LINAC Coherent Light Source II (LCLS-II) Project

Preliminary Oxygen Deficiency Hazard Analyses

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Document Approval | **Date Approved**

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Revision History

Revision	Date Released	Description of Change
R1	9/16/015	Update seismic probability; update for 2 plants, update fatality rate (ϕ), incorporate peer review comments
R0	5/1/2015	Original Release.

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Acronyms

Term	**Definition**
ACR	Accelerator Control Room
AOR	Area of Refuge
ACH	Air Changes per Hour
CAM	Control Account Manager
CDS	Cryogenic Distribution System
CFD	Computational Fluid Dynamics
CFM	Cubic Feet per Minute
CM	Cryomodule
FACP	Fire Alarm Control Panel
FESHM (####)	Fermilab Environment, Health and Safety Manual (Chapter Number)
FMEA	Failure Mode and Effects Analysis
ISEMS	Integrated Safety and Environmental Management Systems
I & C	Instrumentation and Control
ODH	Oxygen Deficiency Hazard
ODHA	Oxygen Deficiency Hazard Analysis
ODM	Oxygen Deficiency Monitor
P&ID	Piping and Instrumentation Diagram
PFHA	Preliminary Fire Hazard Analysis
PODHA	Preliminary Oxygen Deficiency Hazard Analysis
PPS	Personnel Protection System (radiation safety)
SCF	Standard Cubic Feet, (70 deg. F and 14.7 PSIA)
SCFM	Standard Cubic Feet per Minute
USGS	United States Geological Survey

1 Introduction

The Linac Coherent Light Source-II (LCLS-II) Project will introduce new equipment to the existing SLAC National Accelerator Laboratory Linac Housing and Gallery in the form of a new Superconducting RF Linac that is cryogenically cooled with liquid helium. The project also includes an additional building that will house part of a new helium liquefaction plant. There will be an estimated mass equivalent of fourteen thousand liquid liters of helium in the Linac Housing alone. Liquid helium vaporizes quickly when released into the atmosphere and, at room temperature, expands to over 800 times the volume of the cryogenic liquid at operating temperature. A large release of helium could displace enough air to cause injury or death of person(s) in the affected area.

1.1 Purpose

This document provides Preliminary Oxygen Deficiency Hazard Analyses (PODHA) for the Linac Housing and estimates for the Linac Gallery and the new Cryogenic Plant Building. The purpose of these analyses is to determine the Oxygen Deficiency Hazard (ODH) Classification Level for each area. The minimum controls required by ODH Classification are described in Section 2.3 and Table 2 of SLAC ES&H Chapter 36, ODH Requirements. Additional controls may be deemed necessary to reduce the probability of an injury or death, due to an oxygen deficient atmosphere, to an acceptable level.

1.2 Design Requirements

This PODHA has been prepared in accordance with Chapter 36 of the SLAC ES&H Manual and is consistent with DOE Order 420.1C, Facility Safety, and 10 CFR 851, DOE Worker Safety and Health Program. ODH mitigations are being designed in collaboration with the SLAC Fire Marshal to assure coordination with fire hazard codes and standards.

1.3 Approach

The LCLS-II project is a collaborative effort with partner laboratories providing design effort for cryomodules, cryogenic distribution system and the cryogenic plant. Each of the three subsystem CAMs are responsible for providing FMEA and “What-If” analyses for the equipment they design. The final ODH analyses will determine the ODH classification level for each area based on probabilities of failures and resulting oxygen concentration in affected space resulting from plausible events including (but not limited to) those described in the FMEA and “What-If” analyses.

This document is the baseline analysis for oxygen deficiency hazards associated with the new cryogenic equipment to be installed in the newly constructed building as well as the existing Linac tunnel and Gallery. The equipment design is largely derived from that of the International Linear Collider (ILC), the European XFEL and the Cryogenic Helium Liquefaction systems at Jefferson Lab. These designs are being modified to meet LCLS-II needs. Assumptions are made based on available information from similar equipment already in operation.

The general approach is to determine reasonable upper bounds of the hazard and not necessarily to precisely define it. For example, it is difficult to determine the amount of helium that will be stored in the cryogenic system, precisely. However, it is possible to say with confidence it will be less than a mass equivalent to 44k liquid liters (see section 2.1 for details). The approach is to make conservative assumptions rather than exhaustive analyses where appropriate. This PODHA will be iterated and updated as the cryogenic equipment designs mature. Once equipment designs stabilize, information from this document will likely be incorporated into three stand-alone Oxygen Deficiency Analyses, one for each area.

1.4 Limitations

The planned use of a large amount of cryogens required for the LCLS-II project, brings with it some risk of a leak or rupture that, in addition to ODH, could cause injury such as skin burns from exposure to the liquid, or over pressurization of vessels, cryostats or the tunnel itself, due to warming of liquid and/or the rapid expansion of liquid helium flashing to gas. These hazards and others are identified in the comprehensive LCLS-II Project Hazards Analysis Report [3]; this analysis provides a more detailed treatment of the oxygen deficiency hazard.

This analysis considers all credible events, including those caused by human error during routine maintenance and operational activities, for example valve stem replacement or relief valve removal/replacement. In order to maintain a low probability of an ODH event, all work activities in the affected area must be carefully planned and authorized in accordance with SLAC's Work Planning and Control program and with specific consideration of potential ODH hazards created by the activity to be performed. Cryogenic hazards are related to the stored thermal energy of the cryogen and are mitigated through layers of engineering and administrative controls (such as: formal written & validated procedures) in accordance with SLAC ES&H Chapter 51, Control of Hazardous Energy. It is important to note that the system can only be isolated to suction pressure for many activities, such as those mentioned above. Therefore, it is not possible for all activities to be accomplished in a "zero energy" state; the system will be brought to a relatively safer state where the risk of injury or ODH is significantly reduced.

1.5 Summary of Initial Findings

Based on initial assumptions and calculations, all three areas satisfy the criteria for classification as ODH Level 1 as specified in SLAC ES&H Manual Chapter 36 [1]. However, as equipment designs mature and these analyses iterate, the ODH Classification may change.

1.5.1 Linac Housing

The equipment in the Housing was analyzed in accordance with SLAC ES&H requirements and a fatality rate of $2.3\ x\ 10^{-6}/hr$ was calculated. Detailed calculations are included in Appendix B; assumptions used in those calculations are explained in section 2 of this document.

1.5.2 Gallery Building

The ODH classification of the Gallery building is inferred from the analysis of the Linac Housing and is assumed to be ODH level 1 or less. This assumption is based on the following facts and observations:

- The probabilities of credible ODH events in the Gallery are similar to those in the Housing.
- All penetrations will be sealed well enough to prevent most helium released in the tunnel, during a large event, from migrating into the Gallery.
- There is much less cryogenic equipment and therefore much less helium in the Gallery at any time during operations.
- The Gallery building has nearly four times the volume as the tunnel and many more exits; additionally the building envelope is not well sealed and has many exhaust fans that can be used to maximize oxygen concentration during a significant event.

1.5.3 Cryogenic Plant Building

ODH classification of the new building at SLAC is assumed to be ODH Level 1, the same as the building Housing Central Helium Liquefier #2 (CHL2) at Thomas Jefferson National Accelerator Facility (JLab) since the buildings are similar and house nearly identical equipment. See Appendix C for a copy of the JLab ODH analysis for CHL2 Compressor Room and Cold Box Room.

2 General Information Applicable to All Area Analyses

2.1 Cryogenic System Description

The LCLS-II Cryogenic System consists of a Helium Liquefaction Plant (36 kW at 4.5K equivalent, 8kW at 2.0 K), a cryogenic distribution system (CDS) and 37 ILC/TESLA style cryomodules (CMs). Two independent strings of CMs and approximately 450 feet of cryogenic transfer line will be located in the existing Linac Housing. The CDS also includes approximately 300 feet of transfer line and two distribution boxes located in the Gallery with another 200 feet of transfer line running between the Gallery and the Cryoplant above ground. The Cryogenic plant includes two refrigerators, one for each string of CMs; both are copies of the JLAB CHL-II design with some modifications to meet LCLS-II requirements.

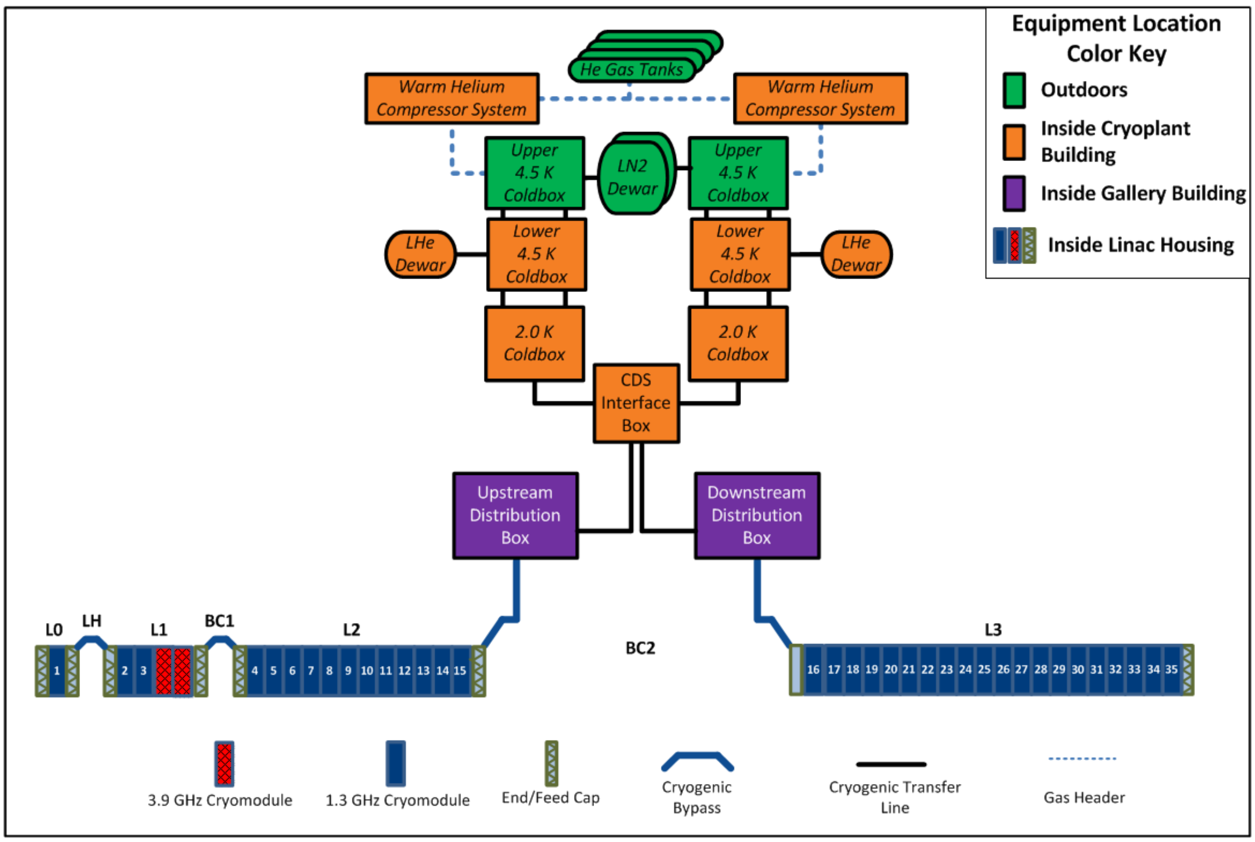


Figure 1 Cryogenic System Schematic

The 21,000 square foot Cryogenic Plant Building is divided into three rooms. The cold box room will house two 2.0K cold boxes, two (low temperature section) 4.5K cold boxes and two 10,000 liter liquid helium dewars. There will be two compressor rooms, each housing six warm helium compressors ranging from 800 to 2500 hp. Outside the building, there will be six helium gas storage vessels with a combined capacity of 20,000 SCF at pressures up to 16 bar; roughly equivalent to another 10,000 liquid liters located outside the building. Also outside the Cryoplant building will be two 117k liter liquid nitrogen dewars and two (high temperature section) 4.5K cold boxes. See Figure 1 for a schematic diagram of the cryogenic system and Appendix A for a more detailed Cryogenic System Schematic as well as a list of Process and Instrumentation Diagrams (P&IDs).

It would be difficult to account for the total helium inventory contained within the various subsystems of the Cryoplant, such as warm and cold helium compressors, cold box and distribution box heat exchangers, helium purification system, etc. The amount of liquid helium in any location will vary depending on the state of the cryogenic system and how much is stored in the various subsystems. It is unlikely all storage capacity would be full while the cryomodules are full of liquid. It is more reasonable to assume the system inventory will not exceed the total gas and liquid storage capability with the cryomodules and distribution system empty. However, we still must account for helium contained in the various plant subsystems. A conservative estimate of the maximum possible helium inventory can made by summing the volume contained in the 37 cryomodules, 1000 feet of transfer line, two liquid dewars and five gas storage vessel. There is nearly 14,000 liters of liquid (mass equivalent at 4.2K) in the CMs and CDS located in Linac Housing, under normal operating conditions. Therefore, total system inventory will not exceed a mass equivalent to 44,000 liquid liters of helium at atmospheric pressure and 4.2 degrees Kelvin.

