Experiment Safety Assessment Document (ESAD) for the Hall B X17/PRAD II Experiments

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Chapter 1

Introduction

This ESAD document describes the identified hazards of the experiment and the measures taken to eliminate, control, or mitigate them. This document is part of the CEBAF experiment review process as defined the Jefferson Lab ES&H manual, and will start by describing general types of hazards that might be present in any of the JLab experimental halls. The document then addresses the hazards associated with subsystems of the equipment in Experimental Hall B and their mitigation. Responsible personnel for each item are also noted. In case of life threatening emergencies call 911 and then notify the guard house at x5822 so that the guards can help the responders. This document does not attempt to describe the function or operation of the various subsystems. Such information can be found in the individual subsystem Operations Manuals.

Chapter 2

General Hazards

2.1 Radiation

CEBAF's high intensity and high energy electron beam is a potentially lethal direct radiation source. It can also create radioactive materials that are hazardous even after the beam has been turned off. There are many redundant measures aimed at preventing accidental exposure to personnel by the beam or exposure to beam-associated radiation sources that are in place at JLab. The training and mitigation procedures are handled through the JLab Radiation Control Department (RadCon). RadCon can be contacted as follows: For routine support and surveys, or for emergencies after-hours, call the RadCon cell phone at (757)-876-1743. For escalation of effort or for emergencies, contact the RadCon manager.

Radiation damage to materials and electronics is mainly determined by the neutron dose (photon dose typically causes parity errors and is easier to shield against). Commercial-off-the-shelf (COTS) electronics is typically robust up to neutron doses of about 10^{13} n/cm^2. If the experimental equipment dose as calculated in the RSAD is beyond this damage threshold, the experiment needs to add an appendix on "Evaluation of potential radiation damage" in the experiment-specific ESAD. There, the radiation damage dose, potential impact to equipment located in areas above this damage threshold, as well as the mitigating measures to be taken should be described.

2.2 Fire

Each of the experimental halls contains numerous combustible materials and flammable gases. In addition, they contain potential ignition sources, such as electrical wiring and equipment. General fire hazards and procedures for dealing with these are covered by JLab emergency management procedures. The JLab fire protection manager (Robert Myles) can be contacted at (757)-269-7571, Cell: (757)-270-9071.

2.3 Electrical Systems

Hazards associated with electrical systems are the most common risk in the experimental halls. Almost every subsystem requires AC and/or DC power. Due to the high current and/or high voltage requirements of many of these subsystems, they and their power supplies are potentially lethal electrical sources. In the case of superconducting magnets the stored energy is so large that an uncontrolled electrical discharge can be lethal for a period of time even after the actual power source has been turned off. Anyone working on electrical power in the experimental halls must comply with the Jefferson Lab ES&H manual and must obtain approval of one of the responsible personnel. The JLab electrical safety point-of-contact (Bill Rainey) can be reached at (757)-269-7898.

2.4 Mechanical Systems

There exist a variety of mechanical hazards in all experimental halls at JLab. Numerous electro-mechanical subsystems are massive enough to produce potential fall and/or crush hazards. In addition, heavy objects are routinely moved around within the experimental halls during reconfigurations for specific experiments.

Use of ladders and scaffolding must comply with the Jefferson Lab ES&H manual. As well, use of cranes, hoists, lifts, etc. must comply with the Jefferson Lab ES&H manual. Use of personal protective equipment to mitigate mechanical hazards, such as hard hats, safety harnesses, and safety shoes, are mandatory when deemed necessary. The JLab technical point-of-contact (Bill Rainey) can be contacted at (757)-269-7898.

2.5 Strong Magnetic Fields

Powerful magnets exist in all JLab experimental halls. Metal objects may be attracted by the magnet fringe field and become airborne, possibly injuring body parts or striking fragile components, resulting in a cascading hazard condition. Cardiac pacemakers or other electronic medical devices may no longer function properly in the presence of magnetic fields. Metallic medical implants (non-electronic) may be adversely affected by magnetic fields. Loss of information from magnetic data storage devices such as tapes, disks, and credit cards may also occur. Contact Jennifer Williams at (757)-269-7882, in case of questions or concerns.

2.6 Cryogenic Fluids and Oxygen Deficiency Hazard

Cryogenic fluids and gases are commonly used in the experimental halls at JLab. When released in an uncontrolled manner these can result in explosion, fire, cryogenic burns, and the displacement of air, resulting in an oxygen deficiency hazard (ODH) condition. The hazard level and associated mitigation are dependent on the subsystem and cryogenic fluid. However, they are mostly associated with cryogenic superconducting magnets and cryogenic target systems. Flammable cryogenic gases used in the experimental halls include hydrogen and deuterium, which are colorless, odorless gases and, hence, not easily detected by human senses. Hydrogen air mixtures are flammable over a large range of relative concentrations from 4% to 75% H_2 by volume. Non-flammable cryogenic gases typically used include He and nitrogen. Contact Jennifer Williams at (757)-269-7882 in case of questions or concerns.

