Experiment Safety Assessment Document for the Base Equipment in Hall B
October 2, 2007


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1 Introduction

Hall B is one of the three experimental areas at JLab. This manual attempts to describe the experimental equipment that makes up this facility, and to provide instructions for the safe and effective use of this equipment. In this operations manual, safety is addressed in the sense that proven procedures are provided. The primary hazards are listed, and procedures detail how we address each of them.

2 General Issues

There are a number of potentially hazardous systems that are required at any accelerator complex. In this section we outline the extent to which these general site hazards affect the operation of experiments in Hall B, and list those that require special training. For more information on site safety systems and regulations, the user is referred to the JLab EH&S Manual.

The principal contacts for the JLab EH&S group are:

1. Bert Manzlak - x7556
2. Charles Hightower - x7608
3. Dennis Skopik - x7740

2.1 Oxygen Deficiency Hazard

Because of the presence of cryogens (for the CLAS superconducting magnets and for cooling the cryogenic targets) Hall B is listed as an Oxygen Deficiency Hazard (ODH) area of Class 0 (except as noted below). This rating requires that those wishing to have unescorted access to the hall must take the JLab ODH training course once every two calendar years. This course is typically taught once monthly by a representative of the EH&S group. There are ODH alarms in the hall and blue lights. The alarms sound and the lights will flash if there is a potential ODH hazard. Further, those working above the crane railing must have more extensive ODH training as documented in the JLab EH&S manual; this area is designated as ODH 2.

2.2 Radiation Safety and the Personnel Safety System

JLab’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 are in place. This is the purpose of the Personnel Safety System.

The current status of Hall B is displayed in the Hall B counting house on a sign with red lighted letters. The possible conditions are:

Beam Permit. There is potentially beam in the hall.
Power Permit. In this mode all devices that normally prevent beam transport to the hall may be removed or energized. This is one level below that required for beam delivery. No personnel are allowed in the hall when it is at this level.

Sweep. The machine safety officers are securing the hall. No access is permitted during this process.

Controlled Access. Access is permitted only by using the keyed interlock system. (A procedure for this type of entry is listed below).

Restricted Access. The entry gate to the hall is open, and trained personnel with appropriate dosimetry may enter.

If the hall is in either Beam Permit or Power Permit status, it is impossible for personnel to enter. If a situation arises that requires a hall entry, then the shift leader will call the Machine Control Center (MCC) and request an entry. The state of Hall B will then be lowered to controlled access, and a limited number of trained personnel can enter the hall via the two door entry gate from the labyrinth. It is required that personnel entering have a Jefferson Lab Radiation Dosimeter, be Jefferson Lab Radiation Worker qualified, and have current ODH training.

The controlled access procedure is as follows:

1. Access to Hall B is allowed under a General Radiation Work Permit (GRWP). The GRWP specifies access requirements for areas within the Hall.

2. The hall status sign in the counting house must read “controlled access.” If not, the shift leader must call the MCC, and they will send a radiation survey team over to check the radiation levels in the hall.

3. Proceed downstairs to the two door entry gate to the hall and call the MCC at extension 7050 before touching the door. Inform the MCC crew chief of your name and the names of those accompanying you and request that they open the outer door.

4. Hang up the phone and enter the two door gate. The last person in should close the outer door after entering the gate area.

5. Each person entering must take a key from the key bank and inform the MCC via the phone or intercom which key they have taken. The keys form a personnel accounting system, and all the keys must be in the bank for the hall to be returned to a beam permit state. Therefore, one should NEVER leave the downstairs area with a key. In addition to the individual key, there is a master key that must be removed from the key bank and placed in the master lock. This is normally done by the radiation officials who survey the hall.

6. The MCC will need to see that all personnel entering have a Jefferson Lab radiation dosimeter. They verify this visually, and it is never permissible for both gate doors to be open simultaneously.
7. After everyone has a key, the inner door will be opened allowing entry into the tunnel leading to Hall B. The inner door must be shut behind the last person entering.