2.2 Hazard Classification Method

2.2.1 ODH Classification Level

ODH classification level is based on a calculated fatality rate per hour in the affected area due to a lack of oxygen. The numerical value for ϕ is used to quantify the relative level of oxygen deficiency hazard in the area and to determine a minimum level of engineering controls.

$$\phi = \sum_{i=1}^{n} P_i F_i \qquad [1]$$

ϕ = the ODH fatality rate (per hour)

P_i= the expected rate of the i^{th} event (per hour)

F_i = the fatality factor for the i^{th} event

The summation includes all events predicted in the FMEA and "What-If" analyses [17, 18] for the cryogenic equipment installed in the affected space. The value of F_i is based on oxygen concentration. If the calculated oxygen concentration resulting from an event is greater than 18 percent, it is assumed there will be zero fatalities resulting from the i^{th} ODH event and the fatality factor (F_i) is set to zero. If the calculated oxygen concentration is 18 percent, then F_i is set to 10^{-7}. It is assumed that a person will die if subjected to an area with an oxygen concentration below 8.8 percent [1] and F_i is set to 1. As oxygen concentrations decrease from 18 to 8.8 percent, F_i increases linearly. See Figure 2 below.

There is limited data available from operational experience at SLAC, therefore data from Fermilab (FESHM 4240TA [9]) will be used to determine the probability factor (P_i) for most events.

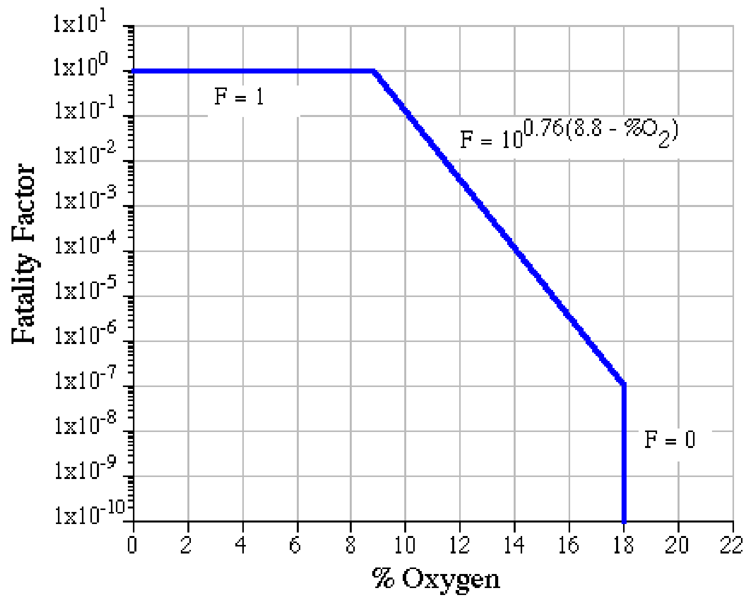


Figure 2 Fatality Factor (F_i) vs Oxygen Concentration [1]

2.2.2 Oxygen Concentration Calculation

Oxygen concentration is defined as the molar fraction of oxygen in air. The oxygen concentration in normal ambient atmosphere is ~21% [9]. The following equation was used to calculate oxygen concentration for the Housing. It assumes perfect mixing with ventilation fans blowing fresh air into the space.

$$C_{(t)} = \left(\frac{0.21}{Q+R}\right)\left[Q + R\, e^{-\left[\frac{Q+R}{V}\right]t}\right] \qquad (FESHM\ 4240\ Case\ A)\ [9]$$

C = fraction of oxygen in air

Q = ventilation rate (CFM)

R = helium spill rate into the space (CFM)

V = volume of the affected space (ft^3)

d = diameter of orifice (inches)

t = time (seconds)

Some reasonable amount of ventilation is important, to mitigate small leaks that are not readily noticeable, as it will not allow the oxygen displacing gas to accumulate and cause an oxygen deficient atmosphere. The Linac Housing ventilation rate is 9000 CFM. A number of values for t were selected during the analysis. Very little difference in oxygen concentration was found 30, 90 or 120 seconds after a significant leak begins, therefore it is reasonable to assume a steady state (as t→∞). Values for oxygen concentration at t = 120 and as t→∞ are included in Appendix B.

2.3 General Assumptions

2.3.1 Forced Air Ventilation Effect on Fatality Factor and Rate

If the fatality rate for a particular event (ϕ_i) is reduced by forced air ventilation, the probability of ventilation loss must also be considered. Ventilation could be impacted if the fan fails to operate or if there is a power outage. Therefore, each event for which F_i is not equal to 1.0, two additional products are included for each ϕ_i. The event probability (P_i) is multiplied by a fatality factor calculated with ventilation $(F_{i(vent)})$ as well as with two other factors, each with an oxygen concentration calculation made without ventilation $(F_{i(no\ vent)})$. One includes the probability of a fan failure and the other includes the probability of a power failure.

$$\phi_i = P_i\left(F_{i(vent)} + P_{Fan\ Fail}F_{i(no\ vent)} + P_{Pwr\ out}F_{i(no\ vent)}\right)$$

2.3.1.1 Fan Failure

Assuming the ventilation is constantly running whenever the tunnel is occupied, the probability of a running fan failure will be less than the probability a standby fan will not come on when needed.

$$P_{Fan\ Fail} = \left(\frac{event}{hour}\right) = 9\ x\ 10^{-6}/_{hr} \qquad [9]$$

2.3.1.2 Power Failure

There is reliable data for power failures at SLAC from 2010. Over the five year period between January 1, 2010 and December 31, 2014, there were five events. In January of 2010 there was a site wide power outage due to an unusually large storm, a switch failed on the 230kV line in October of 2011, a lightning strike caused a major outage in April of 2012, there was an “under-frequency fault in May of 2013 and an animal cause a power outage in August of 2014. The probability of a power failure (or power failure rate) is:

$$P_{Pwr\ out} = \left(\frac{1}{MTBF}\right) = 1.24\ x\ 10^{-4}/_{hr}$$

2.3.2 Earthquake and Seismic Design

California is known to be seismically active. Large forces acting on equipment and piping during large seismic events vary in amplitude, frequency and direction (in three dimensional space). The intended result of the seismic design criteria being applied to the cryogenic system is to sustain little or no damage from frequent earthquakes, minor nonstructural damage for common earthquakes, and provide for life-safety or collapse prevention during large rare earthquakes. Ordinary non-structural components may (or may not) suffer minimal damage, but will not likely experience loss of functionality due to minor ground motions associated with frequent earthquakes; some damage, that may affect functionality, is anticipated for moderate ground motions; although proper design will provide for avoiding significant falling hazards, major damage and likely loss of functionality due to violent ground motions associated with code design level earthquakes is anticipated. Piping and equipment designed and installed according to the standards adopted by the project are expected to maintain position during a seismic event at design conditions. The seismic requirements do not assure cryogenic piping or equipment will remain leak tight after a very large (rare) seismic event.

A recent seismic hazard study [19] to estimate the likelihood of matching or exceeding the ground shaking intensity associated with the ASCE/SEI 7-10 Design Earthquake found the likelihood to be less than 8% in 30 years.

$$P_{i\ (Large\ EQ)} = \frac{likelihood}{hours} = 3.04\ x10^{-7}/hr$$

2.3.3 Effects of Events

Throughout the Housing and Gallery, the LCLS-II cryogenic system is nearly an all welded system as there are no u-tube connections on the cryomodules. The distribution boxes in the Gallery, control valves on CDS Endcaps, J-T valves, liquid level probes and other instrumentation wetted by helium in the tunnel are exceptions to the notion of an “all welded” system. These valves are typically flanged and most have welded bellows. All process pressure relief valves are located outside the tunnel, in the Gallery building, most relieve outdoors. There are a small number of trapped volume relief valves that vent into the Gallery building. However, these circuits have a limited potential to cause harm as they serve a limited volume. Pressure reliefs for insulating and beam line vacuum vent into the Housing, however the helium must first leave the welded system (through some leak or rupture) before it can enter the vacuum space and then the tunnel. There are many welds in the system, therefore the dominate failure type is weld leak or rupture; other possible causes for ODH events include valve flange or stem bellows leak. [17, 18]

Human error during maintenance procedures or material handling operations (for instance a heavy object accidently dropped onto part of the cryogenic system) or a vehicle collision/impact with cryogenic components, are all example of events that could cause release of cryogens and possibly an ODH.

2.3.4 Failure Modes of the Cryomodules and Cryogenic Distribution System

The cryogenic system can be thought of as a collection of nodes. Each node represents a physical component such as a pipe, pressure vessel, etc. The nodes and their associated failure modes are summarized in the simplified schematic of the system below in Figure 3. The cryogenic distribution system in the Housing is very similar to Figure 3 below except that it does not have RF cavities, Line G or H. There are a number of possible failure modes for each node. Table 1 summarizes the possible failure modes for each node. Sections 2.3.4.1 through 2.3.4.4 below describe the failure and are keyed to the schematic in Figure 3 as well as Table 1 below. Also see Appendix A for a detailed schematic of the cryogenic plant as well as diagram illustrating vacuum system segmentation.

2.3.4.1 Helium leaks ($He^{[L]}$) from a helium containing pipe or vessel into the insulating vacuum space causing heat to flow (Q) and pressure to rise (P) in other circuits. The helium in the vacuum space will cause the vacuum relief to open and helium will vent ($He^{[V]}$) into the surrounding area. Pressure increases in other circuits will be vented ($He^{[V]}$) outside through process pressure reliefs.

2.3.4.2 $Air^{[L]}$ leaks into the insulating vacuum space causing heat to flow (Q) and pressure to rise (P) in helium containing circuits. Pressure increases in these circuits will be vented ($He^{[V]}$) outside through process pressure reliefs.

2.3.4.3 $Air^{[L]}$ or Helium ($He^{[L]}$)leaks into the beam line vacuum space causing heat to flow (Q) and pressure to rise (P) in helium containing RF cavity as well as Lines B and G. Pressure increases in these circuits will be vented ($He^{[V]}$) outside through process pressure reliefs.

2.3.4.4 Increase pressure (P) in helium containing circuits caused by process upsets will be vented ($He^{[V]}$) outside through process pressure reliefs.

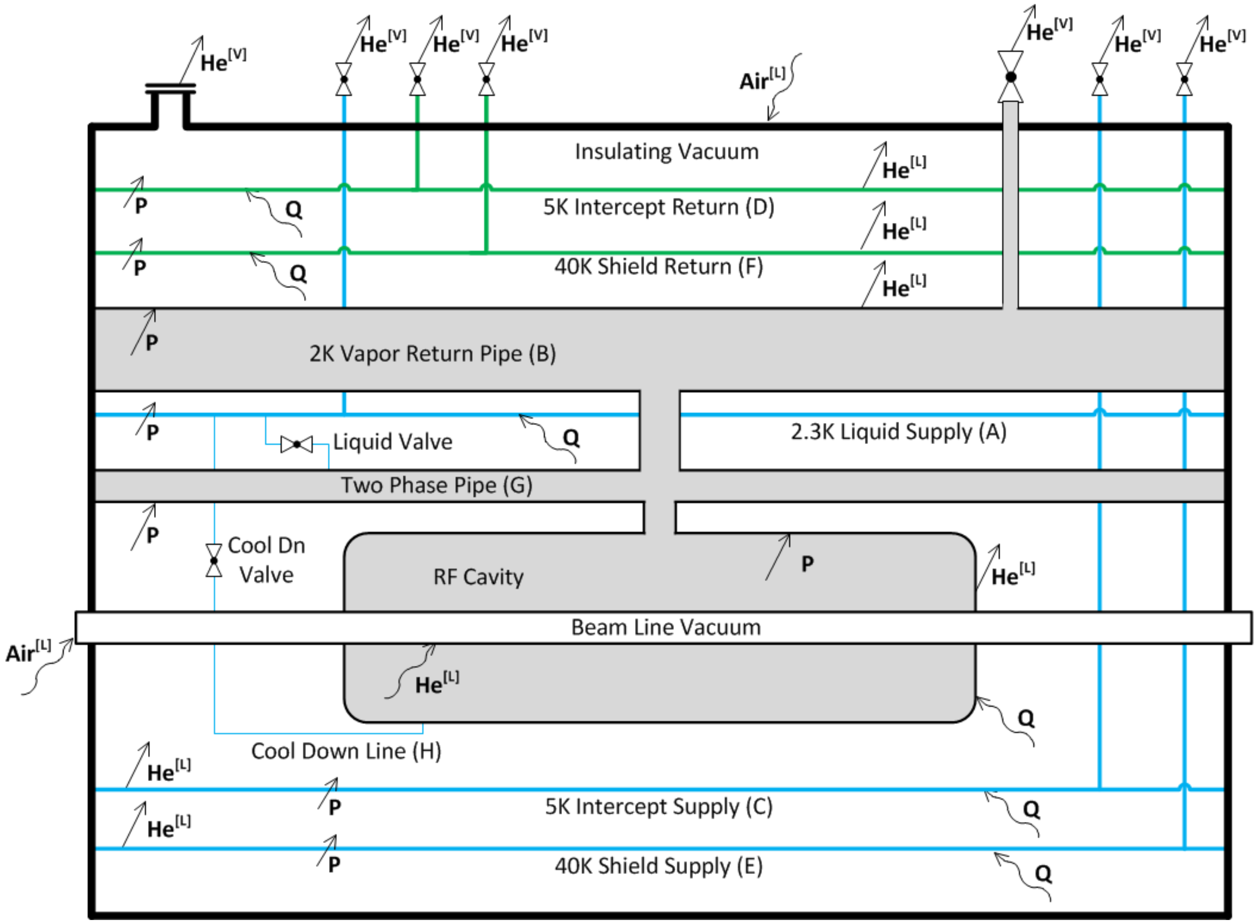


Figure 3 Failure Modes Associated with Cryogenic Nodes in the Tunnel

2.3.4.5 Table 1 below is a summary of the credible failure modes associated with various cryogenic nodes. The ✓box represents a primary failure mode for the particular node identified in the first column. Other possibilities include an indirect effect caused by the same or another node failing or no effect on that node indicated by "n/a."