2.7 Vacuum and Pressure Vessels

Vacuum and/or pressure vessels are commonly used in the experimental halls. Many of these have thin aluminum or Kevlar/Mylar windows that are close to the entrance and/or exit of the vessels or beampipes. These windows burst if punctured accidentally or can fail if significant over-pressure were to exist. Injury is possible if a failure were to occur near an individual. All work on vacuum windows in the experimental halls must occur under the supervision of appropriately trained JLab personnel. Specifically, the scattering chamber and beamline exit windows must always be leak checked before service. Contact Tim Michalski (757)-269-6523 for vacuum and pressure vessel issues.

2.8 Hazardous Materials

Hazardous materials in the form of solids, liquids, and gases that may harm people or property exist in the JLab experimental halls. The most common of these materials include lead, beryllium compounds, and various toxic and corrosive chemicals. Material Safety Data Sheets (MSDS) for hazardous materials in use in the experimental hall are available from the hall Safety Wardens. These are being replaced by the new standard Safety Data Sheets (SDS) as they become available in compliance with the new OSHA standards. Handling of these materials must follow the guidelines of the ES&H manual. Machining of lead or beryllium, which are highly toxic in powdered form, requires prior approval of the ES&H staff. Lead Worker training is required in order to handle lead in the experiment halls. In case of questions or concerns, the JLab hazardous materials specialist (Scott Conley) can be contacted at (757)-269-7308.

2.9 Lasers

High power lasers are often used in the experimental areas for various purposes. Improperly used lasers are potentially dangerous. Exposure to laser beams at sufficient power levels may cause thermal and photochemical injury to the eye, resulting in retina burns and blindness. Skin exposure to laser beams may induce pigmentation, accelerated aging, or severe skin burns. Laser beams may also ignite combustible materials creating a fire hazard. At JLab, lasers with power higher than 5 mW (Class IIIB) can only be operated in a controlled environment with proper eye protection and engineering controls designed and approved for the specific laser system. Each specific laser system shall be operated under the supervision of a Laser System Supervisor (LSS) following the Laser Operating Safety Procedure (LOSP) for that system approved by the Laboratory Laser Safety Officer (LSO). The LSO (Jennifer Williams) can be reached at (757)-269-7556.

Chapter 3

Hall B-Specific Equipment

3.1 Overview

The Hall B subsystems included in this chapter are considered part of the End-station Experimental Equipment for the RG-L (ALERT) experiment. Many of these subsystems impose similar hazards, such as those associated with magnetic fields and power supplies, high voltage systems, cryogenic systems, and vacuum systems. Note that a specific subsystem may have many unique hazards associated with it. For each major system, the hazards, mitigations, and responsible personnel are noted.

The material in this chapter is a subset of the material in the Hall B subsystem Operations Manuals and is only intended to familiarize people with the hazards and responsible personnel for these systems. In no way should it be taken as sufficient information to use or operate this equipment.

3.2 Detector Checkout System

The Hall B equipment readiness for the beam run will be done using the CEBAF Hot Checkout system (HCO) [1]. Each detector system has its own subsystems and items that have to be checked and signed off by the appropriate groups. The systems that have been checked and signed as ready for beam will be indicated by a green "thumbs up". Subsystems that are still waiting for readiness check-out and approval will be indicated with red crosses.

In order to make sure that hall equipment that should be tied into the machine Fast Shutdown (FSD) system has been properly checked, the Hall Work Coordinator must be notified by e-mail prior to the end of each installation period by the system owner that the checks have been performed in conjunction with accelerator operations (*i.e.* checking that the equipment's signals will in fact cause an FSD). These notifications will be noted in the Work Coordinator's final checklist as having been done. System owners are responsible for notifying the Work Coordinator that their system has an FSD tie-in so it can be added to the checklist.

The hall will get permission to run beam only after all systems tied to the delivery of the beam to the designated destination are signed off. At that point the main Hall B system will indicate "Ready" in the HCO tree.

3.3 Beamline

The control and measurement equipment along the Hall B beamline consists of various elements necessary to transport the beam with the required specifications onto the production target and the beam dump, and simultaneously to measure the properties of the beam relevant to the successful implementation of the physics program in Hall B.

The beamline in the hall provides the interface between the CEBAF accelerator and the experimental hall. All work on the beamline must be coordinated with both the Physics Division and the Accelerator Division in order to ensure safe and reliable transport of the electron beam to the dump. The Accelerator Division has the primary responsibility of delivering the electron beam to the experimental target and designated dumps.

3.3.1 Hazards

Along the beamline various hazards can be found. These include radiation areas, vacuum windows, high voltage, and magnetic fields.

3.3.2 Mitigations

All magnets (dipoles, quadrupoles, sextupoles, beam correctors) and beam diagnostic devices (BPMs, scanners, beam loss monitors, viewers) necessary to transport and monitor the beam are controlled by the Machine Control Center (MCC) and/or Hall B personnel through EPICS [2]. The detailed operational procedures for the Hall B beamline are essentially the same as those for the CEBAF machine and beamline.

Personnel who need to work near or around the beamline should keep in mind the potential hazards:

- Radiation "Hot Spots" - marked by an ARM or RadCon personnel,
- Vacuum in beamline elements and other vessels,
- Thin-windowed vacuum enclosures (*e.g.* the scattering chamber),
- Electric power hazards in the vicinity of magnets, and
- Conventional hazards (fall hazard, crane hazard, etc.).

Any work on this system must be covered by ePAS Permit to work(s) (PTW).

