Experiment Safety Assessment Document (ESAD) for the Hall C Base Equipment

Hall C Staff

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Contents

1 Introduction and Scope

This Experiment Safety Assessment Document mostly follows the outline for this document as given in Section 3120-C of the Jefferson Lab EH&S Manual, and will describe specific hazards existing with the "Base" Equipment in Hall C, and the specific measures installed for hazard mitigation. Furthermore, responsible personnel are outlined. This document *does not* attempt to describe the function or operation of the various subsystems. Such information can be found in various standard references on particle and nuclear physics instrumentation and in the Hall C Operating Manual.

The principal equipment available for use in electron scattering experiments in JLab's Hall C are the two magnetic spectrometers, the Short Orbit Spectrometer (SOS) and the High Momentum Spectrometer (HMS). In addition, the Hall C "Base" Equipment includes beam line equipment, a scattering chamber with either solid or cryogenic hydrogen and/or deuterium targets, and specialized non-magnetic detector systems like neutron detectors. The specific subcomponents and their regular operation procedures are described in more detail in the "Hall C Howtos and References", accessible from the Hall C web page (http://www.jlab.org/Hall-C/), or, in some case, in the older Hall C Operating Manual [1]. For some of the major subsystems explicit safety reviews were required before initial operation. Examples are the 1994 HMS Superconducting Magnet Safety Review [2, 3] and the 1995 Hall C Cryogenic Target Safety Review. The Safety Analysis calculations for the HMS Superconducting Magnets will not be repeated in this ESAD, but we refer to the documents associated with these reviews which are situated in the Hall C Counting House. The Safety Analysis calculations for the Cryogenic Targets are included in this ESAD. In view of the various different safety hazards associated with these large subsystems they will be dealt with in specific Sections.

2 Description of Hall C and Hall C Equipment

2.1 Introduction

The following subsystems are considered part of the Hall C Base Equipment

- Hall C Beamline Equipment, including
  1. Arc Beam Energy Measurement System
  2. Raster Systems
  3. Charge Measurement Systems
  4. Møller Beamline Polarimeter
- Hall C Scattering Chamber, including
  1. Hall C LH_2 and LD_2 Cryogenic Targets
  2. Hall C ^3He and ^4He Cryogenic Targets
  3. Solid Target Systems

- High Momentum Spectrometer
- Short Orbit Spectrometer
- Non-Magnetic Neutron Detection System
- Hall C Counting House, including
    1. Counting House Electronics
    2. Laser Pulser System
    3. Upstairs auxillary electronics room

Many of these subsystems impose similar hazards such as those induced by magnets and magnet power supplies, high voltage systems and cryogenic systems. Note that a specific subsystem may have many different hazards associated with it.

2.2 General Issues

The EH&S manual can be found on the web at *http://www.jlab.org/ehs/manual/EHSbook-1.html*. The principal contacts for the JLab EH&S group are

Bert Manzlak - x7556 (Physics EH&S)

Charles Hightower - x7608 (Physics EH& S)

2.3 Flammable Gas Systems

Hall C uses several flammable gas systems. Most notable are the hydrogen and deuterium flammabe gas systems associated to the cryogenic targets. These systems will be discussed in detail in the specific subsection on the Hall C cryogenic target system. Furthermore, the Gas Handling System (GHS) providing gas for the HMS and SOS drift chambers uses a 50:50 mixture (by volume) of argon and ethane gas. The gas is mixed in a specially-built GHS which passes the mixed gas through an alcohol (isopropanol) bubbler before passing it to the chambers. The gas flow is approximately 300 SCCM. Ethane is a flammable gas and should be treated accordingly. The Hall C gas mixing shed and both detector huts have gas monitors which are sensitive to Ethane gas leaks. If a leak is detected, an alarm will go off in the Hall C Counting House and the main valves for ethane and argon supply in the gas mixing shed will be automatically closed. Argon is supplied in an A-cylinder under high pressure $P \approx 2000$ PSI. This confined high pressure gas represents a tremendous amount of stored energy. Care should be taken when handling these high-pressure bottles.

Furthermore the Gas Cerenkovs in both HMS and SOS utilize small amounts of gases, typically CO_2 or N_2 at sub-atmospheric pressure, C_4F_{10} or Freon-12 (CCl_2F_2).

2.4 Electrical Systems

Hazards associated with electrical systems are the most common in the Hall C environment. Almost every subsystem requires AC and/or DC power. Due to the high current and/or high voltage requirements of many of these subsystems the power supplies are potentially lethal.

2.4.1 AC Power

Aside from the resetting of circuit breakers you should not attempt to solve any problems associated with AC power distribution without consulting responsible personnel.

Anyone working on AC power in Hall C must be familiar with the EH&S manual and must contact one of the responsible personnel.

Bill Vulcan - x6271

Joe Beaufait - x7131

2.4.2 Remote Control Systems

The remote control systems to operate the the cryotarget lifter, the Møller detector collimators and the HMS and SOS collimator boxes are all located at the back side of the SOS power supplies (close to the entrance door to Hall C). Regular operation occurs through RS232 (or RS485) communication with the respective stepper-motors or BDS5 motors/actuators. Brake cables are added to prevent vertical ladders from falling in case of a power loss. All systems are equipped with emergency buttons.

2.4.2.1 Hazard Mitigation All non-routine maintenance shall be performed in strict accordance with the Jefferson Lab EH&S Manual, and in particular, with the chapters on Lockout, Tagout, and Electrical Safety.

2.4.3 High Voltage

The Hall C detectors in general require High Voltage, up to 3000 Volts, drawing currents up to a few mA. These voltages are typically provided by a CAEN SY403 high voltage supplies, which can deliver up to 3000 Volts at up to 3 mA current per channel. In rare cases (beam losses monitors, neutron detectors) the voltages are provided by LeCroy 1450 high voltage supply, with similar voltages and currents per channel. The following detector systems require this kind of voltages:

1. HMS and SOS Drift Chambers (about 2700 V)
2. HMS and SOS Scintillator Hodoscopes (about 2500 V)
3. HMS and SOS Shower Counters (about 1500 V)
4. HMS and SOS Gas Cerenkovs (about 2500 V)

5. SOS Aerogel and Lucite Cerenkovs (about 2000 V)
6. HMS Aerogel Cerenkov (about 1500 V)
7. Beam Loss Monitors in the Hall C Beam Line (about 1200 V)
8. Møller Hodoscopes and Shower Counters (about 1000 and 1300 V, resp.)
9. Large Non-Magnetic Detectors like Neutron Detectors (about 2000 V)

Note that in addition the cold cathode gauges which are used to measure the pressure in the spectrometers and/or beam line utilize high voltage!

2.4.3.1 Hazards These High Voltages represent a potential hazard to personnel as well as a potential source of ignition.

2.4.3.2 Hazard Mitigation Cable and SHV connectors are shielded and meet existing EH&S standards. Common guidelines for safe operation have been established and are outlined in the Hall C Operating Manual. The operating policy is to turn off the CAEN High Voltages before work occurs around the detector that does not absolutely require the HV. **DO NOT** attach/remove HV cables when voltages are present on the channels (a red LED above each channel indicates the presence of a voltage). Turn off the main HV supply when attaching/removing HV cables.

Several safety measures are taken to prevent the voltage divider bases from becoming sources of ignition:

- Current limiting and trip on overcurrent at the CAEN HV supply.
- The base PC boards are made of non-flammable materials (note that at most 9 Watts of power is available) and are enclosed in a metal housing.
- The bases of the HMS and SOS hodoscopes have a 1/4 Watt resistor 'fuse' in the base.

2.4.4 Counting House Electronics

Most of the electronics require DC power. These DC voltages are provided by the power supplies of the crates in which the modules sit. There are 8 powered NIM crates, each with a power supply that requires 115 VAC input and provides approximately 200 Watts of power on +/- 6, 12, and 24 VDC output lines. There are 4 CAMAC crates which also require 115 VAC input, and provide a maximum of 400-500 Watts. There are also 3 VME crates, whose power supplies provide approximately 500 W. These all run off of clean power, which is provided from power strips installed in the racks, and use standard power cords.