Cryogenic Node	He[L] flows into Insul. Vacuum	Air[L] Flows into Insul. Vacuum	He[V] Flows Into Area	Heat into Cryo Line (Q)	Helium[V] flows out of Relief	He[L] or Air[L] Flows into BL Vac	Pressure Increase (P)
Liquid Supply (Line A)	✓	Indirect effect	✓	Indirect effect	Indirect effect	n/a	Indirect effect
Vapor Return (Line B)	✓	Indirect effect	✓	Indirect effect	Indirect effect	n/a	Indirect effect
5K Intercept Sup. (Line C)	✓	Indirect effect	✓	Indirect effect	Indirect effect	n/a	Indirect effect
5K	✓	Indirect	✓	Indirect	Indirect	n/a	Indirect

Cryogenic Node	He[L] flows into Insul. Vacuum	Air[L] Flows into Insul. Vacuum	He[V] Flows Into Area	Heat into Cryo Line (Q)	Helium[V] flows out of Relief	He[L] or Air[L] Flows into BL Vac	Pressure Increase (P)
Intercept Ret. (Line D)		effect		effect	effect		effect
40K Shield Supply (Line E)	✔	Indirect effect	✔	Indirect effect	Indirect effect	n/a	Indirect effect
40K Shield Return (Line F)	✔	Indirect effect	✔	Indirect effect	Indirect effect	n/a	Indirect effect
Two Phase (Line G)	✔	Indirect effect	✔	Indirect effect	Indirect effect	n/a	Indirect effect
Warm-up/Cool-dn (Line H)	✔	Indirect effect	✔	Indirect effect	Indirect effect	n/a	Indirect effect
Beam Line Vacuum	n/a	n/a	n/a	Indirect effect	Indirect effect	✔	✔
Insulating Vacuum Vessel	Indirect effect	✔	✔	Indirect effect	Indirect effect	n/a	✔
RF Cavity	✔	Indirect effect	✔	Indirect effect	Indirect effect	Indirect effect	Indirect effect
Valves & Instruments	✔	n/a	✔	Indirect effect	n/a	n/a	Indirect effect

Table 1 Failure Modes Associated with Cryogenic Nodes

2.3.5 Maximum Credible Event

The assumptions in section are based on the “What-if” analyses for the cryomodules and the CDS [17] in addition to discussions with design experts from our partner labs regarding this subject. The maximum credible (rapid) loss of cryogens is most likely due to a very large earthquake (see Appendix B). Based on the discussion in the section 2.3.2 (Earthquake and Seismic Design), it is assumed there will be multiple ruptures of cryomodule interconnection bellows and that most of the cryogens in any area will be released rapidly during a very large, but rare, seismic event. The analysis details a number of very large events, which are typically weld or pressure vessel ruptures. The likelihood of a weld rupture is very low, however since there many welds, the P_i term increases accordingly.

2.3.6 Models of Leaks & Ruptures

In order to calculate a flow rate through a leak or rupture, both were modeled as round orifices with square edges. Leak rates through the orifice are calculated using equation 3-22 from the Crane Technical Paper 410.

$$w = 0.525\, Y\, d^2\, C\, \sqrt{\Delta P \rho} \qquad [10]$$

w = mass flow, lbs/sec
Y = net expansion factor (Y = 1 for liquids)
C = flow coefficient for square edge orifices
d = diameter of orifice, inches
ΔP = pressure differential across orifice, psi
ρ = density, lbs/ft^3

Values for these variables are included in Appendix B.

2.3.6.1 Temperature and Pressure

Pressure differential across the orifice is assumed to be atmospheric pressure on the low side and the safety relief pressure setting for the affected circuit on the high side. This is a very conservative assumption, especially for large ruptures since it is unlikely pressure could build to relieving pressure with a very large hole. The temperature of the fluid is assumed to be the nominal operating temperature. This is another conservative assumption as the lines operating at 2.0 K would not remain at that temperature very long during a significant failure. The rise in temperature would cause a decrease in density and a lower mass flow rate.

2.3.6.2 Pressure Vessels

The SCRF cavities are designed as pressure vessels and therefore the probability for failure is based on the pressure vessel probabilities. In other words, each weld, in each cavity is not considered individually. A small leak in a pressure vessel is assumed to have an equivalent area of 10mm^2 and pressure vessels tend to leak in this manner at a rate of $8\text{x}10^{-8}/\text{hr}$ [9]. Table 2 from FESHM 4240TA provides a probability of $5\text{x}10^{-9}/\text{hr}$ [9] for “disruptive failure;” but does not define the size or shape of a hole in the pressure vessel rupture causing this disruption. A rupture of the pressure vessel is assumed to be a crack with a length equal to ½ the circumference of the outer vessel. The width of the crack is assumed to be ⅛ of the length of the crack.

2.3.6.3 Weld Leaks

Small leaks on welded joints are defined to have an equivalent area of 10mm^2 and the probability of such a leak is $2\text{x}10^{-11}\ \text{x}\ (\text{D}/\text{t})/\text{hr}$ [9]. Large ruptures of piping welds have the probability of $6\text{x}10^{-13}\ \text{x}\ (\text{D}/\text{t})/\text{hr}$ [9]. The leak is assumed to be an opening with a length equal to ½ the circumference of the pipe. The width of the crack is assumed to be ⅛ of the length of the crack.

2.3.6.4 Valves

Small valve leaks are modeled as flanged joint separations with openings half the length of the flange seal which is assumed to be twice pipe circumference and 0.035 inches wide. Control valves are assumed to be 1 inch diameter. The failure rate is assumed to be $1\text{x}10^{-8}/\text{hr}$ [9]. Large valve ruptures are assumed to be blown out packing, with a 0.25” wide leak with the length equal to twice the circumference of the line size. The rate of failure is assumed to be $1\text{x}10^{-8}/\text{hr}$ [9].

2.3.7 General Mitigation Strategies

Table 2 in ES&H Chapter 36 lists minimum measures required for areas depending on their ODH Classification. The Linac Housing, Gallery and Cryoplant building will all likely be designated ODH 1. Although the classification level is relatively low, there is still a real possibility of a significant ODH event at SLAC. The general mitigation strategy is to train people to recognize a potential or real hazard and leave the area immediately. An oxygen deficiency monitoring system, described in Section 2.3.9.1, will notify personnel in the area of an ODH in the area. Once people are safely outside of the affected area, troubleshooting and repairs can be discussed and planned safely.

Administrative measures and thorough work planning processes will reduce the risk of an ODH event caused by human error. For example, limiting vehicular access to areas where cryogenic system components are vulnerable to damage, denying unescorted access to untrained individuals and visitors to these areas are examples typical risk reducing measures. Another type of administrative measure is one that may not reduce the likelihood of an error, but would reduce the severity of effects. For example some maintenance activities will require one or both cryogenic strings to be warmed completely; other activities may require one or both strings be partially warmed, just enough to remove liquid helium from the tunnel thereby reducing the amount of oxygen displacing material workers are exposed to. Formal written and validated procedures similar to those used to control other more common sources of stored energy will help minimize the probability of errors, reduce exposure, and subsequently lower the risk of injury to personnel.

2.3.8 Training

Training will be necessary for anyone entering one of the three LCLS-II ODH areas. People will need to understand the magnitude of the hazard and how to avoid it. People working or visiting these areas will need to understand the signs of an ODH hazard and how to respond to those signs. Training will cover the ODM system and associated alerts. Individuals not trained in ODH hazard recognition and response (e.g., visitors) will be escorted or supervised by trained individuals.

2.3.9 Barriers

The cryogenic areas of the Gallery and Housing will be separated by physical barriers and signage so that untrained people do not inadvertently enter the ODH zone. Physical barriers will also keep motorized heavy equipment away from the cryogenic equipment to avoid an ODH event caused by a collision or other impact accident.

2.3.9.1 Controls

The Oxygen Deficiency Monitoring (ODM) and control system will be a standalone system with interfaces to the Facilities HVAC DDC system, the building Fire Alarm Control system and Personnel Protection control System. Fixed oxygen concentration sensor heads will be installed throughout the three affected areas and will be connected to the ODM system. The system will alert people in affected areas of an ODH event using strobe lights. Strobes indicating an oxygen deficiency hazard will be a unique color in order to avoid confusion. Emergency evacuation, when required, will be signaled through the building fire alarm panel (FACP) strobes and horns. For consistency and to avoid confusion, the FACP will use a “general evacuation” signal to alert people of an emergency evacuation order in the area. In the Linac Housing, the ODM control system will activate dampers in vents to allow helium to leave the tunnel. Consideration is also being given to using the existing Linac Gallery exhaust fans if a significant ODH event were to affect that area.

The PLC based ODM control system will sense oxygen concentration levels, ventilation system faults and will provide damper control, warning notification and alarms. The system will have the capability to archive status and significant signals. The system interface will be available to ACR operators, Main Gate and will allow access to others as appropriate. The control system PLC, sensors, actuators and strobes will have backup power. Once certified, the ODM system hardware and software will be under configuration control managed by the Accelerator Directorate.

The ODM control system will have two levels of alarm. The first (level one) is an ODH warning. The second (level two) is an ODH emergency. The level one warning will alert people in the affected space to leave the area immediately due to a problem associated with ODH, but will not automatically summon outside fire department response. The alert will be communicated by a uniquely colored flashing strobe, solely associated with an ODH warning. The level one warning would be triggered whenever there is trouble with an ODH sensor head, ventilation fan, power outage, etc. The second (or level two) alert is a signal communicating an ODH emergency and calling for immediate evacuation of the affected area. The level two evacuation emergency signal activates the FACP horns and strobes and summons a fire department response. The level two alert would be accompanied with the same strobes as a level one alert so FACP horns and both strobes would be flashing during an ODH emergency. Training will reinforce the message that a level one signal from the ODM system indicates a warning to leave the area immediately due to a problem with the Cryogenic System while a level two alert indicates an ODH emergency and an order to leave the area immediately. Both levels of ODM notification would be sent to the Accelerator Control Room in accordance with SLAC Guidelines for Operations [15], as well as the SLAC Main Gate.

The final design of the ODH Control System will be detailed in a Functional Requirements Specification Document. [16]

2.3.9.2 Lintels

Jefferson Laboratory (Jlab) relies on Lintels to keep stratified helium from entering the tunnel exits. The lintels used at Jlab are typically about twenty four inches tall and located at the ceiling between the exit and a ventilation shaft perpendicular to the path of travel. Buoyant helium above the lower edge of the lintel is stopped from traveling into the escape route and will tend (is directed) to rise up the ventilation shaft. Lintels are not effective for very thick layers of helium or helium that is not stratified. The Project Fire Hazard Analysis [5] requires an Area of Refuge (AOR) every 330 feet in the Housing. The ceiling height inside the AOR is two feet lower that the tunnel ceiling providing an effective lintel at those openings.

2.3.9.3 Visitors

Due to the egress issues and the large quantity of cryogens in the tunnel, visitors (without SLAC specific ODH training) will be accompanied by a SLAC ODH trained escort familiar with the SLAC tunnel. Also, visitors will be restricted to a delineated area that is a short distance from the stairway at Sector 4.

3 Area Specific Content

This section of the document contains information that is specific to each of the three separate areas.

3.1 Linac Housing

3.1.1 Affected Area Description & Boundaries

The affected area under review in this analysis includes the first third of the two mile long Housing. The Housing (tunnel) floor is 35 feet below the Gallery building floor. The tunnel floor slopes down slightly to the South and to the East. The East-West elevation change is significant as the floor level changes approximately 12 feet over the length of the affected area. The West end (aka front, injector, or gun end) of the machine is at the highest elevation. The Linac coordinate system is oriented such that if one were standing in the Housing at the injector looking down-beam, X is positive left to right (north to south); Y is positive moving vertically up and Z is positive moving down-beam (west to east). The approximate location of Linac coordinate 0,0,0 is at the beginning of Sector 1 at the beam line center for the original warm copper Linac. The Housing tunnel is nominally 11 feet wide (in X) by 10 feet tall (in Y). The 2,400 feet long affected area begins at the shielding wall (Z= -74.5 ft.) and ends just before Sector 8 (Z= 2319 ft.). There are 138 vertical penetrations connecting the two spaces ranging from 21 to 40 inches in diameter.