These hazards are noted by signs and the most hazardous areas along the beamline are roped off to restrict access when operational (*e.g.* around the magnets). Signs are posted by RadCon for any hot spots. Surveys of the beamline and surrounding areas will be performed before any work is done in these areas. The connection of leads to magnets have plastic covers for electrical safety. Any work around the magnets will require de-energizing the magnets. Energized magnets are noted by red flashing beacons. Any work on the magnets requires the "Lock and Tag" procedures [3] by appropriately trained and certified electrical workers.

Additional safety information can be obtained from the following documents:

◦ ES&H Manual [3]

◦ PSS description document [**?**]

◦ Accelerator Operations Directive [**?**]

3.3.3 Responsible Personnel

The beamline requires both Accelerator and Physics Division personnel to maintain and operate (see Table 3.1). It is very important that both groups stay in contact with each other to coordinate any work on the Hall B beamline.

Name	Dept.	Phone	email	Comments
Expert on call		757-303-3996		1st contact
E. Pasyuk	Hall B	757-269-6020	`pasyuk@jlab.org`	2nd contact
M. Tiefenback	Accel.	757-269-7430	`tiefen@jlab.org`	beamline optics
K. Price	Accel.	757-269-7067	`kprice@jlab.org`	Contact to OPS

Table 3.1: Responsible personnel for the Hall B beamline.

3.4 Vacuum System

The Hall B vacuum system for the X17PRADII experiment consists of three segments:

- the beam transport line to the experimental target, consisting of 1.5 in to 2.5 in diameter beampipes;
- large vaccume vessel from the target to the Hybrid calorimeter;
- the vacuum beamline to the Hall B electron dump consisting of 2 in to 6 in diameter beampipes.

The vacuum spaces are physically isolated from each other and the vacuum level can be monitored independently using cold cathode gauges. The vacuum in the system is provided by a set of roughing, turbo, and ion pumps, and is maintained at a level of better than 10^{-5} Torr.

3.4.1 PRad vaccuum chamber

PRad experiment a large 5m long vacuum chamber extending from the target to the PRad detector system. There is a 1.7m diameter 63 mil Al window at one end of the vacuum chamber, just before the PRad detectors.

3.4.1.1 Hazards

When this chamber is under vacuum, it has a very large stored energy. The accidental rupture of the window releases this stored energy, which presents a hazard to the personnel and equipment.

3.4.1.2 Mitigation

A window cover has been fabricated from 1/8" thick aluminum to protect the window from damage caused by something falling into it. This cover will be attached to the window at all times except when the experiment is running.

1. Place barriers at all entries to the level 1 spaceframe.
2. Place signs at all entries to level 1 that warn personnel of a thin window under vacuum.
3. Place signs at all entries to level 1 that state earplugs and safety glasses must be worn to enter level 1.
4. Place earplugs and safety glasses at the entries to level 1.
5. Personnel authorized by the Hall Work Coordinator will pump down the vacuum tank and check for leaks.
6. The signs and barriers will remain in place if the tank is under vacuum.

The protective window cover will be installed or removed only when no vacuum is in the tank. This will remove the stored energy in the tank so people can work near the window. Any operations near the window, including maintenance and/or repair work on the PRAD detector, must be done only when there is no vacuum in the tank and protective covers are in place. In the event of a vacuum system leak, personnel authorized by the Hall Work Coordinator will bleed up the vacuum tank vacuum. If there is an emergency and personnel can enter the area, the vacuum tank can be bled up by personnel authorized by the Hall Work Coordinator. If personnel cannot enter the area, the signs are in place to warn emergency responders of the thin window under vacuum

3.4.2 Hazards

Hazards associated with the vacuum system are due to rapid decompression in case of a window failure. Loud noises can cause hearing loss.

3.4.3 Mitigations

All personnel working in the vicinity of the entrance and exit windows are required to wear hearing protection. Warning signs must be posted in that area. In addition, all vacuum vessels and piping are designed as pressure vessels. Any work on this system must be covered by ePAS Permit to work(s) (PTW).

3.4.4 Responsible Personnel

The vacuum system will be maintained by the Hall B Engineering Group (see Table 3.2).

Name	Dept.	Phone	email	Comments
Engineering on call	Hall B	757-748-5048		1st contact
D. Insley	Hall B	757-897-9060	`dinsley@jlab.org`	2nd contact

Table 3.2: Personnel responsible for the Hall B vacuum system.

3.5 Electromagnetic calorimeter

The Electromagnetic Calorimeter (HYCAL)will be located approximately 7.4m (run configuration) or 8.7m (calibration configuration) upstream of the center of the CLAS12. It consists of 1700 lead glass and lead tungstate detector modules, each with photomultiplier tubes with readout enclosed inside a temperature-controlled enclosure. Each module has a PMT supplied with high voltage. In addition, an LED-based light monitoring system is used to deliver a pulse of light to each module via a fiber optic cable. The HYCAL will sit in two positions along the beamline. In the run configuration, HYCAL will sit on a stationary cart. In the calibration configuration, it will be mounted on a transporter, enabling motion in the horizontal and vertical directions. The detector has overall dimensions of 1.5m 1.5m and will be centered on the beamline during production data taking. A 4cm 4cm hole at the center of the detector will allow the passage of the primary electron beam to the beam dump.