There are also 2 Fastbus crates which require 208 VAC input, and can provide a maximum power output of roughly 4000 W. While the NIM, CAMAC, and VME crates contain their own power supplies and are therfore fairly well protected, the Fastbus power supply is separate from the crate and does not provide intrinsic protection for the power leads and connections. Extra precautions must be taken to use these crates safety. There will be shields installed over the back of the fastbus power supply to prevent contact with the power leads. The racks in which they are mounted have rear doors that will be closed at all times when the Fastbus power supply is on.

2.5 Fire Hazards

Fire Hazards are associated with the previously mentioned Electrical Hazards due to the power useage of the electronics. Furthermore, there are Fire Hazards associated with the use of flammable gases and/or materials.

Flammable gases are discussed separately (Section 2.3 and 2.13). All hodoscope materials and neutron detector materials are in principle flammable. While encased in aluminum foil, if exposed to a direct flame these plastic materials would eventually melt. The elements would lose structural integrity, sag or fall to the floor, and the melted elements would likely be exposed to air and burn.

The largest quantity of flammable material in Hall C is the insulation on the many power and signal cables. The hazard is minimized by using insulation that meets the required flammability codes and installing it in an approved manner. Still, workers must be aware of the presence of this large volume of fuel.

2.5.1 Hazard Mitigation

The spectrometers (and Hall C in general) are protected by a VESDA smoke detection system. The head sensitivity of the VESDA is 0.15 to 0.003 %, which means the system is sensitive to a few molecules per liter of air. The spectrometers clean power is interlocked with this VESDA system. In addition, there are sprinkler systems on both spectrometers and in the counting house that are temperature actuated by heat sensors.

The SOS magnet coils are protected from overheating (and hence fire) by a set of Klyxons (temperature-sensitive switches) which are interlocked to the power supplies.

Both detector huts have gas monitors which are sensitive to Ethane gas leaks. Similar sensors are installed in the gas shed and inside the junction box where the gas lines first enter the hall. If a leak is detected, an alarm will go off in the Hall C Counting House and the main valves for ethane and argon supply in the gas mixing shed will be closed.

In the experimental Hall four flammable gas detectors are installed to provide early detection of hydrogen/deuterium leaks (one above the target area, one above the buffer vessels, and two above the gas handling panels). All are interlocked with the Hydrogen alarm system and with beam delivery to Hall C.

2.6 Magnets and Magnet Power Supplies

Hall C utilizes a large number of electro-magnets, both resistive and superconducting. The HMS is a QQQD spectrometer. All HMS magnets use superconducting coils with the capability to bend particles with momenta up to 7.3 GeV/c. The SOS is a normal-conducting QD$\bar{D}$ spectrometer with a maximum central momentum of 1.7 GeV/c. In

Table 1: Voltages and Currents for the Hall C Magnets

Magnet	Current [A]	Voltage [V]
SOS Quad	1000	160
SOS D1	1000	250
SOS D2	1000	160
HMS Q1,Q2,Q3	1250	10
HMS Dipole	3000	10
Møller Small Quad	300	30
Møller Large Quad	1500	150
Møller Solenoid	120	10
Raster Magnets	<100	300-600 (AC)

addition, Hall C contains a number of magnets along the beam line, notably the Møller polarimeter and the Raster Magnets. In Table 1, we give an overview of possible voltages and currents for the main Hall C magnets.

The magnets in the experimental areas are typically energized by remote control. During major down times the magnets are powered down for personal safety reasons as well as to reduce electrical power consumption. During short interruptions of beam delivery, with hall personnel entering the hall in the controlled access mode, the magnets are typically left energized. The main reason is that the time constants of large size magnets are long (of the order of hours), and frequent ramping or cycling will lead to inefficient operation. Also, every ramp of a large superconducting magnet involves some risk of permanent damage to the magnet coil.

The principal hazards associated with the magnets are:

Electrical All the spectrometer magnets, and some of the beam line magnets, are high current devices ($I_{max} \approx 3000$ Amps). The power supplies that provide this current are potentially lethal. The most exposed and hence most dangerous places are inside the supplies themselves and at the magnet power leads.

Magnetic The spectrometer magnets produce large fields ($B_{central} \approx 10$ kG). The magnets all have return yokes and thus the external fields (near the magnets) are not nearly as large as the central fields but they may still be significant (up to about 1 kG). The raster magnets do not have a return yoke and may have external fields of a few hundred Gauss. Personnel working in the proximity of energized magnets are exposed to the following magnetic hazards:

- danger of metal tools coming into contact with exposed leads, shorting out the leads, depositing a large amount of power in the tool, vaporizing the metal, and creating an arc.
- danger of metal objects being attracted by the magnet fringe field, and becoming airborne, possibly pinching body parts.

- danger of cardiac pacemakers or other electronic medical devices no longer functioning properly in the presence of magnetic fields.
- danger of metallic medical implants (non-electronic) being adversely affected by magnetic fields.
- lose of information from magnetic data storage driver such as tapes, disks, credit cards.

LCW The magnet coils in the case of the SOS and the magnet power supplies for both spectrometers as well as the current leads of the HMS are all cooled by the Low Conductivity Water, LCW, system. This is a high pressure system, P = 240 PSI, and an unconfined stream of water at this pressure could cause injury.

Fire There also exists a potential fire problem associated with the high current power supplies. A short in one of the coils, or insufficient water cooling may lead to a fire in the power lines or the coils.

2.6.1 Hazard Mitigation

Two different modes of operation need to be distinguished: (1) *routine operation* involving work in the vicinity of the magnets, but not in close proximity to the electrical connections, and *not* involving any work that could result in purposely getting into contact with the coils or the leads, and (2) *non-routine operation* involving work on or near the exposed current conductors or connections (typically requiring removal of the shield) or any work that could result in contact, intentional or otherwise, with the coils or the leads.

2.6.1.1 Routine Operation The following measures shall be taken by the cognizant hall engineer (or his designee) to mitigate the hazards during routine operation:

- The current carrying conductors must be protected against accidental contact or mechanical impact by appropriate measures (e.g. run cables in grounded metal conduits or cable trays).
- All exposed current leads and terminations shall be covered by non-conductive or grounded shields in such a manner as to make it impossible for personnel to accidentally touch exposed leads with either their body or with a tool (the electrical connections at the SOS quadrupole, "easily" accessible at the Hall C pivot point have been covered with a plexiglass box). Personnel shall be instructed not to reach inside the shields. Warning signs shall to be placed on the shields; the signs shall read:

  DANGER
THIS GUARD MAY ONLY
BE REMOVED BY
AUTHORIZED PERSONNEL
UTILIZING JLAB

LOCKOUT - TAGOUT
PROCEDURES

- Whenever a magnet is energized, a flashing light on the magnet or on the magnet support structure must be activated to notify and warn personnel of the associated electrical and magnetic field hazards.
- Administrative measures shall be implemented, as appropriate for the situation, to reduce the danger of metal objects being attracted by the magnet fringe field and becoming airborne. (Note that for most magnets strong magnetic fields are only encountered within non-accessible areas inside the magnet.) Areas where these measures are in effect shall be clearly marked.
- To reduce the danger of magnetic fields to people using pacemakers or other medical implants, warning signs shall be prominently displayed at the entrance to each hall. The sign shall read:

  DANGER
  SAFETY HAZARDS MAY EXIST FROM
  THE MECHANICAL FORCES EXERTED
  BY THE MAGNETIC FIELDS UPON
  MEDICAL IMPLANTS
  NO PACEMAKERS

2.6.1.2 Electrical Work Restrictions are established according to *hazard class* and *mode* of work.

The *mode* of work is determined by the nature of the work:

1. de–energized
2. energized with reduced safety and restricted manipulative operations
3. energized with manipulative operations

The *hazard class* is determined by the type work (electrical or electronic) and the combination of voltage and current.

- Anyone working on the HMS or SOS power supplies must comply with the Standard Operating Procedure (S.O.P.). They must be trained and qualified and obey the new arc flash and shock hazard procedure.
- All maintenance shall be performed in strict accordance with the Jefferson Lab EH&S Manual, (6220 and 6230) and with Lock Tag and Try (LTT). The following references should be consulted before power supply maintenance or operations are attempted: 1) the operating procedure provided by the manufacturer (Inverpower for the SOS or Danfysik for the HMS [4]) 2) the simplified magnet power supply maintenance procedure.