Helium barriers will be installed around the perimeter of the affected area to stop migration of helium gas into adjacent areas. It is important to locate both the Gallery and Housing helium barrier at the same location in Z. This is to avoid “cross-talk” between penetrations that might allow helium gas to move around a barrier, through penetrations. In the Gallery there is an existing fire wall located just east of penetration 7-17 that will be closed and sealed. A new helium barrier wall will be built in the Housing between penetrations 7-17 and 8-1 (Z= 2321).

3.1.2 Cryogenic Equipment in the Housing

There will be 37 cryomodules connected in two independent strings with 17 up beam and 20 down beam of the second bunch compressor in Sector 4. There will also be approximately 450 feet of cryogenic bypass line installed in 2400 feet of affected tunnel space. See Figure 1 above and Section 2.1 for details of the system and the mass equivalent to nearly 14,000 liters of liquid helium in the tunnel. It is assumed a very large earthquake is the most likely event that could seriously damage both strings simultaneously. It is more likely that any other event would be limited to one string and about half the inventory. For purposes of this analysis, it is assumed there is an infinite supply of helium available to any leak.

3.1.3 Adjacent Areas

The affected area is separated from adjacent areas by sealed barriers designed to limit the movement of helium gas into those areas. The PFHA [5] requires fire rated walls and doors be installed between the new SRF Linac terminating at approximately Sector 7 and the existing warm copper Linac beginning at approximately Sector 11. The existing shielding wall up beam of the Injector (Z= -75 ft.) will also be sealed as will all openings between SRF Linac and stairways, manways and the damping rings. Helium containment barriers, radiation and fire rated barriers may be one in the same, but are not required to be. These barriers are depicted (in red) in Figure 4 below.

3.1.4 Computational Fluid Dynamics Analysis

Computational Fluid Dynamics (CFD) analyses of the Linac Housing will help better understand the effects of various helium release scenarios. At the time of this writing, models of the SLAC Linac tunnel are under development. Once the CFD is complete, it should demonstrate how well the seven dedicated helium ventilation penetrations perform under various release scenarios. We will know if seven penetrations are sufficient or if more are necessary. This Preliminary ODH Analysis is based on conservative steady state assumptions; the CFD analyses may help refine those assumptions.

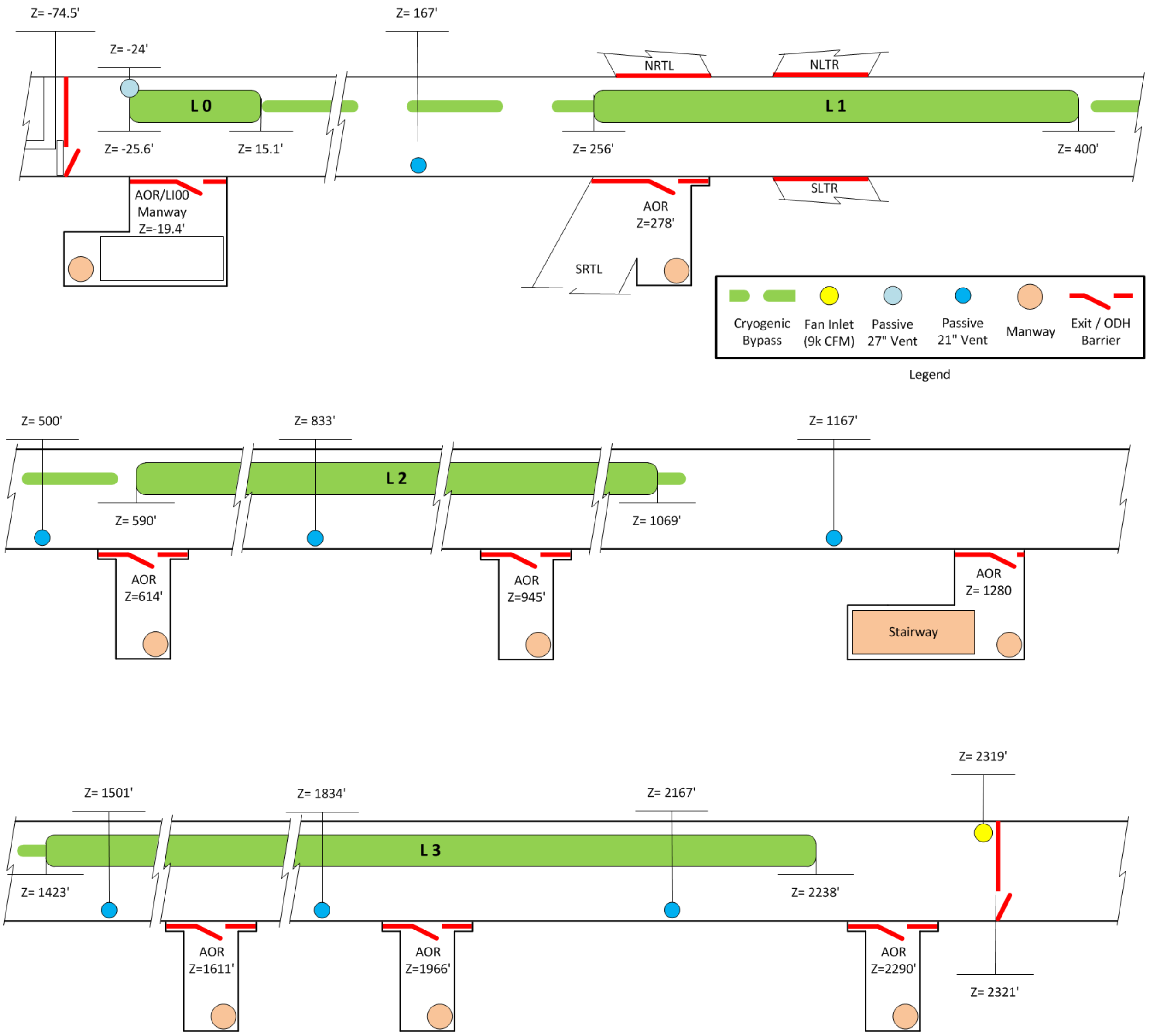


Figure 4 Linac Housing Schematic

3.1.5 Manways

There are 8 vertical ladder manways and one stairway connecting the Gallery building and the affected area of the Linac. The area at the base of the manway is considered part of an Area of Refuge (AOR). These safe areas are proposed in the PFHA [5] but will be useful during a significant ODH event. The AOR includes the space beginning upstairs at a door separating Gallery from the enclosed space surrounding the top of the ladder, down the ladder to an area below that is typically 5 foot wide by 12 foot long and to a new door separating the AOR from the Housing. The AOR will likely have forced air ventilation and will be sealed to keep helium and/or smoke out. The Gallery area beyond the door at the top of the manway is not considered part of the affected area.

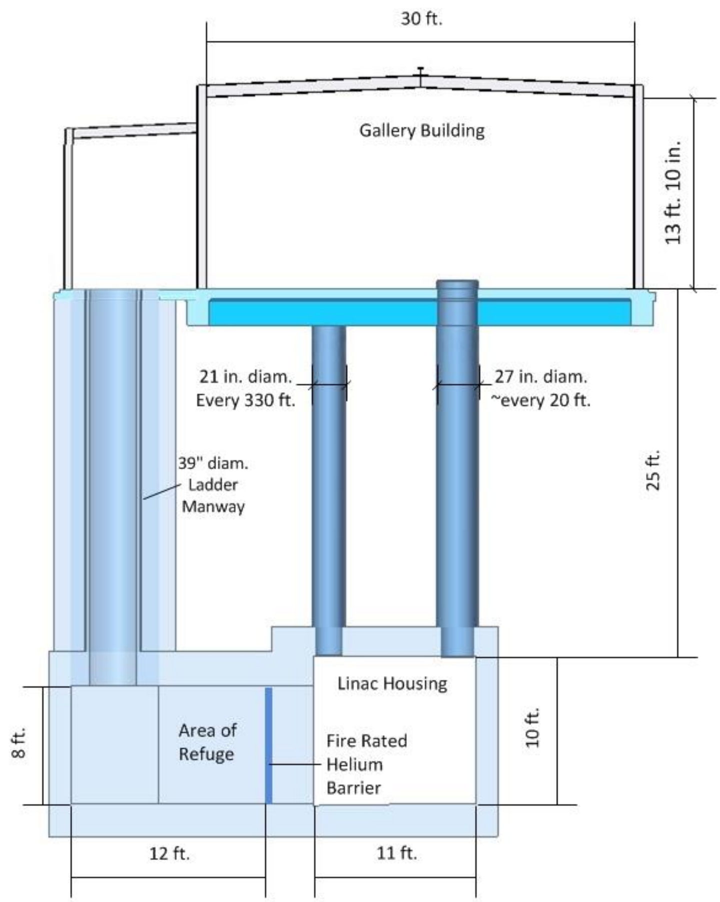


Figure 5 Linac Gallery and Housing Cross Section

3.1.6 Linac Penetrations

There are 130 penetrations (not counting 8 manways) extending from the ceiling of the Linac tunnel up through the Gallery floor, connecting the two affected spaces. The 27 inch diameter standard penetrations are near the north wall of the tunnel, the distance between them varies but they are typically about 20 feet apart. Each ~330 foot sector has 17 standard and one smaller 21 inch penetration. Most of the 123 standard penetrations will be filled with wave guide, electrical conduit, utility piping and shielding materials. Some standard penetrations have been set aside to be used to vent helium from the tunnel (if necessary); others will be completely sealed for radiation protection. There are 7 existing 21 inch diameter penetrations. These smaller penetrations are referred to as the "18th penetration" in as-built drawings of the Linac. The 18th penetrations are used as a chase for low conductivity water (LCW) piping in the original Linac (to be removed for LCLS-II) and are located on the tunnel ceiling, near the south wall. See Figures 4 and 5 above. The 18th penetrations are dedicated to helium removal and will have operable dampers installed. See Section 3.1.8.2 for description of these passive vents. Dampers will be closed during beam operations and will remain closed during occupancy unless oxygen concentration levels drop below 19.5%.

All standard penetrations not specifically used to vent helium will be sealed to prevent helium in the tunnel from leaking into the Gallery. It would be impractical to completely seal these penetrations and keep 100% of helium gas from entering the Gallery building; therefore in the Gallery ODH analysis, it is assumed that 10% of any helium lost in the Housing will find its way through the penetrations into the Gallery building. Helium gas vented into the tunnel will likely stratify near the ceiling and leave the tunnel through one of the 7 passive vents. Any helium that does not stratify will leave the tunnel at Sector 0 through the tunnel ventilation system exhaust vent.

3.1.7 Access & Egress

The Linac Housing is located 35 feet below the Gallery. Access to the tunnel is typically made through a stairway near the midpoint of the SRF Linac (Z=1280 ft.). There are 4 AORs up beam of the stairway and 3 down beam. Walking time between AORs is approximately 1 to 2 minutes as they are approximately 330 feet apart. There will be exits at either end of the affected area in the Housing. The up beam (west end) area egress is through the injector laser room. There will be “crash bars” that shut down laser hazards allowing people to move through the area in an emergency. This is not a routine access or egress route. The down beam (east end) area egress from the affected area is into the warm Linac Housing at Sector 8 through the fire/helium isolation barrier door.

Operational Mode	Housing	Gallery	Cryoplant Bld
Full Linac 2.0K CW Maximum Heat Load	Prohibited	Allowed	Allowed
Full Linac 2.0K CW Nominal Heat Load	Prohibited	Allowed	Allowed
Full Linac 4.5K Standby	Allowed	Allowed	Allowed
Linac Cooldown to 80K or Warm to 300K	Special Authorization	Allowed	Allowed
Single CM warmup and re-cooling	Allowed	Allowed	Allowed
One String Cold, other is warmed up or cooled down	Special Authorization	Allowed	Allowed
Cool down 80K to 4.5K	Allowed	Allowed	Allowed
Fast Cryomodule Cool down from 40K	Allowed	Allowed	Allowed

Table 2 Operational Modes and Access States

3.1.8 Ventilation

3.1.8.1 Forced Ventilation

The Housing will have approximately 9000 CFM of fresh air ventilation during access. The PPS access control system will inhibit air handler operation during beam operations of the SRF Linac. The forced air ventilation system will have dampers at both supply and exhaust penetrations that close only when the system is off due to beam operations. Fresh air will be introduced at the East end of the affected area of the Housing. Fresh air will be pushed into the Housing through penetration 7-17 and exhausted through a penetration in Sector 0. Air entering the Housing will be filtered to remove airborne particulate and keep the Housing clean. The air will also be temperature controlled to avoid thermal effects on warm components in the Housing. Air will move East to West in the tunnel at ~1.6 feet/sec. This volume of air amounts to

2.4 air changes per hour (ACH). The Housing is not completely sealed and it is not assured that all of the air entering from Sector 7 will exit the tunnel at Sector 0. It may be necessary to add an exhaust fan pulling at Sector 0. The need for additional fans will be assessed through CFD modeling and testing once the final tunnel and penetration configurations are determined.