8. When the work in the hall is complete, you must call the MCC to get back into the gate area. The keys should be returned to the bank and the last person leaving must remove the master key from the master lock and replace it in the first position of the bank. (This key is normally placed in the master position by the individual who first surveys the hall when it is opened for a controlled access.)

While downstairs the status of the beam is visible on the yellow run-safe boxes. The lights should either be green or yellow. If the run-safe box in an area where you are working has a red light lit, you should hit the “push to safe” button immediately.

If the hall status reads restricted access then there is free access for trained personnel.

2.2.1 Induced Activity

In addition to the hazard of direct exposure to the electron beam you must be aware of the potential for induced radioactivity in objects near the path of the beam. The GRWP specifies the requirements for hall entry after beam shutdown. Typically, a radiation survey is done to evaluate conditions in the hall. If radiation levels exceed certain thresholds, then specific signs, postings, and barriers will be installed by the RCG or ARMs. In addition, verbal instructions may be given to personnel in the area regarding access to various locations. In any case, always read radiological postings, and follow the instructions. If it is necessary to remove or modify beam line or target components, or to perform any work in a posted Radiation Area, you must consult the RCG before beginning work. In many cases a specific RWP (SRWP) is required for work. SRWPs for many activities will be available in the Counting House for review.

Any item that was in or near the beamline during beam delivery and needs to be removed from the hall must be surveyed by the RCG prior to removal. All hardware, materials, or components that are waste items from these immediate areas should be placed in the large blue drums available for potentially activated material. The RCG will survey these items before disposal.

2.2.2 Radiation Control Personnel

The radiation control group may be reached at 757-269-7236 during normal business hours, and after hours they can be reached by contacting the MCC at 757-269-7048.

2.3 AC Power

There are two voltage levels of three phase, AC power service available in Hall B, 480Y/277 V and 208Y/120 V. These two voltages are available on four separate feeders. The first feeder is distributed from the Hall B Truck Access Electrical Room and it is rated for 1200 A at 480Y/277 V. 280Y/120 V power is derived from this feeder for other low voltage uses via transformers. This feeder supplies utility loads in the Truck access Tunnel (lights, vent fans), the Beam Dump (lights and utility power in the Beam Dump Alcove) and the Experimental
Hall (dome lights, vent fans, A/C fan coils, and all receptacles mounted on the concrete walls of the Experimental Hall). Circuits from this feeder generally have a “TBxx” prefix identification mark. This power originates from a transformer located near SB1 (Bldg. 92). This transformer also supplies power to SB1, which furnishes chilled water for A/C and LCW in the Experimental Halls and cooling tower water for the End Station Refrigerator (ESR) Bldg. (Bldg. 102).

The second feeder is distributed from Hall B and is rated for 1800 A at 480Y/277 B. 208Y/120 V power is derived from this feeder for other low voltage uses via transformers. This feeder supplies loads to large magnet power supplies and to utility loads (lights, convenience receptacles, and fan coils) on the steel structures (Space Frame, forward carriage, clam shells, and pie tower) located in the Experimental Hall. Circuits from this feeder generally have one of two prefix identification marks: “SB ESB” or “B-UP”. This power originates from a transformer that is dedicated to Experimental Hall B.

The third feeder is distributed from Hall B and is rated for 800 A at 480Y/277 V. Power is derived from this feeder for other low voltage uses via transformers. This feeder supplies clean power to electronic loads on the steel structures located in the Experimental Hall and in the Beam Dump Alcove. Circuits from this feeder generally have a “B-CP” prefix identification mark. “Clean power” should be used for noise sensitive applications such as power supplies for detectors. It is not permissible to power machinery or convenience outlets from the clean power. If you are uncertain about the use of AC power in a given situation, ask the shift leader or any Hall B staff member. This power originates from a transformer located near the Counting House (Bldg. 97). This transformer also supplies clean power to Experimental Halls A and C.