- Removal of any protective shield or cover for an electrical conductor shall be performed using administrative lockout procedures. The lockout shall be performed by the cognizant hall engineer (or his designee). The administrative lock shall not be removed until the protective shield or cover has been fully re-installed.

2.6.1.3 Power-on Maintenance

There will be no **mode 3** ("hot work") on any power supply in Hall C. Mode 3 work is defined as manipulative operations that are conducted with equipment fully energized and with some or all normal protective barriers removed.

2.6.1.4 Emergency Situations

There are crash buttons in the counting house which are interlocked with a key (one for each spectrometer). When the keys are locked off, in crash mode, the power supplies cannot be energized. The keys to the crash button are controlled by W. Vulcan (SOS), and S. Lassiter, M. Fowler, P. Brindza, and W. Vulcan for the HMS. The crash buttons are certified by Hall C electrical personnel.

2.6.1.5 Conclusion

The practice of keeping electro-magnets energized in the experimental areas during short accesses provides substantial benefits to the quality and effectiveness of the physics program. The resulting hazards have been mitigated by a combination of protective shields, personnel training, warning lights and signs, and administrative procedures.

2.6.1.6 LCW Hazard Mitigation

The LCW water system for the SOS dipole and quadrupoles has been plumbed using hoses rated for 600 PSI. These hoses have been tested during the magnet mapping. The power supply cooling water hoses have a similar safety margin.

In case of problems with LCW contact one of the responsible personnel listed in Section 4.

2.7 Cryogenic and Oxygen Deficiency Hazards

2.7.0.1 Equipment Hazards

The energy stored in the HMS superconducting quadrupoles is sufficient to cause an unrecoverable quench if all the energy stored is dumped into the magnets. The same is true for the Møller superconducting solenoid. The HMS dipole has been designed to achieve cryostability up to a field of 2 T, and this property has been extensively tested up to a field of 1.11 T. Note that a quench can only happen if the superconducting magnets have their helium level dropped below the coil, and their coils energized.

2.7.0.2 Equipment Hazard Mitigation

In all cases quench protection circuit are incorporated. The dipole cryostable coils are equipped with an energy removal circuit to cover the possibility of an unrecoverable quench.

2.7.0.3 Hazards Contact with cryogenic fluids presents the possibility of severe burns (frostbite). The release and subsequent expansion of cryogenic fluids presents the possibility of an oxygen deficiency hazard. Rapid expansion of a cryogenic fluid in a confined space presents an explosion hazard. Cryogenics in Hall C are present in the superconducting HMS magnets, the scattering chamber with its cryogenic targets (∼12,000 STP liters of hydrogen), and the Møller superconducting solenoid. In the case of the superconducting HMS magnets and the cryogenic targets the ODH hazard is minimal, apart from the area above the Hall C crane. The Møller solenoid contains <2000 STP liters of target fluid. However, this solenoid is located in the alcove thus enhancing a possible ODH hazard.

Apart from cryogenic fluids, the gas in the HMS and SOS gas Cerenkovs pose also a potential oxygen deficiency hazard for access inside these detectors.

2.7.0.4 Hazard Mitigation Normally accessible areas of Hall C are listed as an Oxygen Deficiency Hazard area of Class 0. No unescorted access is allowed without an up-to-date JLab ODH training.

All volumes in the cryogenic systems which can be isolated by valves or any other means are equipped with pressure relief valves to prevent explosion hazards.

All issues concerning the safe operation of both the HMS cryogenic magnet system and the Hall C cryotarget systems were reviewed by outside panels.

No one may enter the Cerenkov tanks while there is radiator gas inside these tanks. The tanks should be pumped out and filled with air before access to the interior of these tanks is permitted. Possible leaks do not impose an additional hazard, e.g the total enclosed volume of the SOS Gas Cerenkov is 30 cubic feet, while the air conditioning unit in the hut replaces the air at a rate of 1100 cfm.

The responsible personnel for access to an ODH-area are the principal contacts for the JLab EH& S group:

Bert Manzlak - x7556 (Physics EH& S)

Charles Hightower - x7608 (Physics EH& S)

2.8 Radiation Safety and the Personnel Safety System

CEBAF's high intensity, high energy electron beam is a potentially lethal radiation source and hence many redundant measures aimed at preventing accidental exposure of personnel to the beam or exposure to beam-associated radiation sources are in place.

When the hall is in an accessible state, all beamline or target chamber equipment requiring machining or disassembly, and **all** components which need to be removed from the Hall, **must** be surveyed by an ARM or a member of the Radiation Control Department (RadCon). Only RadCon can approve unrestricted release of items from the hall (ARMs surveys may allow relocation, under the ARM's direction, but not release).

The radiation safety grouip at JLab can be contacted as follows:

For routine support and surveys, or for emergencies after-hours, call the RadCon Cell phone at 876-1743. For escalation of effort, or for emergencies, the RadCon manager (Keith Welch) can be reached as follows:

Office:	269-7212
Cell:	876-5342
Pager	584-7212
Home:	875-1707

2.9 Vacuum and Pressure Hazards

The greatest safety concern for the vacuum and/or pressure vessels possibly in use in Hall C are the thin Aluminum or kevlar/mylar windows that close the entrance and/or exit of these vessels. Examples are the HMS and SOS Gas Cerenkov tanks, the HMS and SOS spectrometer vacuum cans, and the Hall C Scattering Chamber. The Hazards associated with the Hall C Scattering Chamber will be dealt with in the Section on the Hall C cryotargets. Note that the HMS Gas Cerenkov can operate both above and below atmospheric pressure. *All work on vacuum windows in Hall C must occur under the supervision of appropriately trained Jlab personnel.*

2.9.1 HMS Gas Cerenkov

The HMS Cerenkov Detector is a 1.5 m long by 1.5 m diameter cylinder made of 0.5 inch thick aluminum walls with two photomultiplier tube (PMT) ports and a pump port. When in operation, the vessel is evacuated and then filled with a gas, typically CO_2, N_2, or C_4F_{10} at underpressure, or Freon-12 (CCl_2F_2) at overpressure.

The greatest safety concerns for the Cerenkov Detector are the thin aluminum windows that close off the ends of the tank. These windows must be thin to minimize multiple scattering of the particles we are trying to observe, but thick enough to be structurally safe. The yield strength for the type 2024-T3 aluminum we are using is 50000 psi, and the ultimate strength is 70000 psi. If using the HMS Gas Cerenkov at overpressure (underpressure) 60 (40) mil thick window will be used. According to stress calculations at the maximum overpressure of 35 psig, the load on a 60 mil thick window will be 36770 psi and will cause a center deflection of approximately 3.5 inches. For the 14.7 psi underpressure case, the load on a 40 mil thick window will be 20356 psi with a deflection of 4 inches. Comparing these loads with the yield and ultimate strengths of the material shows that there is a considerable safety margin. In addition, the windows have been hydrostatically preformed to the shape they will assume under stress [1]; this procedure forces the load to be purely tensile, and is known to enhance the strength of the material. Extensive pressure tests of both the tank and the windows were performed prior to installation of the tank in the HMS Detector Hut [5].

2.9.2 SOS Gas Cerenkov

The SOS Gas Cerenkov Counter is a box, approximately 1 cubic meter in volume, made of 0.5 inch thick aluminum walls. There are two end windows each composed of one layer of 0.010 inch lexan (for gas tightness) and a thin layer of tedlar (for light tightness). There are four ports for photomultiplier tubes (PMTs), six holes for gas I/O, and two 0.5 inch thick aluminum access windows. When in operation, the vessel is flushed with nitrogen and filled with Freon-12 at atmospheric pressure.

Because the detector is designed to run at zero overpressure, the bursting of the lexan windows is of minimal concern. The gas system incoporates a large bladder that allows for over and under–pressure relief. The gas pressure of the cerenkov is monitored closely by shift personnel and experts are on call in the event that the pressure deviates by more than 0.025 PSI relative to atmospheric pressure. Calculations show that the stress in the lexan is approximately 800 PSI at a typical overpressure of 0.125 PSI. Given DuPont's failure rating of 8000 PSI for lexan, this seems to be quite adequate.