3.1.8.2 Passive Ventilation

Passive ventilation (no fan) will be used to vent the release of helium from the Housing during and after an event. There are seven 21 inch diameter penetrations (described in Section 3.1.6) dedicated to helium removal. They currently end in a trench just below floor level in the Gallery. See Figure 5 above. Ducting will be added to vent helium outside the Gallery building. Movement of air into and out of the Housing is not permitted during beam operations; therefore actuated dampers will be needed to control the flow of air from the tunnel. Dampers are also necessary to keep unfiltered air out of the Housing and reduce airborne particulate during beam operations. Some equipment in the Housing is temperature sensitive. Dampers will help maintain temperature stability. For these reasons, automated dampers will be added to each 21 inch vent. All dampers will open automatically through the ODM system if oxygen concentration drops below 19.5% or if there is a loss of ventilation. These vents should handle any typical leak experienced over the life of the system. In the case of a very large release, dampers with control actuators will not operate fast enough to avoid tunnel pressurization. Therefore, some or all vents will be fitted with “barometric dampers” which will act instantly to mitigate any possibility of tunnel pressurization. These barometric dampers are gravity operated so they do not require power to function. The seven 21 inch diameter penetrations provide a gross effective cross sectional area equivalent to 16.8 sq. ft. available for passive ventilation during an event. CFD analysis will help determine if seven of these penetrations will be enough to handle all credible events.

3.1.9 Volume Calculation

The tunnel cross section used for volume calculation is reduced by approximately 12% to account for equipment installed in the tunnel. The reduction is based on the cross-sectional area of a cryomodule plus 15% to account for wave guide, couplers, valves, etc., in addition to another 3 square feet allowing for lighting, conduit, cable tray, wiring, etc. This analysis is limited to the tunnel volume that begins at the shielding wall at Z ≈ -74.5 ft (in Sector 0) and ends at Z =2319 ft. (just east of penetration 7-17 in Sector 7). The net volume of this area of interest is approximately 232 thousand cubic feet.

It would be unreasonable to consider the total 2400 feet of affected tunnel space when calculating oxygen concentration near a localized event. The closer an event is to a person (in the tunnel), the greater the impact. Documented tests spills at CERN clearly demonstrate that a person 100 meters from a significant event[1] will hear it, see it and have time to walk away from it [14]. This would not likely be the case for a maximum credible incident at SLAC. This analysis will consider a control volume of 32 thousand cubic feet consisting of ~330 feet of tunnel length and the reduced cross section to calculate oxygen concentration for any leak event in the tunnel.

The following areas are not included in the volume calculation: the manway ladders, the Area of Refuge, the equipment shaft at Sector 1 and the stairway at Sector 4.

[1] Example test 100 grams/second spill rate

3.2 Linac Gallery Building

3.2.1 Affected Area Description & Boundaries

The Gallery is approximately 30 feet wide and 14 feet tall. The affected area will be separated from adjacent areas by exterior walls and by sealing the existing fire rated wall just east of penetration 7-17. The mechanical alcoves on the south side of the Gallery and the I & C alcoves on the north side are included as part of the affected area, since it is impractical to eliminate the possibility of helium entering these spaces.

3.2.2 Cryogenic Equipment in the Gallery

Two new cryogenic distribution boxes and approximately 300 feet of cryogenic transfer line will be installed in the Gallery building in Sector 4 and 5, the equipment center will be near Z=1250 ft. Figure 6 below is a conceptual model of one distribution boxes to be placed in the Gallery and Figure 7 illustrates the basic configuration of the distribution boxes in the Gallery, the CMs in the Housing and the Cryoplant.

The Gallery building is located directly above the Housing and the two spaces are connected by nearly 138 existing penetrations (over the first 10 sectors (1 km)) ranging from 21 to 40 inches in diameter. Most of the penetrations (~123) are 27 inches in diameter and will be filled with wave guide, electrical conduit, utilities piping and shielding materials. It would be impractical to seal all of these penetrations completely to keep helium gas in the Housing from entering the Gallery building; see Section 4.1.5 for discussion. Therefore, in Gallery area fatality factor calculations, it will be assumed that 10% of any helium lost in the Housing will enter the Gallery building through the penetrations with the same probability used in the Housing.

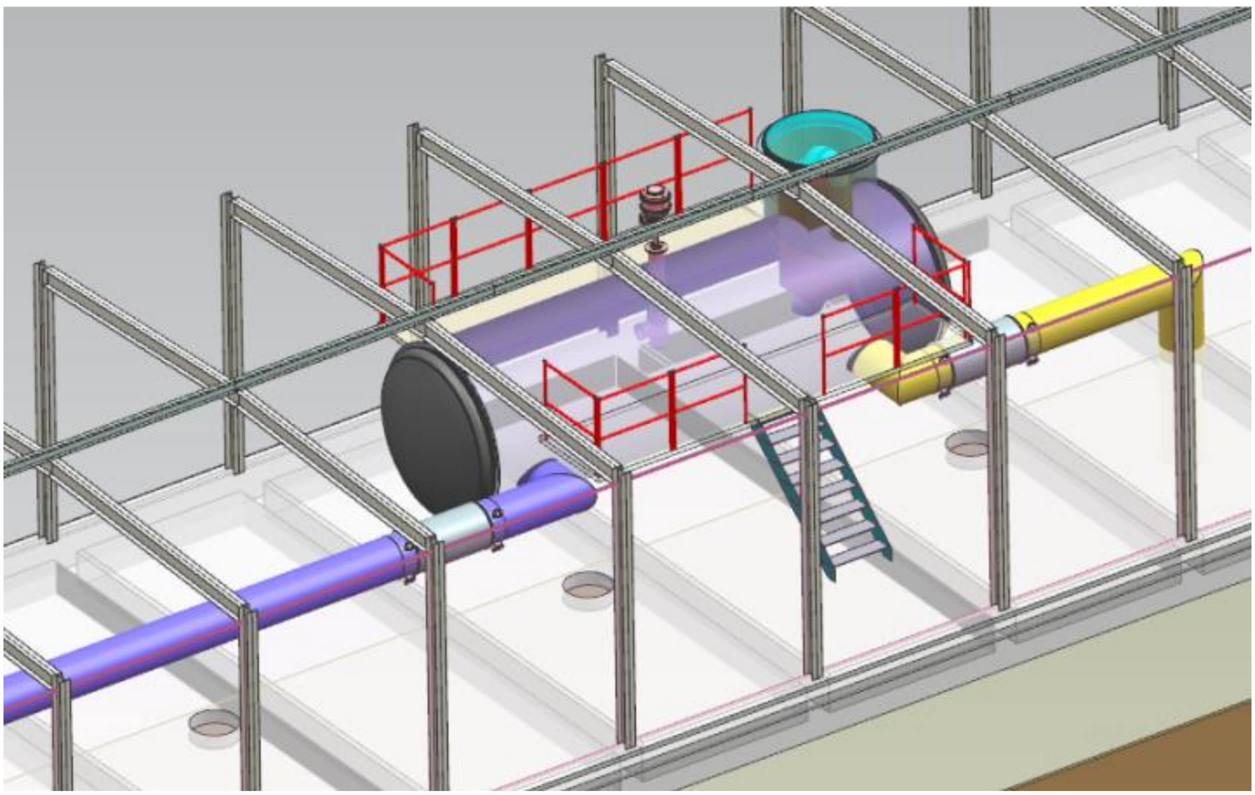


Figure 6 Conceptual Model of Cryogenic Distribution Box in the Gallery

3.2.3 Adjacent Areas

The second two thirds of the Gallery will be separated from the first third by the wall and doors that make up the existing fire wall between Sectors 7 & 8. In the past, these doors typically remain open until they are closed automatically in the event of a fire. These doors will be closed and will become a physical barrier between the ODH Classified area and the rest of the Gallery.

3.2.4 Ventilation

There are five existing exhaust fans mounted on the roof of each sector along the Gallery. Each exhaust fan is rated for 6500 CFM. [13] The fans have local controls with three positions, hand, off and auto. In “hand” they run continuously and in auto they run when a thermostat turns them on. It will be necessary to connect some of these fans to the ODM system. Depending on configuration, it may be necessary to add new exhaust fans above the new distribution boxes. This will be determined in the Gallery area ODH analysis. Makeup air louvers are not likely needed for the Gallery building as it has many openings and there are no current plans to seal up these openings.

3.2.5 Volume Calculation

The cross sectional area of the Gallery building is approximately 400 square feet. The affected area begins at the West wall of the Gallery building in Sector 0 and ends at the fire rated wall between Sectors 7 and 8. Ignoring the volume in the Mechanical and I&C Alcoves, the total volume of this area of interest is approximately 1.2 million cubic feet.

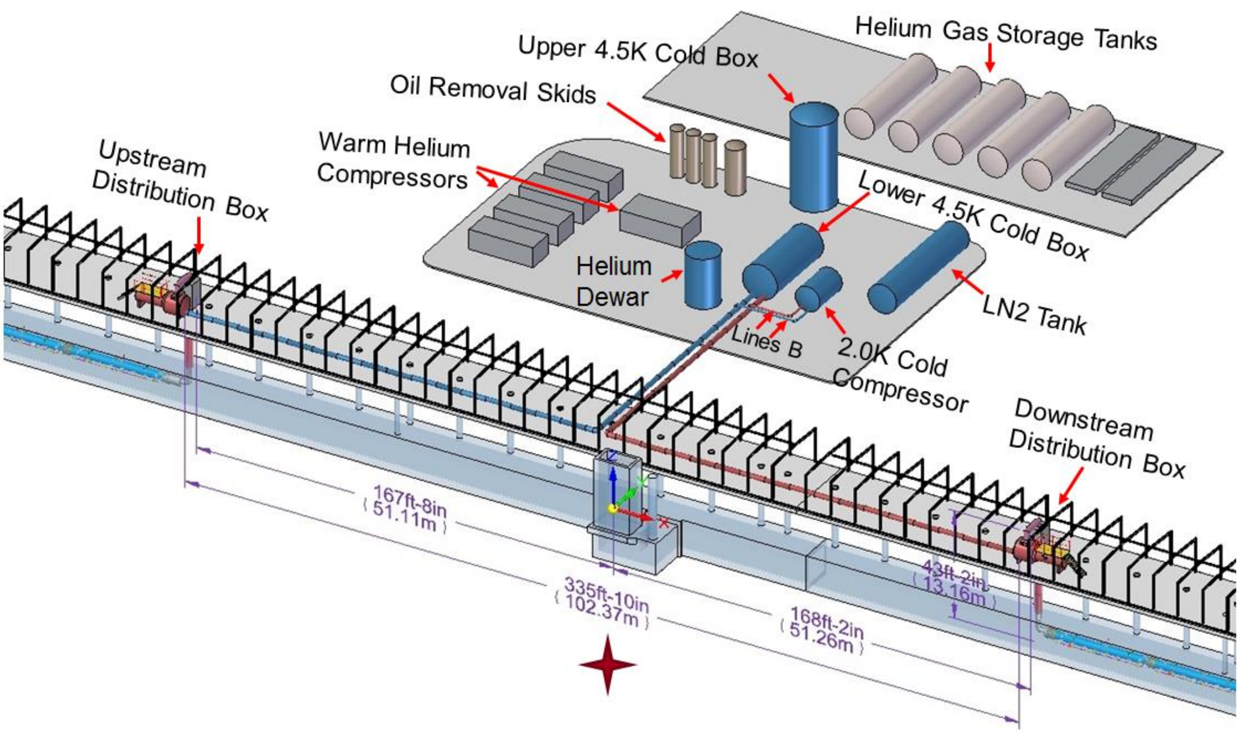


Figure 7 Conceptual Layout of Cryoplant and Distribution Boxes in the Gallery

3.3 Cryogenic Plant Building

3.3.1 Affected Area Description & Boundaries

The new 12,000 square foot Cryoplant building will be located approximately 60 feet north of the Gallery building at Sector 4. The 84 by 146 foot building is located roughly between Z= 1135 and Z=1280 feet.

3.3.2 Equipment in the Cryogenic Building

The Cryoplant building has two major sections, one housing five (with room for a sixth) warm helium compressors and the second space houses a 10,000 liquid liter helium dewar, the 2.0K cold box and the low temperature section of the 4.5K cold box.

3.3.3 Adjacent Areas

There is a Service Monitoring room planned for the second floor of the cold box room. This room will have positive pressurization to keep helium from collecting in that space. There are two exits from the Service Monitoring room; one exit leading directly out doors (to the south) and the second leading into the cold box room. Below the Service Monitoring room is an IT room and a utility room. There is no plan at this time to provide positive pressurization for the first floor rooms.

There will be a 117,000 liter liquid nitrogen horizontal dewar located immediately outside the building to the East. Nitrogen is not expected to migrate into the building. However, oxygen concentration sensors will be mounted in the trench inside of the warm compressor room and near the floor in the cold box room to be safe. The high temperature section of the 4.5K cold box, a helium purification system and oil extraction vessels are all located along the North side of the building. There will be five, 4,000 SCF each, warm Helium gas storage vessels located across the road to the North of the building next to a helium loading station.

An analysis of outdoor spills was completed as part of the LCLS-II Environmental Assessment [4]. A 4,200 gallon liquid helium spill at a rate of 3,740 GPM (potentially resulting from a major earthquake or explosion) was modeled with worst case weather conditions (low wind speeds and stable dispersion) and found that workers within 36 feet of such a spill could experience serious health effects. A similar model was analyzed for 16,000 gallons of liquid nitrogen with a flow rate of 120 GPM. The analysis of a nitrogen spill found no serious health effects would be suffered from the resulting gas plume.