The fourth feeder is distributed from the Hall B Truck Access Electrical Room and it is rated for 225 A at 480Y/277 V. This feeder supplies emergency loads in the Experimental Hall (lights and smoke removal fans) and in the Truck Access Tunnel (lights, smoke removal fans, and roll-up doors). Circuits from this feeder generally have a “TBEM” prefix identification mark.

There are kill switches on each level of the Experimental Hall structures, which allow the power to be shut off in the vicinity of the switch. The power may be de-energized locally with a red mushroom switch or remotely in the Counting House.

There are many circuit breaker panel boards located around Hall B. If you encounter equipment that seems unpowered, it is always worth checking the status of the breakers in these panel-boards. All outlets and disconnects in Hall B have a label that indicates the panel and circuit number of the branch circuit that supplies it. Aside from resetting of circuit breakers, you should not attempt to solve any other problems associated with the AC power distribution system without consulting responsible personnel.

Anyone working on AC power in Hall B must be familiar with the EH&S manual and must contact the personnel responsible for the system.

2.4 LCW Operations

The low conductivity water (LCW) system for Hall B is located on the north wall of the Hall. The system has two outputs, one at 120 psi for most power supplies, magnets and turbo pumps, and another at 230 psi for the Pair Spectrometer magnet and Möller Quadrupole
magnets. The return pressure is typically 30-50 psi on both the low pressure and high pressure lines.

### 2.4.1 Normal Operations

During normal operations, the split of the input LCW into the low and high pressure lines is automatically controlled. The controller located on the north wall should read 125 psi and be in automatic mode. If the LCW control system becomes unstable, the pressure reading will fluctuate by more than 10 psi, this is unacceptable and Plant Services should be contacted immediately. Noise from the system can be reduced during restricted accesses by manually closing the large ball valve. This restricts the flow into the low pressure system before the automatic diverting valve, and lowers the amount of noise the diverting valve makes.

### 2.4.2 Maintenance

Whenever terminating LCW flow to a device or line, it is important to shut the supply line first then the return line. If the LCW circuit is to be opened, it is important to remember that the closed circuit still has 30-50 psi of pressure. The LCW water should be drained in a convenient manner that does not get moisture on any electronics.

When restoring LCW flow to a circuit, the return line should be opened first then the supply line. If any connections have been remade they should be carefully inspected for leaks. Major changes to the LCW demands in the hall should be reviewed by Plant Services before implementation.

### 2.5 Fire

Issues related to fire hazards in Hall B are addressed in a separate document, the “Hall B Fire Assessment Document”, CLAS-Note 98-007. There is a map indicating the evacuation routes of the end station complex posted outside the Hall B counting house.

### 2.6 Mechanical

#### 2.6.1 Crane

Hall B is equipped with a 20-ton polar crane that rotates 360 degrees around the Hall. A space frame with three levels has been erected in the upstream end of Hall B with the uppermost beam having approximately 6” of clearance under the polar crane bridge.

In the center of Hall B, a toroid magnet is hung by two support rods attached to beams supported by four columns from the floor. The support posts separating the six cryostats of this magnet are carbon fiber material that would shatter under a lateral collision. Therefore, the area above and inside of the support columns of this magnet is a keep-out zone for the crane hook.
2.6.2 Carriage Movement

During installation and maintenance of the CLAS detector, the carriages that support the calorimeters, scintillators, and Cerenkov counters must be moved in and out of their installed positions. Due to the weight of these objects and the precision with which they must be located, special care must be taken to insure safe movement.

3 Magnet Operation

3.1 General Layout of Magnets and Power Supplies

This sections details the high current magnets and power supplies in the Hall B experimental area. Fig. 1 shows a schematic of the large magnets and their supplies. The power supply specifications are given in Table 1 and the magnet specifications are given in Table 2. Several supplies serve dual uses depending on whether the experiment is performing electron scattering or real photon experiments. There are many safety issues for magnets and their power supplies that are addressed in the following sections. The main safety issue is personnel safety, the magnets, supplies, and bus lines must be safe enough so that workers can work in the vicinity of the magnets and supplies without any risk of electrical exposure. Equipment protection is also a concern since the magnets and power supplies represent a substantial tax payer investment. The equipment is actively protected by hardware interlocks that prevent the power supplies from damaging themselves or the magnets they supply.