2.9.3 Møller Vacuum System

The space between the Møller target and the two-arm detectors is evacuated to minimize multiple scattering. At the target the vacuum furthermore isolates the cold coil vessel from room temperature. These volumes represent an implosion hazard. This is especially true at the exit of the two arms in front of the Møller detectors where thin vacuum windows are mounted. The vacuum volume is 1.5 m^3 representing a stored energy of 1.5×10^5 Joule. The diameter of the exit windows is 20 cm. Experience from HMS window testing is used and applied to the Aluminum windows. Despite this, it is recommended to wear ear protection plugs, which are available at the entrances to the alcove. If working within 3ft. of the vacuum windows the wearing of ear protection plugs is mandatory.

2.9.4 HMS Vacuum System

The space between the magnet poles of each spectrometer is evacuated in order to diminish multiple scattering. The HMS also has vacuum volumes which are used to thermally isolate the cold coils from room temperature. All of these volumes represent an implosion hazard. The hazard is particularly serious at the entrances and exits of the main spectrometer volumes as these are covered by relatively thin vacuum windows. Catastrophic window failure would generate a significant shock wave as air rushed to fill the evacuated volume. It would also cause a loud noise which could cause hearing damage to anyone in the immediate vicinity.

The HMS spectrometer vacuum can has a volume of approximately 6 m^3, representing a stored energy of 6×10^5 Joules. The exit window is a circle with a center-to-center bolt hole diameter of 40 inches and a 38 inch diameter vacuum opening. It is located in the HMS detector hut and is the largest vacuum window required for Hall C. Under vacuum, this window must support 16,785 lbs (74,425 N).

The vacuum window material is composed of 0.020 inch titanium. Bolt holes are cut into the material and it is then mounted on a ring flange using the standard O-ring vacuum seal technique. The ring flange is mounted on the 8" long HMS hut vacuum extension piece. This window has been used successfully in the HMS, holding a vacuum of $\approx 10^{-5}$ Torr.

The HMS entrance window is located near the pivot and has a center-to-center bolt hole diameter of 10.5 inches. It must support a load of 6200 N (1400 lbs). As the load for these entrance windows is far less than that on the exit windows, the vacuum window material is in this case composed of 0.0045 inch ballistic Kevlar 29 style 713 (31x 31 count, plain weave) with 0.002 inch Mylar on both sides.

2.9.4.1 Hazard Mitigation An interlock prevents access to the HMS detector hut unless one inch thick aluminum safety shutter has been moved to its 'down' position, such that it covers the vacuum window. This is to prevent people from accidentally touching the large vacuum window. Installation of vacuum windows can only be done by the responsible personnel following detailed instructions in the Hall C Operating Manual [1]. The vacuum windows are replaced periodically to prevent accidents due to structural damage of the window material over time.

2.9.5 SOS Vacuum System

The SOS spectrometer vacuum can has a volume of approximately 2 m^3 representing a stored energy of 2×10^5 Joules. The entrance window (near the pivot) is round and has a diameter of 9 inches. It must support a load of 929 lbs. In some cases a small vacuum extension snout is used to minimize the air distance between the scattering chamber vacuum and the SOS spectrometer vacuum. In that case a rectangular entrance window is used with even smaller load. The vacuum window material is composed of 0.0045 inch ballistic Kevlar 29 style 713 (31x 31 count, plain weave) with 0.002 inch Mylar on both sides.

The SOS exit window is the second largest window in Hall C. This window is located in the SOS detector hut. It is rectangular. The opening has a length of 30 inches and a width of 10 inches. The SOS exit window must support a load of $4,400$ lbs ($19,687$ N) under vacuum. The vacuum window material is composed of 0.015 inch ballistic Kevlar 29 style 713 (31x 31 count, plain weave) with 0.004 inch Mylar on one side and 0.001 inch thick Mylar on the other. Bolt holes are cut into the material and it is then mounted on a ring flange using the standard O-ring vacuum seal technique.

Catastrophic window failure would generate a significant shock wave as air rushed to fill the evacuated volume. It would also cause a loud noise which could cause hearing damage to anyone in the immediate vicinity. Extensive testing has been performed to minimize the likelihood of such an occurrence [1].

2.9.5.1 Hazard Mitigation Installment of vacuum windows can only be done by the responsible personnel (Thia Keppel or Paul Hood) following detailed instructions in the Operation Safety Procedures[1]. The vacuum windows are replaced approximately every 6 months to prevent accidents due to structural damage of the window material over time. The wearing of earplugs is required when accessing the SOS shield house to work closer than 3ft. from the SOS vacuum exit window.

2.9.6 Evacuated Beam Dump Line

The Hall C beam dump line has been changed to an evacuated beam line, although specialized dump lines with Helium may still be used for low-current polarized target experiments. In the evacuated beam dump line configuration there will be no Be window separating the scattering chamber vacuum from this beam dump line. Rather we will use a thin foil with hole to allow for differential vacuum. The end window of the beam dump line will be an Al window, with inner 3.75 inches consisting of 30 mil Be. The beam dump line has been strengthened with braces to prevent collapse during evacuation (the safety factor in the present configuration is more than five). Calculations have shown the Be window to reach a peak temperature of 270 F, even when the unlikely scenario occurs of an unrastered, 180 μA beam current hitting the window with no target in place. Such a scenario is unlikely, as we will have less than 100 μA beam currents, and the fast raster is in the accelerator fast shutdown system. The safety factor in the mentioned unlikely situation is still a factor of three. A Be beam diffuser resides at the entrance of the beam dump alcove, to enlarge the beam spot a the beam dump.

2.9.6.1 Hazard Mitigation A beam interlock prevents beam delivery with the fast raster off. This interlock is properly checked at the end of a long (installation) down time. In addition, an administrative cureent limit is imposed on beam delivery conditions, as given in the accelerator operational restrictions
(see http://opweb.acc.jlab.org/internal/ops/ops_webpage/restrictions/ops_restrictions.php).

2.9.7 Working Near Vacuum Windows

Before entering the detector huts or pivot area, all personnel should check the spectrometer and/or scattering chamber vacuum gauges. The HMS gauge is located under and near the Q3 quadrupole. The SOS gauge hangs from the carriage beneath the quadrupole. The scattering chamber vacuum gauge is under the pivot point. Please note that if Hall C uses a polarized target special safety rules restrict access to the pivot area (see Section on Polarized Target).

If the spectrometers and/or scattering chamber are under vacuum:

1. Before entering the detector hut or pivot area, put on hearing protection. It is recommended that nobody should be closer than 3 feet from the windows without ear protection and that only those personnel who need to approach the windows be in their immediate vicinity.

2. If entering the pivot area, check both spectrometer windows visually (from a distance greater than 3 feet if possible). If entering the SOS detector hut, check the SOS exit window visually. If entering the HMS detector hut, verify the HMS shutter is really down in front of the vacuum window. If you observe any of the following problems, vacate the area and contact one of the responsible personnel:

    - Visual defects, particularly wrinkles, discoloration, or uneven fiber stress.
    - Date of removal on tag near spectrometer window indicates a date near or after current date.
    - HMS shutter malfunction (troubles opening or closing).
    - The pre-traced ring drawn onto the window perimeter has moved away from the perimeter.

3. Never touch the vacuum windows, neither with your hands nor with tools.

4. Never attempt to bypass the HMS shutter interlock system.

5. Use careful judgement if it is necessary to work near the vacuum windows. Do not place objects so that they may fall on the windows, etc.

6. Do not work near the windows any longer than is absolutely necessary.

2.10 Conventional Hazards

2.10.1 Crane Operation

If construction work occurs in Hall C, the wearing of a hard hat is obligatory. Since Hall C is not normally in a "construction" state, signs will be posted at the entrance to the hall when a hard hat is mandatory.

If one must work in the immediate vicinity of the Hall C crane when it is in use, a hard hat is also required.

2.10.2 HMS and SOS Carriage

The carriages are the support structures of the spectrometers. First and foremost as it is a multileveled structure it is important to keep in mind that people may be working above you. This means that the wearing of hard hats in Hall C is strongly advised. Taller individuals should be mindful when using the flight of steps leading towards the higher levels due to the limited head room at some points. Safety railings have been installed everywhere along the carriage perimeters. Be aware that some of these may be removed during the experimental data taking to enable spectrometer rotation and will need to be installed (or you need to wear a safety harness) before accessing these areas.