3.5.1 Hazards

Hazards associated with this device are electrical shock or damage to the PMTs if the enclosure is opened with the HV on. There is also a hazard associated with the coolant leak inside the enclosure.

3.5.2 Mitigations

Whenever any work has to be done on the calorimeter, whether it will be opened or not, HV and LV must be turned off. They are interlocked with the access doors of the calorimeter. Turn the chiller off if the enclosure will be opened for maintenance. The chiller is interlocked with the internal leak detector. Any large (more than a couple of degrees in C) temperature changes must be investigated to make sure that there are no leaks.

3.5.3 Responsible personnel

to be added

3.6 HYCAL Transporter

The HYCAL transporter system is composed of two stepper motors that move the detector on the X and Y axes. Each axis has hardware switches that limit its path of motion. In addition to end limit switches at the edges of axis travel, there are home switches in mid travel that will facilitate easy positioning during the experiment. To determine the exact location of the transporter, digital and analog encoders are used to transmit its position. The transporter is controlled by our standard EPICS software interface, and there are hardware interlocks installed to prevent unwanted movement.

The transporter operates in two modes: normal mode and storage mode. The normal mode is used during the experiment when the transporter is positioned within its normal operation limits. The storage mode is used when the transporter must traverse higher in the Y axis than normal. This is used to clear the area for other experiments or work that may need to be done in the hall.

During normal operation, the system must stay within set boundaries in the beam-line area. This area will be kept clear during an experiment, minimizing the damage risk to personnel and equipment. During transporter storage, operator alertness is essential. The transporter will traverse the height of the space-frame and an operator must ensure that the path is clear at all times.

Under any operational condition the transporter must be checked for mechanical problems that may arise. Drive-train problems, movement of the transporter outside of preset limits, and unbalanced loading are all examples of events that may cause damage to personnel and equipment. Interlocks have been designed into the system to stop all transporter movement in the event of a problem. With these precautions and operator alertness, the transport will operator efficiently and safely.

3.6.1 Hazards and Mitigations

There are two risks associated with the motion system.

- In case of unbalanced load between two vertical driving screws there is a small chance of the shaft break down. To mitigate this risk the tilt sensors are included in the interlock system. They will prevent any motion in case any tilt is detected. There is also central home switch which ensures balanced load on driving screws This will prevent vertical motion between operational and storage positions.

- During transition between storage and running configuration there is a risk of someone got caught under the HYCAL moving down. To mitigate this the interlock system inculdes Dead-man switch. It must be depressed while HYCAL moves below the human height. It ensures that someone is continuously watching while HYCAL is moving down and motion will stop immediately when the switch is released.

In addition to hardware interlocks administrative measures will be taken to mitigate the risk of injury involving the transporter. A rope barrier will be maintained around the HYCAL. The barrier will remain in place whenever the detector is in motion, or has the potential of being moved. A camera, viewable from the Hall B Counting Room, will be focused on the HYCAL to enable the observation of the detector while it is in motion. Persons will not be permitted in the vicinity of HYCAL while it is in motion. Transition between storage and operational positions must be performed by authorized personnel only.

3.6.2 Responsible Personnel

to be added

3.7 GEM Tracker

The Gas Electron Multiplier (GEM) tracker consists of two pairs of large area 1.2 m$\times$ 0.6 m three layer ionization chambers. All four chambers will be powered by a single HV power supply. The signals will be read out via HDMI cables between the on-board pre-amplifier and digitizer boards and the MPD system located next to the detector. A gas mixture of 70% Ar and 30% CO_2 will be supplied continuously to the chamber.

3.7.1 Hazards

Hazards to personnel include the high voltage which biases the chamber, and the low current which powers the readout electronics.

3.7.2 Mitigations

Hazards to personnel are mitigated by turning off HV and LV power before disconnecting cables or working on the chambers and internal electronics. There are no exposed wiring that can be touched by personnel.

3.7.3 Responsible personnel

Individuals responsible for the system are:

3.8 PRad Target System

The Proton Charge Radius experiment in Hall B (PRad) utilizes a windowless, hydrogen gas jet target constructed by the Jefferson Lab Target Group.

Room temperature hydrogen flows through a 25 K heat exchanger attached to a mechanical cryocooler, and accumulates in a 50 mm diameter, 40 mm long copper target cell located within a small (¡ 1 m3) differentially pumped vacuum chamber. The target cell, which is suspended from the top of the vacuum chamber using a precision, 5-axis motion mechanism, has 25 µm-thick Kapton covers at both ends with 4 mm orifices for the electron beam. The covers are easily detachable, so different orifice sizes can be used to examine the effects of possible beam halo. The gas is pumped from the chamber using two large turbomolecular vacuum pumps with a combined pumping speed of 5700 l/s. The gas pressure within the cell is measured by a precision capacitance manometer and is expected to be approximately 0.6 torr during the PRad experiment, giving in an areal density of about 10^{18} H_2/cm^2. Two additional turbo pumps are attached to the upstream and downstream ends of the vacuum chamber to maintain a beamline vacuum less than 10^{-5} torr. Hydrogen gas is metered into the target system using a precision, room-temperature mass flow controller, while gas pumped from the chamber is exhausted outside the experimental hall via the Hall B vent header. Mechanical interlocks are used to stop the flow of hydrogen gas in the event any of vacuum, pressure, or temperature failures. These interlocks ensure that the quantity of H_2 in the chamber is always less than 30 mg

