consequence, moderate probability of occurrence, and three layers of protection (automatic ventilation, oxygen sensor/alarm system, cryogenic plant alarm system).



Release Scenarios 3a and 3b:

The LINAC is unoccupied and in beam permit. The Control Room is staffed, and some adjacent areas may be occupied. The smoke removal dampers are closed. There is no sign in adjacent areas that a release has or is occurring. The accidental release continues for 30 minutes before discovery, and the release is terminated.

Conclusions for Scenarios 3a and 3b:

No immediately dangerous to life or health conditions outside the plume area are expected.

LINAC/HEBT during release:

This area is unoccupied.

Front End Building Mezzanine:

The ODH is "low marginally acceptable" assuming the probability of this type of release is "high." Administrative controls can be used to satisfactorily mitigate the hazard.

Table F-4

Summary of Oxygen Deficiency Hazard for Accidental Release of Helium to the LINAC Tunnel

Occupancy/Accelerator Status	Hazard Summary	
	Rapid Release/Short Duration (Cryomodule(s) Release at 4500 g/s: 1000 liters LHe, 30,283 ft^3 GHe, 32s max duration, 57,620 ft^3/min. volume release rate)	**Slow Release/Long Duration** (Supply line release at 150 g/s: 60,000 liters LHe, 1.8×10^6 ft^3 GHe, 1,920 ft^3/min. volume release rate)
People present in LINAC, adjacent structures, Control Room/not in beam permit. Smoke removal dampers open. No active ventilation credited.	LINAC—See and flee operational. Other Areas—Cannot rely on see and flee; however, short-duration release is insufficient to present risk beyond immediate vicinity of release point in LINAC.	LINAC—See and flee operational. Other Areas—Cannot rely on see and flee. Control Room staff detects release within 30 minutes and takes action before significant involvement of adjacent structures.
Staff returning after prolonged absence. May enter LINAC or adjacent structure/not in beam permit. Smoke removal dampers open. No active ventilation credited. Control Room unoccupied; therefore, no one to detect release.	LINAC and Adjacent Areas—Insufficient He to present risk beyond immediate vicinity of release point and, only then, during active release.	LINAC—Cannot rely on see and flee. Passive venting may not maintain ambient oxygen at acceptable levels. Other Areas—Cannot rely on see and flee. **Mitigation in the form of active ventilation required. SIL-1 designation.**
LINAC unoccupied, Adjacent Areas occupied/In beam permit. Smoke removal dampers closed. No active ventilation credited.	LINAC—No entry permitted while in beam permit. After beam shutdown, radiological concerns prevent immediate entry. Release ends quickly or Control Room staff detects release within 30 minutes and takes action to control. FE Mezzanine—only occupied area with potential for oxygen deficiency. Other Areas—Release terminated before ODH develops.	