2.10.3 Hall C pivot area

The pivot area is the platform giving access to the Hall C scattering chambers. The Hall C pivot area is to a large extent part of the SOS carriage, and as such access to this pivot area requires also installment of the safety railings or the wearing of a safety harness. Furthermore, if the scattering chamber is pumped down ear plugs will need to be worn when working closer than 3ft. from the vacuum windows. This is also true if you need to work within 3ft. from the HMS and/or SOS spectrometer vacuum windows if those spectrometers are under vacuum.

In case a polarized target is used, special safety measures are taken to be allowed access to the pivot area (see the separate Section on Polarized Targets).

2.10.4 Fall Hazards

It cannot be overemphasized that one of the most significant hazards in hall C is a simple fall. Even standard access routes such as stairs or ladders can lead to serious injury if proper care is not taken. The risk is multiplied if the individual is carrying a load of equipment such as oscilloscopes.

Another fall hazard exists in the form of non-standard access routes. Generally speaking, these are to be avoided. An egregious example might be climbing a rickety chair on the HMS platform to access the pivot area. However, use of a non-stndard access route such as a well-secured ladder may occassionally be necessary.

Certain areas on the pivot and the HMS carriage will have the handrails removed during experiment operations. When acess to these areas is required, use fall protection as mandated by the EHS manual.

2.10.5 Spectrometer Rotation

The obvious problem with spectrometer rotation is that one rotates a many-ton object which will crush whatever is in its way. Rotation of the spectrometer is accomplished by using the two motors on the carriage itself (the motors on the shield house bogies are not used in the present rotation system). These AC motors are controlled by synchronous pulse width modulated drives which are mounted near the bottom of the shield house steps. The spectrometer motors may only be controlled by trained personnel. At least two people are required for manual spectrometer rotation, one to run the motors and at least one spotter. Prior to rotating the spectrometer a visual inspection of the area should be made to insure that there is nothing in the spectrometer's path or on the rails. The spotter should pay special attention to the cables which run from the spectrometer to the target motor controller to make sure that nothing is hung up or stretching. After the possible angle range of both HMS and SOS have been verified by the Hall C engineering staff, limit switches will be installed at forward and backward angles. Remote spectrometer rotation occurs by PLC computer. Commands can be issued to this PLC (Texas Instruments 5000), which executes these commands following algorithms stored in its memory. The verified minimal angle between the HMS and SOS spectrometers has been loaded into this PLC. The PLC is situated at the first level of the HMS carriage, opposite to the magnet power supplies. The CPU of this PLC is located in the HMS Detector hut. The advantages of using the PLC are:

- No direct access by users to the algorithms, preventing unsafe rotation attempts (instead, the algorithms have to be loaded locally into the PLC).
- Rotation of both HMS and SOS by the same smart controller, enabling security checks of both angle decoders. This renders a better handle on the minimum allowed angle in between both spectrometers.

The PLC communicates directly with the control electronics of several limit switches, proximity switches, and decoders. Next to the limit switches also hard limit switches are installed on the floor, in the event of failure of the PLC limit switches.

2.10.6 Slit Systems

The HMS and SOS slit ladders each consist of three heavy densimet blocks, two collimators and one sieve slit. The total weight for each slit ladder amounts to 350 Lbs (160 kg) and can easily cause serious damage to body parts. **Install a metal support under**

the slit ladder when you work with your hands under it. The remote control systems are equipped with a brake cable to prevent the slit ladders from sliding down in case of a power failure, but this must not be relied upon for personnel safety.

2.10.7 SOS Shield House Doors

The shield house interior access is covered by a two piece door. The two halves counterweight against each other, opening vertically. The bottom door (30 tons) is 5 tons heavier than the top door. Thus, the door will want to open naturally if unconstrained. The door control system is used to keep the doors closed.

The valves in the control system are set by a PLC that resides in a box mounted beneath the stairs at the rear of the spectrometer. The user operates the door electronically via a control box mounted along the walkway near the door (or from the panel beneath the stairs). The main hazards are associated with differential motion of the two hydraulic cylinders enabling the door motion. This can bend or destroy these hydraulic cylinders causing major down time. Alternatively, one has to be careful with body parts in between the two door parts when closing the door.

2.10.7.1 Hazard Mitigation

- With the loss of electrical power all valves close automatically. This will stop all movement of the door. The fluid in the cylinders may slowly leak past the seals causing the door to open.

- Hydraulic pressure indicators in the system will stop the system if loss of pressure is detected.

- The solenoid valves have lifetimes of many thousands of cycles. If a valve fails, the two pressure indicators will start to differ, soon resulting in a too large difference between the two decoders (one for each side of the door), causing the motion mechanism to stop.

- In the unlikely event of a cylinder failure, the door will slip slightly to one side in the track and any motion will stop.

- The hydraulic pump has two motors that are independently switched. Either will provide adequate power to operate the SOS door hydraulics. The motion of the door is monitored by the control system. Linear displacement encoders on each cylinder provide analog signals to the controls. The two cylinders must move at the same rate or the control system will stop the door progress. The doors will stop if the difference between the cylinders becomes more than 0.020”. The control system will attempt to level the door and continue. Massive skewing of the door will cause the door to wedge in the track.

- A section of handrail is attached to the downstream end of the flip-down section of walkway. It is advised to stay behind this handrail until the doors open completely and the flip-down walkway can be rotated over the lower door.

2.11 Hazardous and Toxic Materials

Some of our target materials may pose a serious safety concern. At this moment the only two special target materials we own are ceramic Beryllium-Oxide (BeO) and Beryllium (Be). In solid form, BeO is completely safe under normal conditions of use. The product can be safely handled with bare hands. However, in powder form all Beryllia is toxic when airborne. Overexposure to airborne Beryllium particulates may cause a serious lung disease called Chronic Berylliosis. Beryllium has also been listed as a potential cancer hazard. Furthermore exposure to Beryllium may aggravate medical conditions related to airway systems (such as asthma, chronic bronchitis, etc.). Since beryllia are mainly dangerous in powdered form, do not machine, break, or scratch these products. Machining of the Beryllia can only be performed after consulting the EH&S staff. It is good practice to wash your hands after handling the ceramic BeO. If handling the pure Beryllium target wear gloves and an air filter mask. These target materials are stored in the yellow target storage cabinets, either in the back room of the counting house or in the black safe downstairs in the Hall C experimental area.

Note that the lead shielding blocks we use also form a potentially toxic material. Unwrapped or painted lead blocks may only be handled by certified lead workers who have undergone lead worker training. Gloves must be worn when handling uncovered blocks (this excludes blocks that are completely painted or wrapped in Heavy-Duty Aluminum Foil). Lead worker training is not required for the handling of lead bricks contained plastic bags. However, steel–toed shoes must always be worn when handling lead bricks of any type. Do not machine lead yourself, contact the EH&S personnel or the Jefferson Lab workshop to ask for the procedure to machine lead.

2.12 Hydrogen and Deuterium Cryogenic Targets

The potential hazards associated with the operations of cryogenic targets in Hall C are reviewed and the efforts to ameliorate these hazards are described.

2.12.1 Introduction

The Hall C cryogenic target system typically consists of two completely instrumented targets, normally containing cryogenic H_2 and D_2. In addition a third target loop is installed in the scattering chamber but these cells are usually not connected to a full gas handling system. This third loop is used as a spare or as a Helium target.

The hydrogen and deuterium targets present a number of potential hazards. The most notable of these are associated with the fire/explosion hazard of the flammable gas, the hazards connected with the vacuum vessel and those of handling cryogenic liquids (ODH and high pressure). In this document the hydrogen target will be referred to but the deuterium target is essentially identical and almost all comments apply to both targets.

2.12.2 Flammable Gas

Hydrogen and deuterium 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. Detonation of explosions can occur with very low energy input, less than $\frac{1}{10}$ that required by mixtures of air and gasoline. At temperatures above -250° C hydrogen gas is lighter than (STP) air and hence will rise. At atmospheric pressure the ignition temperature is approximately 1000 degrees F but mixtures at pressures of 0.2 to 0.5 Atm can be ignited at temperatures as low as 650 degrees F. Hydrogen mixtures burn with a colorless flame [6].

The total volume of liquid hydrogen in the target depends on which type of target cell is installed. For the typical machined cell design with a 4 cm and a 15 cm cell in each loop, the total liquid volume is about 7.5 liters per loop. The volume changes between the liquid state and gas at STP by a factor of about 800. Thus filling the target requires about 6,000 STP liters of hydrogen (roughly the contents of a standard high pressure gas cylinder).