3.8.1 Hazards

The target utilizes hydrogen gas as the target material, while the cryocooler uses helium gas as a coolant. Therefore, a potential ODH risk is present. The total inventory of the H2 gas in the target system is about 1 liter, while the volume of helium gas necessary to operate the PTR is 81 liters. The volume of Hall B is approximately 1.2×10^7 liters (437,500 ft^3). Release of the targets hydrogen/helium gases in this area would be completely negligible, decreasing the Hall B oxygen levels by less than 0.001%. Therefore, the gas jet target does not impact the ODH classification of this location. High-pressure cylinders of hydrogen, each containing approximately 8000 standard liters, will be used to supply gas to the target. A few control electronics will be attached to an uninterruptable power supply (UPS), including the LS336 temperature controller and scattering chamber vacuum readout. This is primarily for monitoring reasons, because the system is designed to be intrinsically safe in the event of power outages. In all cases, the cryocooler simply turns off and the target slowly warms to room temperature. The

(Normally Closed) valves that provides hydrogen gas to the target close, the upstream and downstream gate valves on the chamber close, and the turbo pumps spin down. The volume of the vacuum chamber is approximately 0.26 m^3, representing a stored energy of 26 kJ. This is less than the 100 kJ limit imposed by the Jefferson Lab EH&S manual for buckling analysis. It is also exempt from Code welding/brazing requirements. There are no thin windows on the chamber. Two new components in the target system fall under the purview of pressure systems safety: 1) The gas handling panel in the experimental hall, 2) Chilled water lines between a pair of water chillers and the vacuum pumps and the cryocooler compressor. The gas panel is constructed in accordance with ASME B31.3 (2012). It is supplied with gas from a standard H2 cylinder, with regulator, located in the Hall B gas pad using existing pipes between the pad and the experimental hall. Relief valves located at the exit of the regulator ensure a maximum gas pressure of 30 psig in the gas handling system Chilled water is supplied to the turbo pumps and cryocooler compressor from a pair of NESLAB ThermoFlex 10000 chillers, each with a maximum outlet pressure of 60 psi. All fittings, lines and other components in the chilled water system are rated to a minimum working pressure of at least 90 psig. The chilled water system is now considered a low hazard system (stored energy less than 1000 ft-lbf) and is exempted from the pressure system program requirements now in effect. Nonetheless, it was constructed to and is in compliance with ASME B31.3 (2012) Cat D. The PRad target utilizes hydrogen gas, which is flammable in air over a range of concentrations from 4% to 75%, by volume. The quantity of hydrogen gas inside the PRad target system (comprising the gas panel, internal piping and target cell, and target chamber) is about 1 standard liter, or 0.09 grams. Therefore the system may be classified as a Class 0 risk (Q¡0.6kg). All potential ignition sources on the gas panel (pressure transducers and flow controllers) meet CLASS I DIV 1 GROUPS A, B, C, & D standards. All thermometers inside the chamber operate at very low voltage and currents. A 100 W heater is used to control the cryocooler temperature at about 25 K. It is automatically de-energized by the 1 torr pressure switch on the scattering chamber. Therefore the maximum quantity of H2 that can be in contact with this potential ignition source is only 26 mg. The chamber will be evacuated of hydrogen and purged with an inert gas such as nitrogen or argon before it opened to air. A standard cylinder of hydrogen (approx. 8200 standard liters) is used to provide a constant supply of H2 gas to the target system. This cylinder is part of the standard Hall B liquid hydrogen target, is located in the Hall B gas pad, away from any ignition sources. It is capped when not in use and properly labeled Danger-Flammable Gas. The lines leading from the cylinder to the target installation have also been used for several years for the Hall B liquid hydrogen target. Any necessary extensions to these lines will be constructed in accordance to ASME 31.3 (2012). All pump exhausts and relief lines from the target are attached to the same Hall B vent header that has been utilized for the Hall B liquid hydrogen target. A steady purge of inert nitrogen gas is used to prevent a flammable mixture in the vent. Any necessary piping between the PRad target installation and the vent header will be constructed in accordance to ASME 31.3 (2012). The vent header will be properly labeled Danger Flammable Gas. The Hall B flammable gas monitoring system will be in operation throughout the PRad experiment. No cold portions of the PRad target are accessible by personnel. Due to the windowless nature of the target, no condensed cryogenic fluids can be accumulated within its volume, and the total quantity of vapor is only about 0.03 g. Cernox thermometers monitor the temperature of the fluid at numerous locations, including the cryocooler cold head, the copper target cell, and the vapor inside the cell itself. The temperature of the cold head is regulated at about 25 K using a Lake Shore Model 336 temperature controller. Normally open contacts on the controller turn off the cryocooler before the temperature reaches the condensation point of H2, about 22.3 K at 1 atm. Frozen contaminates in the H2 gas could impede or stop the flow of gas to the target cell. However this does not represent a hazard, as no condensed fluids exist in the system. Nevertheless precautions are made to ensure the purity of the target gas for the PRad experiment. Detailed gas handling procedures will be utilized to ensure that no gases other than hydrogen (or helium, for purges) are present in the system. Only high purity hydrogen gas (research or scientific grade) will be used in the target, and this will be introduced into the cell through a purifier installed on the gas panel for further removal of water and oil.