3.3.4 Ventilation

Six exhaust fans are planned for the Cryoplant building; each fan is sized to provide 20,000 CFM. The fans are intended primarily for heat removal and are not considered in the ODH Classification.

3.3.5 Volume Calculation

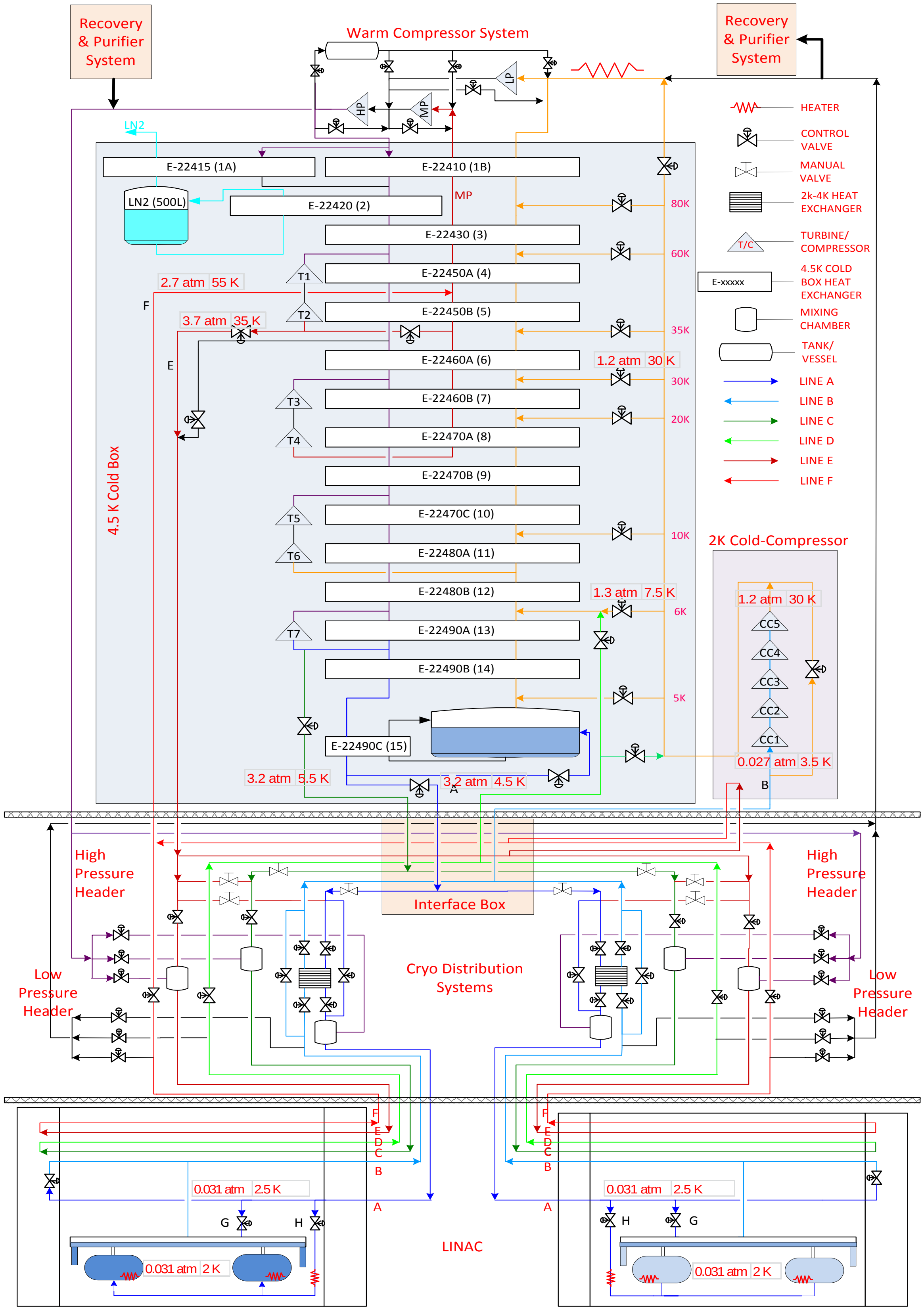
The Cryoplant building total volume is approximately 42,000 cubic feet. The equipment to be installed in the Cryoplant building is very similar to the Jefferson Lab CHL2 equipment for their 12-GeV upgrade. The approach used to calculate the ODH classification was to assume any major leak would cause an Oxygen concentration less than 8% and F_i is assumed to be 1.

4 References

Reference Number		Document Title
[1]	SLAC-I-720-0A29Z-001-R023.4	SLAC ES&H Manual, Chapter 36 Cryogenic and Oxygen Deficiency Hazard Safety
[2]	SLAC-I-730-0A06C-001-R002	SLAC ODH Safety Review Procedure
[3]	LCLSII-1.1-PM-0004-R1	Hazard Analysis Report
[4]	DOE/EA-1975	Linac Coherent Light Source-II Environmental Assessment
[5]	LCLSII-1.1-PM-0149-R0	Project Fire Hazard Analysis
[6]	DOE-STD-1020-2012	DOE Standard - Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities
[7]	LCLSII-X.X-PM-0XXX-RX	Cryogenic Building & Infrastructure Project (CP1), Draft Fire Hazard Analysis
[8]	ISSN 2327-6916	The Uniform California Earthquake Rupture Forecast, Ver. 3 (UCERF3)
[9]	FESHM 4240TA	Fermilab, ODH Technical Appendix, rev January 2015
[10]	Crane 410	Flow of Fluids Through Valves, Fittings and Pipe, Technical Paper #410
[11]	LCLSII-1.1-DR-0251	LCLS-II Final Design Report
[12]	JLAB-TN-07-041	ODH Risk Assessment, CHL Compressor Room
[13]	D-502-501	Klystron Gallery, Mechanical Ventilation Plans and Details
[14]	EDMS # 1373195	Helium spill tests in the LHC Tunnel, R. Trant, *International Technical Safety Forum, Batavia IL, 2014*
[15]	SLAC-I-010-00100-000-R008	SLAC Guidelines for Operations
[16]	LCLSII-1.2-FR-0386	Functional Requirements Specification for Oxygen Deficiency Monitoring System
[17]	LCLSII-4.9-EN-0253	CDS/Cryomodule What-If Analysis
[18]	LCLSII-4.9-EN-0255	CDS/Cryomodule Failure Mode and Effects Analysis
[19]	2015-081G	Seismic Hazard Study, Rutherford & Chekene

Appendix A

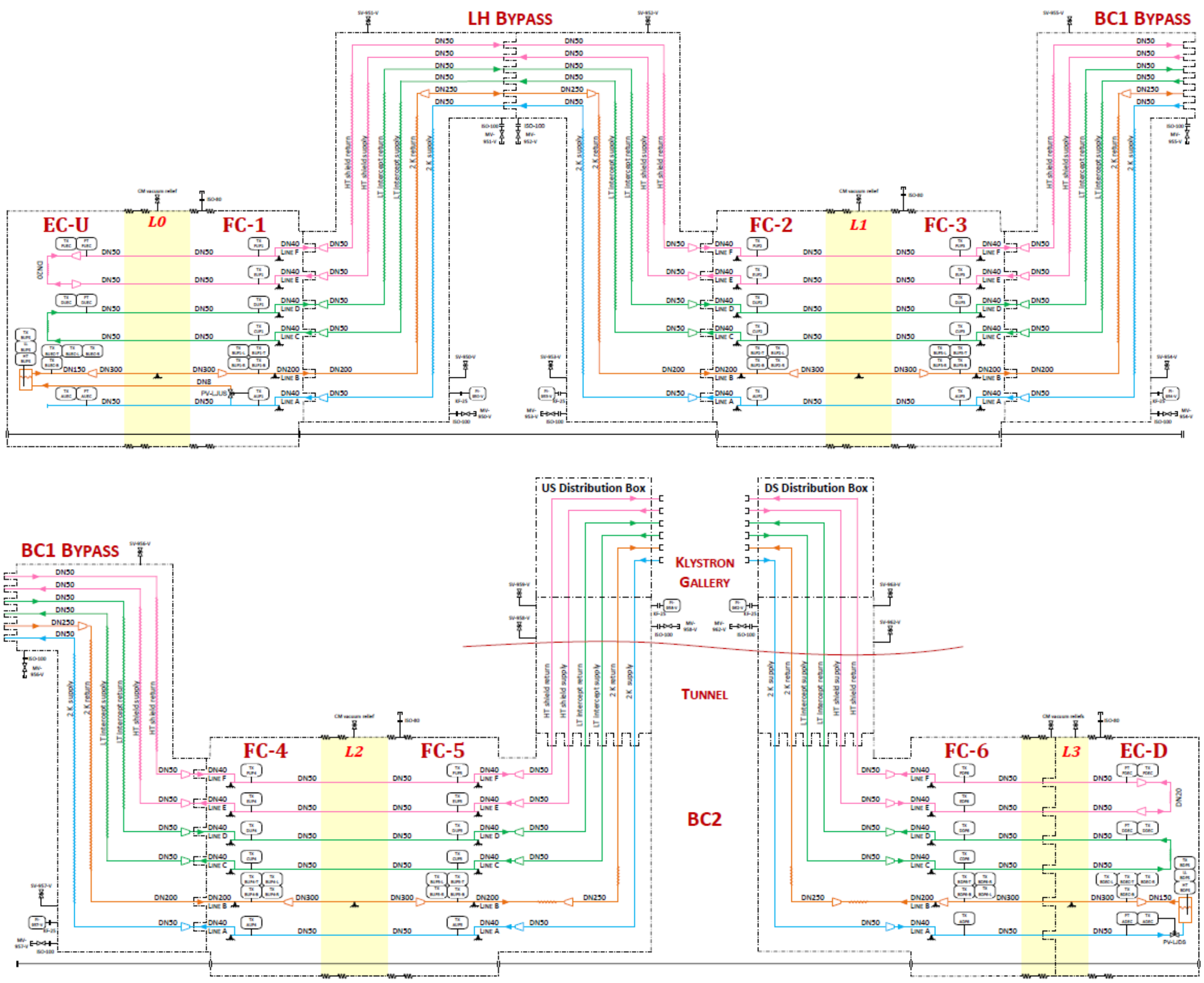
Single Refrigerator Cryogenic System Schematic



Cryogenic System P&IDs

P&ID Title	JLAB Drawing Number
LCLSII Warm Helium Compressor System	79120-0002
LCLSII Low Pressure Compressor	79120-0003
LCLSII Medium Pressure Compressor	79120-0004
LCLSII High Pressure Compressor	79120-0005
LCLSII Oil Removal System	79120-0700
LCLSII Oil Management System	79120-0701
LCLSII Gaseous Helium Storage	79720-0000
LCLSII LHe Storage Dewar System P&ID	79720-0120
LCLSII LN2 Storage Dewar P&ID	79720-0200
LCLSII He Gas Distribution System P&ID	79320-0000