Each target is attached to a large, 1000 gallon (3800 liter) recovery tank. These tanks are charged to 50 PSIA (3.4 ATM) when the targets are warm. Each target is thus connected to about 13000 STP-liters of inventory. In addition, there is usually a partial high pressure cylinder of target gas in the racks behind the gas panels. The total explosive gas inventory associated with the targets is thus quite substantial.

The basic idea behind safe handling of any flammable or explosive gas is to eliminate oxygen (required for burning) and to prevent exposure to any energy source that could cause ignition. In the Hall C environment the most likely source of oxygen is of course the atmosphere and the most likely ignition sources are from electrical equipment.

2.12.3 Electrical Installation

Hall C contains a lot of electrical equipment and almost all of it could serve as an ignition source in the presence of an explosive oxygen and hydrogen mixture. We have made an effort to minimize the dangers from the equipment that is most likely to come into contact with hydrogen gas.

There are a number of electrically powered devices associated with the target gas handling system. The solenoid valves on the gas panels are approved for use in a hydrogen atmosphere as are all the pressure transducers in the system. The AC power for the solenoids is carried by wires which are contained in either hard or flexible conduit. There are also LED's on the gas panels that provide an indication as to the status of the valve solenoids. These are powered by a 24 Volt DC supply (of which the power leads are not shielded). The readouts for the pressure transducers are mounted on the gas panels and the AC power for these readout units is in conduit. All the pressure transducers have 4-20 mA outputs.

In addition to the electrical devices in the gas handling system there are a number of devices inside of or mounted on the scattering chamber.

All the devices which are in the scattering chamber must have their power delivered to them by wires in vacuum. The insulation of these wires should be radiation resistant, so Kapton has been used where available.

The following electrical items are in close proximity to or are actually in the hydrogen system.

Axial Circulation Fan The fans which circulate the hydrogen in the target are AC induction motors and therefore contain no brushes and are practically immune to sparking. The three phase power for these fans is delivered to them by 18 gauge stranded copper wire with Kapton insulation. The power for these fans is supplied by commercial pulse width modulated variable frequency controllers. These controllers are located in the target control racks behind the gas panels. The input power for these controllers is three phase 480 V. They should only be serviced by the experts. The current and voltage drawn by the fans is monitored by the control system. Typical values are 3 Amps at 30 Volts for 60 Hz operations.

Fan Motor Tachometer The fans have a tachometer associated with them which consist of a coil that views the flux change caused by a permanent magnet attached to the motor rotor. The tachometer signals are carried on 22 gauge stranded wire with Kapton insulation. This is a low power signal. The control system monitors the frequency of the fans.

High Power Heater This is a "hair dryer" style heater that is immersed in the hydrogen. The heater is made of 0.051 inch diameter Nichrome wire with a resistance of 0.2544 Ωs per foot wrapped on a G10 or an anodized aluminum carrier board. The maximum power available to this heater is of order 800 Watts. The heater has a DC resistance of 2 Ωs and is driven by a 40 Volt, 25 Amp power supply. The current and voltage supplied to this heater are monitored by the control system and there is a software power maximum enforced on the power setting of this heater.

The heater is connected to the outside world by 8 gauge stranded wire with Teflon insulation. The lower portion of this wire is encased in a fiberglass sheath which will serve as additional insulation should the Teflon be damaged by exposure to radiation. No noticeable deterioration of the insulation occurred in the first two years of running.

Resistors There are two Carbon and three Cernox resistors immersed in each target loop. These resistors provide temperature measurements of the target fluid. The temperature controllers that read them use a constant current of 10 μA to excite them (into up to 7500 Ω). The Cernox resistors are connected to the outside world with quad strand 36 gauge phosphor bronze wire with Formvar insulation. The Carbon resistors are wired with 30 gauge Kapton insulated copper stranded wire.

Target Lifter An AC servo motor provides the power to lift the target ladder. This motor is powered by three phase 208 Volt power and is equipped with fail safe brakes (the brakes are **released** by a 24 Volt DC control voltage) and a 50 to 1 gear reducer. On power up there is a delay relay that insures that the motors are always energized before the brakes are released.

Vacuum Pumps The scattering chamber is evacuated by a Leybold 1000 liter per second turbo pump that is backed by a Leybold 65 cfm mechanical pump. The turbo pump is powered by 120 Volt AC power while the backing pump requires three phase 208 Volt AC power. The motor on the backing pump is explosion proof and approved for use in NEC Class 1, Division 1, Group D (hydrocarbons **but not** hydrogen) environments. An identical mechanical pump is used in the pump and purge system of the gas panels.

Vacuum Gauges The chamber vacuum is monitored by a MKS cold cathode gauge. This gauge operates at 4000 Volts with a maximum current of 133 μA. The pressure at the entrance to the roughing pump is measured by a pair of Hastings thermocouple gauges (models DV-6 and DV-4D). The DV-4D requires 0.009 Watts (0.029 AC Amps and 0.32 AC Volts). The DV-6 requires 0.008 Watts (0.021 AC Amps and 0.38 AC Volts).

A vacuum interlock is now part of the target system. This interlock is triggered whenever the vacuum in the scattering chamber crosses above 5-10 Torr. It kills the power to the target high power heater, to the cold cathode gauge, and it closes the gate valve to the turbopump.

2.12.4 Flammable Gas Detectors

There are four flammable gas detectors installed to provide early detection of hydrogen/deuterium leaks. These detectors are sensitive (and calibrated) over the range from 0 to 50 % Lower Explosive Limit (LEL) of hydrogen. The electro-chemical sensors were manufactured by Crowcon Detection Instruments LTD and the readout (four channels) was purchased from CEA Instruments, Inc (The Gas Master Four System). The readout unit provides two alarm levels per channel. The low level alarm is tripped at 20 % LEL while 40 % LEL activates the high level alarm. **These detectors require periodic calibration**. This calibration is checked by the Polarized Target Group. Each channel has a relay output for both low and high level alarm states and there is also a set of common relays for both alarm levels (these common relays respond to the "logical or" of the sensor inputs). The common relays are connected to the Fast Shut Down System, FSD, which removes the beam from the hall.

2.12.5 Pressure

The most important aspect of hydrogen safety is to minimize the possibility of explosive mixtures of hydrogen and oxygen occurring. To this end the gas handling system has been made of stainless steel components (wherever possible) and as many junctions as possible have been welded.

The pressure in the gas handling system is monitored in numerous places. Most importantly the absolute pressure of the target is viewed by two pressure transducers, one on the fill line, PT9013 for H_2 and PT9083 for D_2, and one on the relief line, PT9023 for H_2 and PT9093 for D_2. These pressures are also measured by manual gauges. The fill line gauges are PI9031 for H_2 and PI9101 for D_2. The relief line gauges are designated PI9013, H_2 and PI9083, D_2.

2.12.5.1 Target Cells The target cells themselves represent the most likely failure point in the hydrogen system. The outer wall and downstream window of each cell is typically made of $\approx$ 0.004 to 0.005 inch thick 3004 aluminum (Coors beer cans in a former incarnation). There are usually two cells connected with metal gaskets to each cell block, one 15 cm long and one 4 cm long. Both cells have an outer diameter of approximately 2.5 inches. The upstream windows of the cells are made from 0.0028 inch thick 5052 aluminum. These windows are machined out of 1.75 inch diameter (0.065 inch wall) upstream window tubes which are in turn connected to the cell block with metal gaskets.

The cell block components have been pressure tested hydrostatically at CEBAF. Several beer cans have been pressure tested to over 100 PSIG. Upstream windows of both 5052 and 6061 aluminum have been tested to similar pressures. Finally, the entire completed cell block assemblies were pressurized to 75 psig with helium gas, $>$1.5 times the maximum pressure expected (50 psia) during a sudden loss of vacuum incident.

2.12.5.2 Pressure Relief The gas handling and controls system have been designed to prevent excessive pressure build up in the system in order to protect the target cells from rupture. The relief line of the target leads directly to the large recovery tanks. These tanks act as huge ballast and tend to damp out pressure excursions. In the event of a target disruption, such as loss of coolant, the gas evolved during boiloff goes to the recovery tanks. There are two sets of manual valves between the target and the recovery tanks which are used to isolate the tanks when the target is not in use. **These valves must be locked in the open position before the targets are filled**.