Figure 1: Schematic of the large magnets and their power supplies in Hall B. The order shown is the order in which the magnets reside on the beamline, with the beam running left to right. The solid lines between magnets and power supplies represent 535 high-current cable, dashed lines represent water-cooled bus lines (either thick-walled copper or thick walled aluminum pipe).


<table>
<thead>
<tr>
<th>Power Supply</th>
<th>Manufacturer</th>
<th>Max. Current (A)</th>
<th>Max. Voltage (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dyna-A</td>
<td>Dynapower</td>
<td>10000</td>
<td>40</td>
</tr>
<tr>
<td>Dyna-B</td>
<td>Dynapower</td>
<td>8000</td>
<td>40</td>
</tr>
<tr>
<td>Dyna-C</td>
<td>Dynapower</td>
<td>8000</td>
<td>40</td>
</tr>
<tr>
<td>Tagger</td>
<td>Inverpower</td>
<td>2400</td>
<td>70</td>
</tr>
<tr>
<td>Torus</td>
<td>Danfysick</td>
<td>3700</td>
<td>10</td>
</tr>
<tr>
<td>Dyna-switch</td>
<td>Dynapower</td>
<td>8000</td>
<td>NA</td>
</tr>
</tbody>
</table>

Table 1: Hall B power supply specifications.

<table>
<thead>
<tr>
<th>Magnet</th>
<th>Power Supply</th>
<th>Coil Configuration</th>
<th>Max. Current (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moller Quad A</td>
<td>Dyna-B</td>
<td>parallel</td>
<td>3600</td>
</tr>
<tr>
<td>Moller Quad B</td>
<td>Dyna-C</td>
<td>parallel</td>
<td>3600</td>
</tr>
<tr>
<td>Tagger</td>
<td>Tagger</td>
<td>series</td>
<td>2700</td>
</tr>
<tr>
<td>Sweeps A and B</td>
<td>Dyna-B</td>
<td>coils: series, magnet: series</td>
<td>2000</td>
</tr>
<tr>
<td>Mini Toroid</td>
<td>Dyna-A</td>
<td>series</td>
<td>8000</td>
</tr>
<tr>
<td>Main Toroid</td>
<td>Torus</td>
<td>series</td>
<td>3700</td>
</tr>
<tr>
<td>Pair Spectrometer</td>
<td>Dyna-A</td>
<td>parallel</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Hall B magnet specifications.

### 3.2 Safety Procedures for Magnets in Hall B

The magnets in the experimental hall are typically energized by remote control to simplify operation when there is beam in the hall. During major down times the magnets are powered down for personnel 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.

#### 3.2.1 Identification of Potential Hazards

Personnel working in the proximity of energized magnets are exposed to the following hazards:

- danger of being electrocuted by coming into contact with exposed leads;
- danger of metal tools coming into contact with exposed leads, shortening 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
• 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.

3.2.2 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.

Routine Operation. The following measures shall be taken by the cognizant hall engineer (or his designee) to mitigate the hazards described in Section 3.2.1 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 or use plastic piping to cover the water-cooled bus);

• All exposed current leads and terminations shall be covered by non-conductive or grounded shields (typically Plexiglas or fire-rated Lexan) in such a manner as to make it impossible for personnel to accidentally touch exposed leads with either their body or with a tool. Personnel shall be instructed not to reach inside the shields. Warning signs shall 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. The beacons at the magnet are to be activated when the power supply is turned on, regardless of whether current is actually flowing to the magnet. This serves as notice to any workers in the area that the magnet is presently activated or can be activated at any time remotely, and any magnetic material should not be placed near the magnet;

• 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

**Non-Routine Operation** Non-routine operation shall be pre-approved and closely supervised by the cognizant hall engineer (or his designee).