3.8.2 Mitigations

The high pressure hydrogen cylinders will be located in the Hall B gas shed and connected to the target gas panel using existing lines in Hall B. The target is designed such that upon power failure the Cryocooler shuts off, gas valves close. The vacuum system of the target is designed to minimize volume and avoid any thin windows. A pressure switch on the chamber will automatically shut off hydrogen gas to the chamber at 1 torr. A check valve with Cv=0.66 is installed on the chamber to prevent overpressure, should the switch fail. All pressure systems of the target have been design and constructed in compliance with relevant ASME pressure system codes. Hazards will be mitigated by routine inspection, testing, and replacement of system components. The flammable gas hazard will be mitigated by flammable gas and hydrogen monitoring, use of non-sparking tools, minimization of ignition sources, compliance with ASME 31.12 for hydrogen piping, proper posting of Flammable Gas Area, inerting system prior to maintenance and repair, leak testing system before operating system, and following approved procedures during operation. Cryogenic system hazards will be mitigated by temperature and pressure alarms, temperature interlocks, minimization of target gas and volume, and Documented gas handling procedures.

3.8.3 Responsible personnel

The target system will be maintained by the Hall B engineering group.

3.9 DAQ and Trigger

The DAQ and Trigger systems consists of multiple VXS, VME, and other crates housing various readout modules such as FADC250 ADCs, TDC1190 and TDC1290 TDCs, 16-channel discriminators, trigger modules, and various other units. These crates are powered by industrial power supplies, most of them produced by Wiener, Germany.

The computer cluster contains about 30 computers located mostly in the Hall B Counting House, but some computers are installed in the hall. The network consists of about 20 switches and routers located in both the Counting House and in the hall. Backup power is provided by three large UPS devices, one in the Counting House and two in the hall.

Signal and power transmission is handled by a large number of copper cables interconnecting the various electronics modules and detector elements. A smaller number of optical cables are employed to transmit synchronization, time-keeping signals, and various other communication services throughout the experimental hall.

3.9.1 Hazards

Hazards to personnel include the electric power supplied to the electronic components. There is also a fire hazard associated with cabling throughout the experimental hall.

3.9.2 Mitigations

All of the crates and chassis are commercially available and are powered from 208 V AC. These meet stringent safety requirements set by various qualified agencies such UL and TUV. Internal fans help manage thermal loads and several internal controls are implemented to provide limits on over-current and over-temperature excursions. All structures are grounded. Additionally, aluminum blank panels have been installed to limit access to the backplane on the rear of the chassis and on the front side where slots are unused. All power distribution is power-limited for current and voltage and interlocked via the Slow Controls system. All cables are NEC UL rated CL2 or better and conform to the 2011 edition of the NEC NFPA70 code requirements for fire prevention and thus, limit flame propagation in case of fire. Additionally, all cables are shielded and referenced to ground for added personnel and equipment safety. Any work on this system must be covered by ePAS Permit to Work(s) (PTW).

There are possible electrical hazards if a malfunctioning electronics component is replaced. The associated task hazard analysis concluded that the consequence level is low, the probability level is low, and the risk code is 1. The mitigation for these electrical jobs is to place the equipment in Mode 0 (de-energized) when replacing or repairing hardware during routine maintenance.

3.9.3 Responsible Personnel

Individuals responsible for the DAQ and Trigger systems are (see Table 3.3):

Name	Dept.	Phone	email	Comments
S. Boyarinov	Hall B	757-232-6221	`boiarino@jlab.org`	1st contact

Table 3.3: Personnel responsible for the CLAS12 DAQ and Trigger system.

3.10 Drift Chambers

The CLAS12 Drift Chamber (DC) system is comprised of 18 separate chambers. There are three types: "region 1", "region 2", and "region 3" depending on location upstream, within, or downstream of the CLAS torus magnet. Each chamber has wires arranged in two superlayers of 6 layers by 112 wires. The gas system supplies mixed, clean, pressure-controlled argon/CO_2 gas to each of the 18 drift chambers. The on-chamber amplifier and readout boards are called "signal translator boards" (STBs). There are 7 such boards per superlayer. They distribute low voltage (LV) power to pre-amplifiers located on the board, one for each sense wire. The pre-amps are placed in groups of 16, with six such groups per board. There is an individual fuse for every group of sixteen. Thirty-four conductor signal cables (16 twisted-pair signals) connect each STB group of 16 pre-amps with one connector on the drift chamber readout board (DCRB). High voltage (HV) is supplied to the wires by on-chamber "high-voltage translator boards" (HVTBs), located on the opposite endplate from the STBs. The high voltage is supplied to the HVTBs by a chain of cables connecting the HV crates to the "high voltage distribution boards" (HVDBs) and from there by cables to the HVTBs.

3.10.1 Hazards

Hazards to personnel include the high voltage supplied to the wires and the low voltage that powers the on-chamber pre-amplifiers. Hazards to the drift chambers themselves include damage to the gas windows should the pressure deviate more than a few psi from atmospheric.