In addition to the tank there are a number of other pressure reliefs in the system. Under normal conditions (and even pretty abnormal conditions) these will never be needed but they are provided for extra safety.

All target pressure reliefs are connected to a dedicated hydrogen relief line 2 inches in diameter. The relief line is inerted with helium provided by the ESR 300K supply. The relief line leads to an elevated stack outside, on top of the Hall C dome behind the recovery tanks. On top of the stack is a parallel plate relief set at about 2 psi. Thus any vented target gas is placed in an inert environment until it is released outside of Hall C.

In addition to the reliefs on the gas handling system described above, the scattering chamber itself has a one PSIG relief, RV9064. This is the path that the hydrogen will take in the event of a cell failure.

2.12.5.3 Scattering Chamber Vacuum Failure The scattering chamber is always leak checked before service but obviously the possibility of vacuum loss can not be eliminated. The most likely sources of vacuum failure are:

1. **Spectrometer Windows:** The scattering chamber has two aluminum windows, one for each spectrometer.
2. **Beam Exit Window:** There is a thin beam exit foil, typically 0.03 inch beryllium, at the downstream end of the beamline at the entrance to the dump tunnel.
3. **Target Cell Failure:** This is a multiple loop system. If a target cell fails then the remaining targets will have their insulating vacuum spoiled.

The two spectrometer windows are both made from aluminum. The SOS window is fifteen inches high and subtends 77 degrees (24° to 101°). The window diameter on its frame is 47.5 inches. The SOS window is made of 0.020 inch thick 2024 T3 Aluminum clad foil. The HMS window is eight inches high and subtends 97.5 degrees (5.5° to 103°). The window diameter on its frame is 45.0 inches. This window is made of 0.016 inch thick 2024 T3 Aluminum clad foil. These scattering chamber windows have been hydrostatically tested to 28 psig (1.9 atm), well above the required safety factor of 1.25.

The small beam exit window has an even larger safety margin according to stress analysis. This window was purchased from a commercial vendor (Brush-Wellman).

In the unlikely event of a catastrophic vacuum failure it is important that the relief line of the targets be sized such that it can handle the mass flow caused by the sudden expansion of its cryogenic contents due to exposure to the heat load. A calculation has been performed which models the response of the system to sudden vacuum failure. That calculation indicates that the relief plumbing is sized such that the flow remains sub-sonic at all times and that the maximum pressure in the cells remains well below their bursting point. The calculation is presented in detail at https://polweb/hallc/Cryotarget. However, that document was created in 2004, before the upgrade to the Hall C scattering chamber and target loops took place. The subsequent upgrade essentially made the new Hall C scattering chamber and target loops identical to those described in the document for Hall A. Therefore, the calculations appropriate for the larger Hall A volumes should be used, not those appropriate for the older Hall C system which is no longer in use as of spring, 2007.

The calculation was performed by following methods in an internal report from the MIT Bates laboratory [7]. The formulas and algorithm in the report were incorporated in two computer codes and those codes were able to reproduce results in the report (hence they represent an accurate implementation of the Bates calculation).

The calculation can be logically broken into two parts. First, the mass evolution rate is calculated from geometric information and the properties of both the target material and vacuum spoiling gas. The principal results of this first stage are the heat transferred per unit area, q, the boiloff time, t_b, and the mass evolution rate, w. Second, the capability of the plumbing to handle the mass flow is checked. The principle result of this second step is the maximum pressure in the target cell during the discharge, P_1. The calculations indicate that the reliefs are adequate.

The reference document referred to above also describes the safety calculation for potential over-pressurization of the Hall C scattering chamber. The scattering chamber can vent through relief valves and a burst disk into the dedicated hydrogen vent in the even of a cell rupture. The maximum pressure inside the ∼1900 liter scattering chamber in an event of this type, as described in the Hydrogen Target Safety Assessment Document is expected to be only about 4 psig.

In the unlikely event that a line which carries helium coolant were to rupture the large chamber relief valve is capable of handling the full coolant flow rate.

2.12.6 Temperature Regulation

This is really more an issue of target stability than one of safety. However, a target with a carefully regulated temperature will presumably not undergo worrisome pressure changes.

The targets are normally temperature regulated using a software PID loop that takes as input the temperature as given by one of the Cernox resistors and outputs a control voltage to the power supply of the high power heaters.

2.12.7 Target Freezing

Solid hydrogen is more dense than the liquid phase so freezing does not endanger the mechanical integrity of a closed system. The chief hazard is that relief routes out of the system will become clogged with hydrogen ice making the behavior of the system during a warmup unpredictable.

The freezing point of deuterium is higher than that of hydrogen and higher than the temperature of the gas used for cooling.

Experience has shown that it is difficult to freeze the targets as the efficiency of the heat exchangers is ruined by even a small amount of ice. Still care needs to be taken to keep the targets free from air or water contamination and a trained operator should always be present.

2.12.8 ODH

The total volume of the targets is relatively small with the entire scattering chamber containing only 6500 STP liters of target fluid when both targets are full. As the scattering chamber is located in the middle of Hall C (ie. not in a confined area) which has a volume of approximately 26 x 10^6 leters, the ODH hazard is minimal.

2.12.9 Controls

The target controls have been implemented with the EPICS control system and with hardware very similar to that employed by the accelerator. The basic control functions reside on a VME based single board computer. The graphical interfaces to the control system require one of the Hall C computers to be present as well.

All of the instrumentation for the target is downstairs in Hall C. Most of the equipment (in fact all of the 120 V AC equipment) is on an Uninterruptable Power Supply (UPS). The equipment whose power is not on UPS is

- The scattering chamber vacuum pumps and the gas panel backing pump.
- The target lifting mechanism
- The target circulation fans.

This is a 7 kVA zero switching time UPS which is dedicated to the target. The target computer in the counting house is on an UPS as well. The target's dedicated UPS provides 18 minutes of power at full load (or 50 min at one half load). The status of the UPS, online or offline, is read by the control system.

The principal functions that the control system performs are:

Pressure Monitoring The pressure at various places in the system is monitored and alarm states are generated if a transducer returns a value that is outside user defined limits.

Temperature Monitoring The temperature of the target is read from resistors and vapor pressure bulbs and alarm states are activated when any temperature sensor returns a value outside the user defined limits.

Temperature Regulation The control system allows the target temperature to be regulated.

Solenoid Valve Control The gas systems have a number of solenoid valves that must be switched.

J-T Valve Control The flow of coolant through the heat exchangers is controlled by a set of three J-T valves. These valves control the total helium flow to each target.

Circulation Fan Monitoring and Control The fans which circulate the target fluid are monitored (current, voltage, frequency). The voltage supplied to the fans is adjustable and alarm states can be set on out of range frequency, voltage or current values.

Vacuum Monitoring The scattering chamber vacuum is monitored by the control system. Unacceptable values will generate an FSD and close the upstream scattering chamber valves.

Target Lifter The target lifting mechanism is controlled by the computer. This allows one to place the desired target in the beam.

2.12.10 Target Operators

Whenever hydrogen (or deuterium) is condensed in the system, a responsible person must be on duty in the counting house. This individual is designated the target operator. He/she must be authorized to operate the target and the local target expert must keep a list of all the authorized individuals. In order to become eligible to act as a target operator a person must first be trained by one of the target experts, and then sit at least a few hours with an already trained target operator as a practical. The training from one of the experts forms the "theory" part of the training and consists of a prepared talk given by the expert during which questions are strongly encouraged. The practical training typically takes place in the Hall C counting house and consists of a guided walk through of the controls system.

Target Operators **must** be familiar with the documents
http://www.jlab.org/~smithg/target/target_operator.ps which describes the things a target operator should know how to do, and
http://www.jlab.org/~smithg/target/tgt_howtos.ps which describes how to do those things. An extensive source of information of assistance to the target operator is provided at
http://www.jlab.org/~smithg/target/Hall_C_Cryotarget.html#Standard-Pivot-Targets
Pump-purge procedures, cooldown procedures, and emptying procedures are the responsibility of the JLab Target Group. In case of problems the Target Operator's first point of contact is one of the Target Experts, typically the Hall C Contact Person first, then the target experts not belonging to the JLab Target Group, then the JLab Target Group members. Names and pager/phone numbers are included in the above links.