The following measures shall be taken during non-routine operation to mitigate the hazards described in Section 3.2.1:

- 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;

- 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.

**Power-on Maintenance** Any maintenance work performed on the magnets and associated power supplies and cabling while the magnets are energized must be done by appropriately trained and authorized personnel following the rules and procedures defined in the Electrical Safety section of the Jefferson Lab EH&S Manual, and/or following specific procedures outlined in approved OSP’s or TOSP’s.

### 3.3 Upstream Pair Spectrometer Magnet

The dipole magnet located upstream of CLAS and downstream of the tagger is the Upstream Pair Spectrometer Magnet, sometimes referred to as the “PRIMEX” magnet. It is used for real photon experiments to remove secondary charged particles originating at the collimator from the photon beam.

The magnet is energized from the EPICS magnet gui. The power supply is located at the floor level of CLAS, in-between the power supplies for the mini-torus and the tagger.

A red beacon indicates whether the magnet can be powered remotely or is currently powered. Normal caution should be exercised when working near the magnet when it is energized, since a strong magnetic field is present and large currents are flowing through its conductors.
3.4 Møller Quadrupole Magnets

Møller quadrupole magnets are an integral part of the Møller polarimeter. Their function is to transport the two electrons to the detectors downstream of the magnets. Since the polarized electron beam can be of different energies, the magnets are to be operated at different currents. In fact the first quadrupole must have its polarity changed depending on the beam energy. For this reason the first quadrupole is connected to the Dyna-B supply and Dyna-switch. In order for these supplies to energize the quadrupoles, the individual pole coils were reconfigured to be parallel instead of in series. Each pole is still in series with the other poles, thereby each pole still has the same current flowing through it. The bus lines from the power supply or switch are water cooled aluminum busses.

3.4.1 Møller Quadrupole Operation Checklist

The following checklist must be completed before energizing the Møller Quadrupole magnets to protect personnel and the equipment.

1. All flags are to be buffed and cleaned before connecting;
2. All protective shields on bus and flags must be in place;
3. The warning beacons in the Møller area must be functioning;
4. LCW flow verified to power supply, switch, bus lines and magnets;
5. The Møller quadrapole area must be clean of magnetic debris;
6. The temperature sensor klixons on the magnet and flags must be verified to be connected to the external interlock on the power supply and the interlock must be verified to be working;
7. The current limit on the supplies must be set to 4000 A.

At present we do not envision any special procedures that need to be done at the end of Møller quadrupole operation.

3.5 Mini-Toroid Magnet

The mini-toroid magnet consists of six resistive water cooled coils. The magnetic field produced by the Mini-Toroid protects the drift chamber from low energy Møller electrons originating from the target. The magnet was designed for a maximum current slightly more than 8000 A, however, the Dyna-A power supply becomes voltage limited at about 7900 A. The Mini-Torus is used during electron scattering experiments, and is removed for real photon and polarized target experiments.
3.5.1 Mini-Toroid Installation and Operation

The following items must be performed during installation and operation of the Mini-Torus.

1. The circuit breaker for the Dyna-A supply must be locked out by all personnel working on the bus connections.
2. The LCW integrity of the coupling at the Mini-Torus must be checked before insertion.
3. The electrical isolation of the magnet coils from ground must be verified before connecting them to the power supply.
4. All exposed bus, flags, and connections must be placed behind protective shields.
5. Verify that the temperature sensor klixons on the magnet and flags are connected to the external interlock on the power supply and that the interlock is working.
6. All electrical connection surfaces should be void of oxides before connecting.

3.5.2 Mini-Toroid Removal

In order to safely remove the Mini-Torus the following safety procedures must be observed.

1. All workers that work with the bus connections must lock and tag the power supply or breaker that feeds the power supply.
2. Verify that the LCW flow has been turned off before disconnecting the water-cooled bus.