Cryogenic Distribution System Schematic



Appendix B

Summary Fatality Factor Calculation Sheets

Preliminary ODH Analysis for Linac Tunnel LCLS-II SRF Linac - w/9000 CFM of Forced Fresh Air	Comments	Quantity (Items or Demands)	Inside Diameter (inches)	Leak Length[1] (Inches)	Leak Width[1] (inches)	Leak Effective Area[1] (in^2)	Leak Effective diameter[1] (inches)	Temperature[2] (K)	Pressure[3] (PSI)	He mass flow[4] thru orfice (lbs/sec)	He gas volumetric[5] flow rate (SCFS)	Oxygen Conc. ($\%O_2$)[6] with t=120	Oxygen Conc. ($\%O_2$)[6] as t→∞	F_i (fatality factor)	P_i (failures/hr)	ODH Rate (fatality/hr) $=F_i*P_i*\#$
CM Cavity (Pressure Vessel)	Rupture	296	9.4	14.84	1.86	27.54	5.92	2	21.8	1.80E+02	17,338.87	0.2	0.2	1.00E+00	5.00E-09	1.48E-06
Very Large Earthquake	Many Ruptures	1	n/a			n/a	n/a	n/a	n/a	n/a	n/a	0.1	0.1	1.00E+00	3.04E-07	3.04E-07
Valve Leak CM Cool-Down and Liquid Level Control Valves	Leak	74	1.0	3.14	0.04	0.11	0.37	2.3	174.0	1.92E+00	184.66	12.8	9.4	3.42E-01	1.00E-08	2.53E-07
Weld Leak CM Helium Circuit (G) - 2-phase pipe	Rupture	888	3.8	6.02	0.75	4.54	2.40	2	21.8	2.97E+01	2,855.72	1.0	1.0	1.00E+00	9.23E-11	8.20E-08
Valve Leak CM Cool-Down and Liquid Level Control Valves	Rupture	74	1.0	6.28	0.25	1.57	1.41	2.3	174.0	4.42E+01	4,254.93	0.7	0.7	1.00E+00	5.00E-10	3.70E-08
Weld Leak Transfer Line, End & Feed Cap Circuit (B) - 2K Return	Large leak	220	12.4			1.55	1.40	2	21.8	8.83E+00	848.69	3.6	3.2	1.00E+00	1.38E-10	3.03E-08
Weld Leak CM Helium Circuit (G) - 2-phase pipe	Large leak	888	3.8			1.55	1.40	2	21.8	9.12E+00	876.98	3.5	3.1	1.00E+00	2.77E-11	2.46E-08
EC/FC Pneumatic Valve	Leak	2	1.0	6.28	0.04	0.22	0.53	2.3	174.0	4.03E+00	387.20	7.9	5.9	1.00E+00	1.00E-08	2.00E-08
Weld Leak CM Helium Circuit (H) - warm up / cool dn	Rupture	2664	1.5	2.41	0.30	0.72	0.96	2.3	174.0	1.41E+01	1,352.08	2.2	2.1	1.00E+00	6.56E-12	1.75E-08
Weld Leak CM Helium Circuit (B) - 2K Return	Large leak	111	12.4			1.55	1.40	2	21.8	8.83E+00	848.69	3.6	3.2	1.00E+00	1.38E-10	1.53E-08
Weld Leak Transfer Line, End & Feed Cap Circuit (B) - 2K Return	Rupture	220	12.4	19.46	2.43	47.35	7.76	2	21.8	3.10E+02	29,812.05	0.1	0.1	1.00E+00	4.13E-11	9.09E-09
Weld Leak CM Helium Circuit (A) - 2.3 K Liquid Supply	Rupture	481	2.2	3.39	0.42	1.44	1.35	2.3	174.0	2.79E+01	2,683.27	1.1	1.1	1.00E+00	1.19E-11	5.71E-09
Weld Leak CM Helium Circuit (B) - 2K Return	Rupture	111	12.4	19.46	2.43	47.35	7.76	2	21.8	3.10E+02	29,812.05	0.1	0.1	1.00E+00	4.13E-11	4.59E-09
Weld Leak Transfer Line, End & Feed CapCircuit (C) - 5K TI Supply	Rupture	220	2.2	3.39	0.42	1.44	1.35	5	174.0	2.65E+01	2,546.58	1.2	1.2	1.00E+00	1.19E-11	2.61E-09
Weld Leak Transfer Line, End & Feed CapCircuit (D) - 5K TI Return	Rupture	220	2.2	3.39	0.42	1.44	1.35	5	174.0	2.65E+01	2,546.58	1.2	1.2	1.00E+00	1.19E-11	2.61E-09
Weld Leak Transfer Line, End & Feed CapCircuit (E) - 40K TI Supply	Rupture	220	2.2	3.39	0.42	1.44	1.35	40	174.0	5.54E+00	532.63	5.9	4.6	1.00E+00	1.19E-11	2.61E-09
Weld Leak Transfer Line, End & Feed CapCircuit (F) 40K TI Return	Rupture	220	2.2	3.39	0.42	1.44	1.35	40	174.0	5.54E+00	532.63	5.9	4.6	1.00E+00	1.19E-11	2.61E-09
Weld Leak Transfer Line, End & Feed CapCircuit (A) - 2.3 K Supply	Rupture	220	1.7	2.65	0.33	0.88	1.06	2.3	174.0	1.70E+01	1,636.78	1.8	1.8	1.00E+00	9.27E-12	2.04E-09
Weld Leak CM Helium Circuit (C) - 5K Supply	Rupture	111	2.2	3.39	0.42	1.44	1.35	5	174.0	2.65E+01	2,546.58	1.2	1.2	1.00E+00	1.19E-11	1.32E-09
Weld Leak CM Helium Circuit (D) - 5K Return	Rupture	111	2.157480315	3.39	0.42	1.44	1.35	5	174.0	2.65E+01	2,546.58	1.2	1.2	1.00E+00	1.19E-11	1.32E-09
Weld Leak CM Helium Circuit (E) - 40K Supply	Rupture	111	2.2	3.39	0.424	1.44	1.35	40	174.0	5.54E+00	532.63	5.9	4.6	1.00E+00	1.19E-11	1.32E-09
EC/FC Pneumatic Valve	Rupture	2	1	6.28	0.250	1.57	1.41	2.3	174.0	4.42E+01	4,254.93	0.7	0.7	1.00E+00	5.00E-10	1.00E-09
Weld Leak CM Helium Circuit (F) - 40K Return	Rupture	111	2.1	3.25	0.41	1.32	1.30	40	174.0	5.08E+00	488.86	6.4	4.9	1.00E+00	8.05E-12	8.94E-10
Weld Leak CM Helium Circuit (H) - warm up / cool dn	Leak	2664	1.5			0.02	0.14	2.3	174.0	2.62E-01	25.19	19.6	18.0	1.05E-07	4.71E-10	1.32E-13
Weld Leak CM Helium Circuit (A) - 2.3 K Liquid Supply	small leak	481	2.2			0.02	0.14	2.3	174.0	2.62E-01	25.19	19.6	18.0	1.05E-07	3.96E-10	2.01E-14
Weld Leak Transfer Line, End & Feed CapCircuit (A) - 2.3 K Supply	Leak	220	1.7			0.02	0.14	2.3	174.0	2.62E-01	25.19	19.6	18.0	1.05E-07	3.09E-10	7.17E-15
Weld Leak CM Helium Circuit (G) - 2-phase pipe	small leak	888	3.8			0.02	0.14	2	174.0	2.62E-01	25.18	19.6	18.0	1.05E-07	2.77E-11	2.59E-15
CM Cavity (Pressure Vessel)	Leak	296	9.4			0.02	0.14	2	21.8	8.83E-02	8.49	20.5	19.9	0.00E+00	8.00E-08	0.00E+00
Weld Leak CM Helium Circuit (B) - 2K Return	Small Leak	111	12.4			0.02	0.14	2	21.8	8.83E-02	8.49	20.5	19.9	0.00E+00	1.38E-09	0.00E+00
Weld Leak CM Helium Circuit (C) - 5K Supply	small leak	111	2.2			0.02	0.14	5	174.0	2.49E-01	23.91	19.6	18.1	0.00E+00	3.96E-10	0.00E+00
Weld Leak CM Helium Circuit (D) - 5K Return	small leak	111	2.2			0.02	0.14	5	174.0	2.49E-01	23.91	19.6	18.1	0.00E+00	3.96E-10	0.00E+00
Weld Leak CM Helium Circuit (E) - 40K Supply	small leak	111	2.2			0.02	0.14	40	174.0	5.57E-02	5.35	20.7	20.3	0.00E+00	3.96E-10	0.00E+00
Weld Leak CM Helium Circuit (F) - 40K Return	small leak	111	2.1			0.02	0.14	40	174.0	5.57E-02	5.35	20.7	20.3	0.00E+00	2.68E-10	0.00E+00
Weld Leak Transfer Line, End & Feed Cap Circuit (B) - 2K Return	small leak	220	12.4			0.02	0.14	2	21.8	8.83E-02	8.49	20.5	19.9	0.00E+00	1.38E-09	0.00E+00
Weld Leak Transfer Line, End & Feed CapCircuit (C) - 5K TI Supply	small leak	220	2.2			0.02	0.14	5	174.0	2.49E-01	23.91	19.6	18.1	0.00E+00	3.96E-10	0.00E+00
Weld Leak Transfer Line, End & Feed CapCircuit (D) - 5K TI Return	small leak	220	2.2			0.02	0.14	5	174.0	2.49E-01	23.91	19.6	18.1	0.00E+00	3.96E-10	0.00E+00
Weld Leak Transfer Line, End & Feed CapCircuit (E) - 40K TI Supply	small leak	220	2.2			0.02	0.14	40	174.0	5.57E-02	5.35	20.7	20.3	0.00E+00	3.96E-10	0.00E+00
Weld Leak Transfer Line, End & Feed CapCircuit (F) 40K TI Return	small leak	220	2.2			0.02	0.14	40	174.0	5.57E-02	5.35	20.7	20.3	0.00E+00	3.96E-10	0.00E+00
															∑Φ- w/ventilation	2.30E-06

Preliminary ODH Analysis for Linac Tunnel LCLS-II SRF Linac - with No Forced Fresh Air	Comments	Quantity (Items or Demands)	Inside Diameter (inches)	Leak Length[1] (Inches)	Leak Width[1] (inches)	Leak Effective Area[1] (in^2)	Leak Effective diameter[1] (inches)	Temperature[2] (K)	Pressure[3] (PSI)	He mass flow[4] thru orfice (lbs/sec)	He volumetric[5] flow rate (SCFS)	Oxygen Conc. ($\%O_2$)[6] with t=120	Oxygen Conc. ($\%O_2$)[6] as t→∞	F_i (fatalities/ failure)	P_i (failures/hr)	ODH Rate (fatality/hr) $=F_i*P_i*\#$
Weld Leak CM Helium Circuit (H) - warm up / cool dn	no ventilation	2664	1.5			0.02	0.14	2.3	174.0	2.62E-01	25.19	19.1	0.0	1.00E+00	4.71E-10	1.26E-06
Weld Leak CM Helium Circuit (A) - 2.3 K Liquid Supply	no ventilation	481	2.2			0.02	0.14	2.3	174.0	2.62E-01	25.19	19.1	0.0	1.00E+00	3.96E-10	1.90E-07
Weld Leak Transfer Line, End & Feed CapCircuit (A) - 2.3 K Supply	no ventilation	220	1.7			0.02	0.14	2.3	174.0	2.62E-01	25.19	19.1	0.0	1.00E+00	3.09E-10	6.80E-08
Weld Leak CM Helium Circuit (G) - 2-phase pipe	no ventilation	888	3.8			0.02	0.14	2	174.0	2.62E-01	25.18	19.1	0.0	1.00E+00	2.77E-11	2.46E-08
CM Cavity (Pressure Vessel)	no ventilation	296	9.4			0.02	0.14	2	21.8	8.83E-02	8.49	20.4	0.0	1.00E+00	8.00E-08	2.37E-05
Weld Leak CM Helium Circuit (B) - 2K Return	no ventilation	111	12.4			0.02	0.14	2	21.8	8.83E-02	8.49	20.4	0.0	1.00E+00	1.38E-09	1.53E-07
Weld Leak CM Helium Circuit (C) - 5K Supply	no ventilation	111	2.2			0.02	0.14	5	174.0	2.49E-01	23.91	19.2	0.0	1.00E+00	3.96E-10	4.39E-08
Weld Leak CM Helium Circuit (D) - 5K Return	no ventilation	111	2.2			0.02	0.14	5	174.0	2.49E-01	23.91	19.2	0.0	1.00E+00	3.96E-10	4.39E-08
Weld Leak CM Helium Circuit (E) - 40K Supply	no ventilation	111	2.2			0.02	0.14	40	174.0	5.57E-02	5.35	20.6	0.0	1.00E+00	3.96E-10	4.39E-08
Weld Leak CM Helium Circuit (F) - 40K Return	no ventilation	111	2.1			0.02	0.14	40	174.0	5.57E-02	5.35	20.6	0.0	1.00E+00	2.68E-10	2.98E-08
Weld Leak Transfer Line, End & Feed Cap Circuit (B) - 2K Return	no ventilation	220	12.4			0.02	0.14	2	21.8	8.83E-02	8.49	20.4	0.0	1.00E+00	1.38E-09	3.03E-07
Weld Leak Transfer Line, End & Feed CapCircuit (C) - 5K TI Supply	no ventilation	220	2.2			0.02	0.14	5	174.0	2.49E-01	23.91	19.2	0.0	1.00E+00	3.96E-10	8.70E-08
Weld Leak Transfer Line, End & Feed CapCircuit (D) - 5K TI Return	no ventilation	220	2.2			0.02	0.14	5	174.0	2.49E-01	23.91	19.2	0.0	1.00E+00	3.96E-10	8.70E-08
Weld Leak Transfer Line, End & Feed CapCircuit (E) - 40K TI Supply	no ventilation	220	2.2			0.02	0.14	40	174.0	5.57E-02	5.35	20.6	0.0	1.00E+00	3.96E-10	8.70E-08
Weld Leak Transfer Line, End & Feed CapCircuit (F) 40K TI Return	no ventilation	220	2.2			0.02	0.14	40	174.0	5.57E-02	5.35	20.6	0.0	1.00E+00	3.96E-10	8.70E-08
															∑Φ- wo/ventilation	2.62E-05
														P-pwr fail/hr	1.24E-04	3.25E-09
														P-fan fail/hr	9.00E-06	2.36E-10
															total Φ	**2.31E-06**

* See Misc tab for footnotes and miscellaneous calcuations

Appendix C
Jlab ODH Analysis for CHL2

JLAB-TN-13-0xx
Mathew C. Wright

ODH Assessment

Date: **9 Sept 2014**

Division: **Cryogenics**

Location: **CHL II Compressor Room**

Assessment Author: **Mathew Wright**

Jonathan Creel

Approval

Accelerator Division Engineering Department Head: **Will Oren**

ODH Risk Assessment, CHL II Compressor Room
July 31, 2007

Introduction

The following assessment addresses the risk of oxygen deficiency hazard (ODH) for the CHL compressor room (bldg. 08). The assessment is conducted according to Jefferson Lab's ODH Risk Assessment Process (ODHRAP). The general category of ODH hazard identified in the facility is liquid helium, gaseous helium, liquid nitrogen, and gaseous nitrogen. These are sources of helium gas which can dilute the normal oxygen content with health effects as outlined in ODH Risk Assessment Process.