3.10.2 Mitigations

Electrical hazards:

- High Voltage: high voltages up to 2000 V are used routinely for all detectors. Mitigation: very low current limits (40 μA) are set. All mechanical structures are properly grounded. There are possible electrical hazards if a malfunctioning HV board is replaced. The associated ePAS concluded that the risk is low, but any work on this system must be covered by ePAS Permit to Work(s) (PTW).

- Low Voltage: In order to power up the on-chamber electronics, we use low voltage at 7 V with 50 A per supply (1 supply per chamber). Mitigation: voltage is low enough not to be a danger to personnel. All mechanical structures are properly grounded. All cables and connectors are certified for this rating and shielded. To protect against possible over-heating of the on-chamber pre-amplifier boards, each individual conductor (positive and neutral return) is fused; with the fuses located in a fuse panel with a red LED signaling a blown fuse. If a fuse is removed and/or replaced there is no risk to personnel because of the low voltage.

Gas system hazards:

- Personnel: because most of the system operates very close to atmospheric pressure there is no hazard to personnel in the hall due to pressure. The gas is non-toxic and non-flammable. Because of the large volume of the hall and the location of the chambers in the main open area of the hall, there is no ODH hazard to personnel.
- Detectors: there is a potential danger to the chamber gas windows if the pressure in the chamber differs from atmospheric by one psi. This is mitigated during standard operation by our pressure-difference control system with fail-safe over-pressure and under-pressure bubblers providing an additional level of safety.

3.10.3 Responsible Personnel

Individuals responsible for the DC system are (see Table 3.4):

Name	Dept.	Phone	email	Comments
Expert on call		757-748-5048		1st contact
F. Hauenstein	Hall B	757-746-3395	`hauenst@jlab.org`	2nd contact
M. Cook	Hall B		`mcookiv@jlab.org`	3rd contact

Table 3.4: Personnel responsible for the CLAS12 DC system.

3.11 Superconducting Solenoid Magnet

The CLAS12 solenoid magnet provides the magnetic field for the tracking of charged particles and suppression of low energy electron background. It hosts several detector packages including the ALERT detector, the Central Time-of-Flight, and the Central Neutron Detector. They all are located in the 780-mm-diameter warm bore. The solenoid has four main coils and one shield coil. The solenoid produces a magnetic field of 5 T when powered at 2416 A. The magnet has an overall inductance of 5.89 H and stored energy of 17.2 MJ.

3.11.1 Hazards

The hazards of the solenoid magnet include the following:

- Electrical hazard
- Cryogenic hazard
- Vacuum hazard
- Magnetic field
- Stored energy

3.11.2 Mitigations

Any work on this system must be covered by ePAS Permit to Work(s) (PTW).

3.11.2.1 Electrical Hazard

The power supply for the solenoid operates with input voltages of 120 VAC and 480 VAC and is interlocked to a current limit of 2450 A. Maintenance and servicing of the power supply can only be conducted by “Qualified Electrical Workers”. Additional information can be found in the ePAS and procedures for the Hall B solenoid magnet. During normal operation, connections at the power supply are made inside the cabinet that has interlocked doors. Insulated cables carrying current to the magnet are routed with cable trays with all exposed leads and terminations covered by non-conductive or expanded metal enclosures. During a fast dump or quench, high voltage spikes may be induced on current leads and voltage taps. The leads from the voltage tap wires connect to the control system wiring through current limiting resistors to reduce any current-voltage combination to within the class-1 Electrical Classification of the ES&H Manual.

3.11.2.2 Cryogenic Hazard

Nitrogen and helium are two types of cryogens used to keep the coils superconducting. The total volume of liquid helium and liquid nitrogen in Hall B is less than 900 liters and 130 liters, respectively. Proper insulation is installed on all piping accessible to personnel. In the event of a quench or loss of insulating vacuum event, relief valves on the helium and nitrogen circuits vent generated gas to the hall. In case of such an event, Hall B remains ODH-0. In case of a power outage, the hall ODH rating would go up to ODH-2 after five hours. Appropriate ODH signs are posted at all entrances to the hall and an oxygen monitoring system is installed in the hall and operational.

3.11.2.3 Vacuum Hazard

The purpose of the vacuum system is to provide 10^{-5} Torr or better thermal insulating vacuum to four superconducting coils and one cryogenic distribution box. After liquid helium is introduced into the coils, a Loss of Vacuum (LOV) event with a full air inrush can lead to very high heat transfer to the helium and nitrogen circuits with a resulting phase change in the liquid helium and nitrogen and potential high pressure expulsion from the system. In the event of an LOV event, relief valves on the helium and nitrogen circuits vent generated gas to the hall.

3.11.2.4 Magnetic Field

When powered up to 2416 A, the solenoid can generate up to 5 T field in the center of the magnet and up to 1 kG in the zones that extend beyond the magnet boundaries. The 5 G boundary restricting access by personnel with surgical implants and bioelectric devices, the 200 G crane boundary, and the 600 G whole body boundary were found and recorded during the commissioning of the magnet. These contours are be marked up and appropriate signage posted. Strong magnetic fields will attract loose ferromagnetic objects, possibly injuring body parts or striking fragile components. Prior to energizing the magnet, a sweep of the surrounding area must be performed for any loose magnetic objects. All personnel entering the 600 G area will also be trained to remove ferromagnetic objects from themselves. To prevent personnel with surgical implants and bioelectric devices from entering the 5 G boundary, lighted warning signs are placed at the doors of the hall when the solenoid is energized, and flashing red beacons and personnel barricades are installed at the actual 5 G contour.