2.12.11 Conclusion

The principal problem in hydrogen safety is the prevention of explosive hydrogen and air mixtures. The mechanical aspects of this system have been built to minimize the possibility of a hydrogen release. The components that are most susceptible to failure have been tested and the results of these tests indicate that the system should stay intact under the most extreme conditions that are likely to be encountered.

In the unlikely event that hydrogen is released, a mechanism is in place to detect its presence quickly and remove at least the beam as a possible ignition source.

A control system has been developed to allow the careful monitoring of the target systems behavior and it will respond to any aberrant behavior in order to minimize the consequences. Essentially the entire control system has been placed on uninterruptable power so that short power outages can be waited out.

2.13 Helium Cryogenic Targets

^{3}He and ^{4}He gas targets are sometimes used instead of the more usual LH2 and LD2 target configuration. The helium targets are typically operated at 5.5K and 200 psia. Clearly, the primary concern associated with LH2 and LD2 targets discussed in the previous section, namely the flammable gas hazard, is not a problem with helium targets.

These targets are contained in a scattering chamber, so thin vacuum window eye and ear protection is still required in the vicinity of the pivot while the scattering chamber is evacuated.

The high pressure associated with these targets also presents a hazard. The target cells are pressure tested to 1.5 times the design operating pressure of 15 atm. Pressure relief valves (set to 400 psi) can be found on every section of piping that can be isolated. The primary pressure relief is a solenoid valve tied to a pressure switch, in parallel with 260 psi relief valves, a 300 psi rupture disk, and a 400 psi relief valve.

Finally, new deliveries of ^{3}He are checked for tritium contamination. The JLab radcon group has insured that the tritium concentration in the current 3900 STP liter ^{3}He inventory is less than 15 μCi.

2.14 Polarized Targets

To be included.

3 Experiment Readiness Clearance

Checklist on safety items to be checked before an experiment can start data taking. The following items must be included in typical pre–experiment checklists. The Hall C Physics Liaison is responsible for ensuring that the checklist has been completed.

[ ] VESDA system activated?

[ ] Hydrogen sniffers not past calibration date?

[ ] Manual valves between cryogenic targets and recovery tanks locked in the open position before the targets are filled?

[ ] All magnets equipped with functioning warning beacon?

[ ] All magnet current leads covered by non-conductive or grounded shields?

[ ] All of above shields equipped with properwarning signs?

[ ] All magnet power supply doors are closed and properly interlocked?

[ ] All power leads of fastbus power supplies covered by shields?

[ ] Visual inspection of all vacuum windows performed?

[ ] Dates of removal on tags of vacuum windows not expired or close to expiring?

[ ] Proper warning signs installed close to all thin vacuum windows?

[ ] Ear plugs available close to all thin vacuum windows?

[ ] HMS shutter in HMS detector hut operational?

[ ] Air-conditioning on in both HMS and SOS detector hut?

[ ] Hardware switches installed to limit spectrometer rotation?

[ ] HMS and SOS hardware angle limitations verified?

[ ] HMS and SOS angle ranges loaded in rotation PLC?

[ ] No oil leaks in SOS door hydraulics?

[ ] Safety rails removed where they conflict with required angle ranges by experiment?

4 Responsible Personnel

General		
ODH	Bert Manzlak	7556
	Charles Hightower	7608
Radiation Safety	On–call cell	876-1743
	Keith Welch	7212
AC Power	Bill Vulcan	6271
	Joe Beaufait	7131
LCW Operations	Joe Beaufait	7131
	Bill Vulcan	6271
	Walter Kellner	5512
Fire	Dave Kausch	7674
	Bert Manzlak	7556
	Charles Hightower	7608
Cryogenics	On–call pager	6393
	Walter Kellner	5512
Mechanical	On–call pager	6393
	Walter Kellner	5512
Beam Line		
Raster Systems	Chen Yan	7349
	William Gunning	5017
Superharp Systems	Chen Yan	7349
	Mark Jones	7733
	Steve Wood	7367
Møller Polarimeter	Dave Gaskell	6092
Bremsstrahlung Radiator	Dave Meekins	5099
	Bill Vulcan	6271
Current Measuring Devices	Dave Mack	7442
Scattering Chamber	Mike Seely	5036
	Dave Meekins	5434
	Andy Kenyon	7555
Cryogenic Targets	Mike Seely	5036
	Greg Smith	5405
	Dave Meekins	5434
	Thia Keppel	7580

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HMS		
Magnets and Power Supplies	Paul Brindza	7588
	Steve Lassiter	7129
	Mike Fowler	7162
	Bill Vulcan	6271
	Joe Beaufait	7131
Vacuum System	Andy Kenyon	7555
	Walter Kellner	5512
Slit System	Bill Vulcan	6271
Carriage and Rotation System	Steve Lassiter	7129
	Mike Fowler	7162
	Paul Brindza	7588
Shield House	Walter Kellner	5512
High Voltage Supplies	Bill Vulcan	6271
	Joe Beaufait	7131
	Dave Mack	7442
	Steve Wood	7367
Drift Chambers	Bill Vulcan	6271
	Joe Beaufait	7131
	Howard Fenker	7431
	Dave Mack	7442
Scintillator Hodoscopes	Dave Mack	7442
	Hamlet Mkrtchyan	7860
	Howard Fenker	7431
	Bill Vulcan	6271
Gas Cerenkov	Bill Vulcan	6271
	Howard Fenker	7431
	Andy Kenyon	7555
Lead Glass Shower Counter	Dave Mack	7442
	Hamlet Mkrtchyan	7860
	Howard Fenker	7431
	Bill Vulcan	6271

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SOS		
Magnets and Power Supplies	Bill Vulcan	6271
	Joe Beaufait	7131
	Steve Wood	7367
	Steve Lassiter	7129
	Paul Brindza	7588
Vacuum System	Walter Kellner	5512
	Andy Kenyon	7555
Slit System	Bill Vulcan	6271
	Dave Gaskell	6092
Carriage and Rotation System	Walter Kellner	5512
	Steve Lassiter	7129
	Mike Fowler	7162
	Bill Vulcan	6271
Shield House	Walter Kellner	5512
	Bill Vulcan	6271
High Voltage Supplies	Bill Vulcan	6271
	Joe Beaufait	7131
	Dave Mack	7442
	Steve Wood	7367
Drift Chambers	Howard Fenker	7431
	Bill Vulcan	6271
	Dave Mack	7442
	Joe Beaufait	7131
Scintillator Hodoscopes	Dave Mack	7442
	Howard Fenker	7431
	Bill Vulcan	6271
Gas Cerenkov	Bill Vulcan	6271
	Howard Fenker	7431
Lead Glass Shower Counter	Hamlet Mkrtchyan	7860
	Howard Fenker	7431
	Dave Mack	7442
	Bill Vulcan	6271
Aerogel Detector	Hamlet Mkrtchyan	7741
	Howard Fenker	7431

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Spectrometers - General		
Vacuum Windows	Thia Keppel	7580
	Walter Kellner	5512
	Andy Kenyon	7555
Gas Mixing System	Howard Fenker	7431
	Brian Kross	7022
	Bill Vulcan	6271
	Dave Mack	7442
Counting House		
Electronics	Mark Jones	7733
	Steve Wood	7367
	Rolf Ent	7373
Data Acquisition	Steve Wood	7367
	Mark Jones	7733
	Dave Abbott	7190
Laser Pulser	Bill Vulcan	6271
	Hamlet Mkrtchyan	7860

References

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[2] HMS Superconducting Magnet Safety Review - Quadrupoles (1994)

[3] HMS Superconducting Magnet Safety Review - Dipole (1994)

[4] Danfysik Magnet Power Supply 8000 Section 5, "Maintenance".

[5] C. D. Cothran, D. Day, and J. H. Mitchell, "Temporary Operating Safety Procedure for the HMS Cerenkov Detector Pressure Testing"

[6] R.D. Mc Carty, "Hydrogen Technology Survey: Thermophysical Properties," N76-11297, NBS 1975

[7] W. Schmitt and C. Williamson " Boiloff Rates of Cryogenic Targets Subjected to Catastrophic Vacuum Failure," Bates Internal Report # 90-02, Sept 1990