The following sections cover the modeling scope and methodology for cryogen dispersion release, a description of the work space, risk assessment, failure rates of components, and requirements.

Model for Cryogen Dispersion Release

Source of ODH

The Model for Cryogen Dispersion Release is based on any source of gas that will deplete the oxygen level in the CHL II compressor room. Helium is the only source of gas in the CHL II compressor room.

Helium is supplied to the compressor room from seven 20,000 gallon storage tanks. One storage tank at a relief pressure of 18 atmospheres and standard temperature of 72.09 °F represents 68,223 standard cubic feet of helium. All seven helium storage tanks together represent ~478,000 standard cubic feet of helium. The worst case scenario of the entire warm helium gas inventory will be considered for catastrophic modes of failure (failed pipes or components). All other modes of failure that are not catastrophic will be considered to have a leak rate no larger than 30,000 standard cubic feet per hour.

Failure rate estimates (P_i) are based on JLAB listed equipment rates under ODHRAP. Fatality Factors (F_i) are derived from Figure 3, from ODHRAP. The sum of the failure product of the F_i and P_i determined the area classification in accordance with table 6 of ODHRAP.

Description of Work Space

The CHL II compressor room is joined to the CHL building by way of a sound resistant wall. The room is approximately 60' wide, 77' long and 30 feet in height. The overall volume of the room is approximately 139,000 cubic feet.

There are three doors, one on the North next to a rollup door, one on the South, and one on the East side of the building. There are no doorways that lead to the other rooms. The compressor room houses large helium compressors and a instrument air system On both the north and south walls there are louvers that allow fresh air to come into the rooms.The louvers are approximately 60 inches tall by 12 feet wide and there are three per wall.There are four fans in the compressor room that are designed to suck the air out of the room. In accordance with Appendix 6500-T2, reliable ventilation may be considered as a relevant factor in this ODH assessment if the volume of air in the room is replaced with fresh air at a minimum of once an hour.

ODH Risk Assessment

This assessment was done in two parts. Part one was to look at all the major possible catastrophic events. Due to the amount of helium represented in the warm helium gas tanks, a Fi of one will be used for the catastrophic events. Part two was to look at all other modes that have a leak rate less than 30,000 standard cubic feet per hour. Because 30,000 standard cubic feet per hour of helium will not lower the oxygen level less than 18% in the compressor room, a Fi of zero will be used for non-catastrophic events. Because a Fi of zero will yield a **f** of zero, only the catastrophic analysis has to be calculated.

The ODH class is determined using the "Oxygen Deficiency Hazard Classification" table in Appendix 6500-T3. This table uses the ODH fatality rate (per hour) (**f**). To calculate **f** the following equation must be used:

$$\phi = \sum nP_iF_i$$

Where:

φ = the ODH fatality rate (per hour),
P_i = the expected rate of the i^{th} type of event, (per hour)
F_i = the fatality factor for the i^{th} type event,
n = the number of components

Values for n were not counted, but instead a value much larger than what is real was used. That is mostly because there is no real effect in counting each item. Knowing that there are more than 33 welds in the compressor room, it was not possible to have an ODH rating less than one. Therefore, by using such grossly large values for n, the calculations show that the compressor rooms are no more than an ODH rating of one. Furthermore, the following calculation does account for the event that a compressor ruptures, but does not use the Pi value for an estimated median failure rate of a leak listed inODHRAP. Instead, a value of 300 years was converted to hours, inversed, and then used as the Pi value.

Component	Event	n	Pi	Fi	f
Compressor (warm)	Rupture	11	3.81E-07	1	4.19E-06
Pipes > 3", high quality	Rupture (section)	50	1.00E-10	1	5.00E-09
Pipes < 3"	Rupture	50	1.00E-09	1	5.00E-08
Manually operated valve	External leak-rupture	50	1.00E-08	1	5.00E-07
Air operated valve	External leak-rupture	50	1.00E-08	1	5.00E-07
Check valve	External leak-rupture	50	1.00E-08	1	5.00E-07
Valves: orifices, flow, meters, (test)	Rupture	50	1.00E-08	1	5.00E-07
Welds	Leak	1000	3.00E-09	1	3.00E-06
				S	9.24E-06

ODH Classification

Because $\Phi \geq 10^{-7}$ but $< 10^{-5}$, the **ODH classification is 1**.

Appendix C1

Jlab ODH Analysis for CHL Cold Box Room

JLAB-TN-07-042
Mathew C. Wright

ODH Assessment

Date: **31 May 2007**

Division: **Cryogenics**

Location: **CHL Cold Box Room**

Assessment Author: **Mathew Wright & Dana Arenius**

Approval

Accelerator Division Engineering Department Head: **Will Oren**

ODH Risk Assessment, CHL Cold Box Room
July 31, 2007

Introduction

The following assessment addresses the risk of oxygen deficiency hazard (ODH) for the CHL cold box room (bldg. 08). The assessment is conducted according to the requirements of Appendix 6500-T3, "ODH Risk Assessment". The general category of ODH hazard identified in the facility is cold helium, warm helium, cold nitrogen, and warm nitrogen.

The following sections cover the modeling scope and methodology for cryogen dispersion release, a description of the work space, risk assessment, failure rates of components, and requirements.

Model for Cryogen Dispersion Release

Source of ODH

The Model for Cryogen Dispersion Release is based any source of gas that will deplete the oxygen level in the CHL cold box rooms. Helium and nitrogen are the only sources of gas in these rooms.

Helium is supplied to the cold box rooms by way of the compressor room from six 20,000 gallon storage tanks. One storage tank at a relief pressure of 18 atmospheres and standard temperature of 72.09 ºF represents 68,223 standard cubic feet of helium. All six helium storage tanks together represent 409,338 standard cubic feet of helium. A large quantity of helium is also available to the cold box rooms from the cryomodules in the LINAC's. The LINAC's have a possible 2,324,242 standard cubic feet of helium stored at cryogenic temperatures.

Nitrogen is also supplied to the cold box rooms from two 20,000 gallon nitrogen dewars. The nitrogen is piped both in liquid and gaseous form to the cold box rooms. The maximum possible amount of both nitrogen dewars is approximately 3,732,331 standard cubic feet.

The worst case scenario of the entire warm helium gas inventory or the cold inventory of the LINAC's will be considered for catastrophic modes of failure (failed pipes or components). All other modes of failure that are not catastrophic will be considered to have a leak rate no larger than 18,000 standard cubic feet per hour for the original cold box room and 14,000 standard cubic feet per hour for the K100 room.

Failure rate estimates (P_i) are based on JLAB listed equipment rates under EH&S Section 6500. Fatality Factors (F_i) are derived from Figure 3, from EH&S Appendix 6500-T3. The sum of the failure product of the F_i and P_i determined the area classification in accordance with table 6 of Section 6500 of the EH&S manual.

Description of Work Space

The CHL cold box rooms consist of two rooms, the original cold box room and the addition of the K100 room. The original cold box room has an area that has been sectioned off.

The sectioned off area is comprised of a storage room, bathroom, hallway, stairway, and control room. The control room is on the second level and can be accessed without entering the cold box room by way of the stairway. This sectioned off area does not share the same air space as the cold box room. There is an independent positive pressure HVAC air source for this area. All sources of air communication with the cryogenic process area (the cold box room) are sealed off. The only chance that there is air communication is when one of the two doors is opened and the there is an ODH event in the cold box room.

The original cold box room houses the 4K cold box, one of the 2K cold boxes (SCM), and associated piping and equipment. Both these cold boxes are on the lower level. Access to the lower level is from either the south set of stairs, north set of stairs, or from the K100 room. The south set of stairs are directly adjacent a door on the south side wall of the cold box room that is also adjacent to a stair case that leads to the mezzanine and control room. These sets of stairs are located in a way that makes egress as available as possible. There is also a door on the north side of the room to the hallway of the segregated area that leads to outside the building and a roll-up door on the north side of the cold box room. The open space in the original cold box room is 111,720 cubic feet.

The additional cold box room, the K100 room, houses the other 2K cold box and associated piping and equipment. This cold box is also on the lower level. Access to the lower level is from either the south set of stairs in the K100 room or from the original cold box room. On the lower level there is no wall between the original cold box room and the K100 room, only pre-existing foundation. The open space in the K100 room is 85,752 cubic feet. There is a door and a roll-up door on the north wall and a door on the south side of the K100 room.

There is a pit in both the original cold box room and the K100 room. The pit in the original cold box room has grating covering the section of the opening that the 4K cold box does not fill leaving no egress without removing the grating. The pit in the K100 room has rails that make egress into the pit very difficult.

On the south wall in the original cold box room there are air louvers that are approximately 45 inches tall by 26 feet wide. In the K100 room there are louvers on the south and west walls that are also 45 inches tall but total 42 feet wide. The louvers are designed to open when the seven and half horsepower fans on the roof are on. There are two fans in the original cold box room and four in the K100 room that are designed to suck the air out of the room. In accordance with Appendix 6500-T3, reliable ventilation may be considered as a relevant factor in this ODH assessment if the volume of air in the room is replaced with fresh air at a minimum of once an hour.

ODH Risk Assessment

This assessment was done in two parts. Part one was to look at all the major possible catastrophic events. Due to the amount of helium represented in the warm helium gas tanks, a Fi of one will be used for the catastrophic events. Part two was to look at all other modes that have a leak rate less than 18,000 and 14,000 standard cubic feet per hour for the original and K100 cold box rooms respectively. Because 18,000 and 14,000 standard cubic feet per hour of helium or nitrogen will not lower the oxygen level less than 18% in the original and K100 rooms respectively, a Fi of zero will be used for non-catastrophic events. Because a Fi of zero will yield a φ of zero, only the catastrophic analysis has to be calculated.

The ODH class is determined using the "Oxygen Deficiency Hazard Classification" table in Appendix 6500-T3. This table uses the ODH fatality rate (per hour) (φ). To calculate φ the following equation must be used:

$$\phi = \sum nP_iF_i$$

Where:

φ = the ODH fatality rate (per hour),
P_i = the expected rate of the i^{th} type of event, (per hour)
F_i = the fatality factor for the i^{th} type event,
n = the number of components

Values for n were not counted, but instead a value much larger than what is real was uses. That is mostly because there is no real effect in counting each item. Knowing that there are more than 33 welds in either cold box room, it was not possible to have an ODH rating less than one. Therefore, by using such grossly large values for n the calculations show that the cold box rooms are no more than an ODH rating on one.

Component	**Event**	**n**	**Pi**	**Fi**	φ
Dewar	Leak or Rupture	3	1.00E-06	1	3.00E-06
Pipes > 3", high quality	Rupture (section)	50	1.00E-10	1	5.00E-09
Pipes < 3"	Rupture	50	1.00E-09	1	5.00E-08
Manually operated valve	External leak-rupture	50	1.00E-08	1	5.00E-07
Air operated valve	External leak-rupture	50	1.00E-08	1	5.00E-07
Check valve	External leak-rupture	50	1.00E-08	1	5.00E-07
Valves: orifices, flow, meters, (test)	Rupture	50	1.00E-08	1	5.00E-07
Welds	Leak	1000	3.00E-09	1	3.00E-06
				Σ	5.21E-06

ODH Classification

For the **cold box room**:

Because $\Phi \geq 10^{-7}$ but $< 10^{-5}$, the **ODH classification is 1**.

For the **sectioned off area**:

Because there is no direct source of an asphyxiant, yet there is still a possible hazard, the sectioned off areas the

OHD classification is 0.

Christensen, Lisa

From:	Ross, Marc C.
Sent:	Wednesday, September 16, 2015 9:45 AM
To:	Christensen, Lisa
Cc:	Cutino, Phil; Evans, Ian Walter; Reichanadter, Mark; Ross, Marc C.
Subject:	FW: PODHA

Dear Lisa,

I approve and sign (via email) LCLSII-1.1-PM-0349-R1. Thank you for your patience.

For the record, I would like to re-state my objections to the solutions proposed in this preliminary analysis. These are:

1) Linac-housing forced-air ventilation scheme. I think the scheme shown here is not practical and is unworkable. I strongly object to the design-development/integration effort that was implemented for the proposed preliminary analysis.
2) Application of CFD. I think the applicability of CFD for this purpose is not established.
3) (specific recommendation from CS PDR) The LN2 outdoor spill-case appears to be weak namely assumes a low-level leak. A much more serious helium-leak event was modelled and found to be injury-causing.

Marc

-----Original Message-----
From: Reichanadter, Mark
Sent: 15 September 2015 13:46
To: Evans, Ian Walter; Ross, Marc C.
Subject: RE: PODHA

Marc,

This is high priority. Please put this on the top of the "In Box".

Thanks, Mark

-----Original Message-----
From: Evans, Ian Walter
Sent: Tuesday, September 15, 2015 1:39 PM
To: Ross, Marc C.
Cc: Reichanadter, Mark
Subject: PODHA

Marc,

Not sure when up are back, but can you please sign off the PODHA that's with Lisa. Once done, I can submit for concurrence to ESH and follow the path we established for approval.

Thanks, Ian