3.11.2.5 Stored Energy

At 2416 A, the total energy stored in the magnet is about 17.2 MJ. Upon sudden loss of hall electrical power or quench or LOV, the energy is dumped into a dump resistor.

3.11.3 Responsible Personnel

Individuals responsible for the CLAS12 solenoid system are (see Table 3.5):

Name	Dept.	Phone	email	Comments
Engineering on call		757-748-5048	–	1st contact
B. Miller	Hall B	x7867	`miller@jlab.org`	2nd contact
K. Bruhwel	Hall B	x7868	`bruhwel@jlab.org`	3rd contact

Table 3.5: Personnel responsible for the CLAS12 solenoid magnet system.

3.12 Superconducting Toroidal Magnet

The CLAS12 torus magnet provides the magnetic field for the tracking of forward-going charged particles and hosts several detector packages, including the Drift Chambers and Forward Tagger. It consists of six coils housed in an aluminum case that is approximately $2 \times 4 \times 0.05$ m^3. The six coils produce a peak magnetic field of 3.58 T when powered at 3770 A. The magnet has an overall inductance of 2.0 H, stored energy of 14.2 MJ, and is roughly 8 m in diameter. Each coil is conductively cooled by supercritical helium gas supplied at 4.6 K from cooling tubes located on the coil inner diameter.

3.12.1 Hazards

The hazards of the torus magnet include the following:

- Electrical hazard
- Cryogenic hazard
- Vacuum hazard
- Magnetic field
- Stored energy

3.12.2 Mitigations

Any work on this system must be covered by ePAS Permit to Work(s) (PTW).

3.12.2.1 Electrical Hazard

The power supply for the torus operates with input voltages of 120 VAC and 480 VAC and is interlocked to a current limit of 3800 A. Maintenance and servicing of the power supply can only be conducted by "Qualified Electrical Workers". Additional information can be found in the ePAS and procedure for the Hall B toroidal magnet. During normal operation, connections at the power supply are made inside the cabinet that has interlocked doors. Insulated cables carrying current to the magnet are routed within cable trays with all exposed leads and terminations covered by non-conductive or expanded metal enclosures. During a fast dump or quench, high voltage spikes may be induced on current leads and voltage taps. The leads from the voltage tap wires connect to the control system wiring through current limiting resistors to reduce any current-voltage combination to within the class-1 Electrical Classification of the ES&H Manual.

3.12.2.2 Cryogenic Hazard

Nitrogen and helium are two types of cryogens used to keep the coils superconducting. The total volume of liquid helium and liquid nitrogen in Hall B is less than 900 liters and 130 liters, respectively. Proper insulation is installed on all piping accessible to personnel. In the event of a quench or loss of insulating vacuum event, relief valves on the helium and nitrogen circuits vent generated gas to the hall. In case of such event, Hall B remains ODH-0. In case of a power outage, the hall ODH rating would go up to ODH-2 after five hours. Appropriate ODH signs are posted at all entrances to the hall and an oxygen monitoring system is installed in the hall and operational.

3.12.2.3 Vacuum Hazard

The purpose of the vacuum system is to provide 10^{-5} Torr or better thermal insulating vacuum to six superconducting coils and one cryogenic distribution box. After liquid helium is introduced into the coils, a Loss of Vacuum (LOV) event with a full air inrush can lead to very high heat transfer to the helium and nitrogen circuits with a resulting phase change in the liquid helium and nitrogen and potential high pressure expulsion from the system. In the event of an LOV event, relief valves on the helium and nitrogen circuits vent generated gas to the hall.

3.12.2.4 Magnetic Field

When powered up to 3770 A, the torus can generate up to 3.58 T field close to the cold hub and up to 600 G in the zones that extend somewhat beyond the magnet boundaries. The 5 G boundary restricting access by personnel with surgical implants and bioelectric devices, the 200 G crane boundary, and the 600 G whole body boundary were found and recorded during the commissioning of the magnet. These contours are marked up and appropriate signage posted. Strong magnetic fields will attract loose ferromagnetic objects, possibly injuring body parts or striking fragile components. Prior to energizing the magnet, a sweep of the surrounding area must be performed for any loose magnetic objects. All personnel entering the 600 G area will also be trained to remove ferromagnetic objects from themselves. To prevent personnel with surgical implants and bioelectric devices from entering the 5 G boundary, lighted warning signs are placed at the doors of the hall when the torus is energized, and flashing red beacons and personnel barricades are installed at the actual 5 G contour.

3.12.2.5 Stored Energy

At 3770 A, the total energy stored in the magnet is about 14.2 MJ. Upon sudden loss of hall electrical power or quench or LOV, the energy is dumped into a dump resistor.

3.12.3 Responsible Personnel

Individuals responsible for the CLAS12 torus system are (see Table 3.6):

Name	Dept.	Phone	email	Comments
Engineering on call		757-748-5048	–	1st contact
B. Miller	Hall B	x7867	`miller@jlab.org`	2nd contact
K. Bruhwel	Hall B	x7868	`bruhwel@jlab.org`	3rd contact

Table 3.6: Personnel responsible for the CLAS12 torus magnet system.

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