3.6 Pair Spectrometer Dipole Magnet

The pair spectrometer magnet is located in the downstream tunnel behind the first shield wall. This magnet is only used during real photon experiments and is powered by the Dyna-A power supply. When operating this supply the following items need to be verified first:

1. All flags are to be buffed and cleaned before connecting.
2. All protective shields on bus and flags must be in place.
3. The warning beacon in the pair spectrometer area must be functioning.
4. LCW flow verified to power supply, bus, and magnets.
5. The pair spectrometer area must be clean of magnetic debris.
6. The temperature sensor klixons on the dipole magnets and flags must be verified to be connected to the external interlock of the power supply and the interlock must be verified to be working.
3.7 Tagger Magnet and Power Supply

The tagger magnet is a large C magnet that is installed in the upstream alcove in Hall B. Its purpose is to deflect the full-energy electron beam through an angle of 30 degrees into the tagger beam dump, while deflecting lower-energy electrons into the detectors of the tagging system. The magnet is suspended from a steel support structure called the gantry.

The tagger power supply is located on the floor in Hall B, next to the wall on the north side of the alcove. Power is supplied to the magnet by eight 535 mcm insulated copper cables, four supply and four return. The power cables run in grounded cable trays along the wall of the hall. The magnet is grounded by a bare 500 mcm copper cable that runs in the same cable trays. The ground cable is connected to the grounding plate in the hall floor, adjacent to the power supply. Additionally, the gantry steel is grounded directly to the magnet steel; ground does not rely on the support connections between the magnet and the gantry. Strain relief is provided for all cables.

The power supply delivers up to 2400 A DC, at approximately 70 V. At full 2400 A excitation, the magnet can deflect a 6.1 GeV electron beam into the tagger beam dump.

The power supply doors are interlocked. Additional interlocks are from a flow meter on the cooling water return for the magnet (not currently connected), and on a series of “Klixon” temperature gauges in contact with the magnet coils. The LCW system is used to cool both the power supply and the magnet. The power supply has an internal flow meter for its cooling water that is interlocked as well.

Access to the high-field region is very restricted by the stainless steel vacuum extension to the magnet gap. Furthermore, the field is less than 100 Gauss at distances greater than 1 foot from the magnet, and less than 5 Gauss at distances greater than 10 feet from the magnet.

3.7.1 Safety Hazards and Precautions

The power supply can be run locally using front-panel controls, or remotely under EPICS control. During run conditions, the magnet is controlled via EPICS from MCC.

- Following any modification or maintenance of the magnet or power supply, the following will be verified:
  
  1. DC power leads are all in place and torqued down.
  2. Magnet-to-Gantry and Magnet-to-Ground Plate cables are in place and torqued down.
  3. LCW water is connected and operating properly.
  4. Magnet interlocks are connected and verified to trip the power supply.
  5. DC lead protective covers are in place on the magnet.

- Prior to each start up, the following will be verified:
  
  1. A sign saying:
DANGER
Strong Magnetic Fields—No Pacemakers
No Access Except Authorized Personnel

will be posted at all access points, including the entrance to the alcove from the
tunnel.

2. The area around the magnet will be roped off.

3. The area within 3 feet of the magnet will be searched and cleared of tools and
other loose items that may be affected by the field.

4. Red rotating or flashing lights on both upper and lower levels (near power con-
nections) will be used at the magnet to indicate “Power On”. These lights will
be activated by control power in the near future.

5. Immediately prior to energizing the system, a final check will be performed to
verify that no one is in contact with the system.

The EPICS control program shall ensure that, whenever beam is present in the Hall B
channel, the current in the power supply is within 5 percent of the nominal calculated value.
The nominal value is calculated from the beam energy by the EPICS program. For reference,
some of the nominal values are listed in Table 3.

<table>
<thead>
<tr>
<th>Beam Energy (GeV)</th>
<th>Current (Amperes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.845</td>
<td>281.71</td>
</tr>
<tr>
<td>1.645</td>
<td>549.38</td>
</tr>
<tr>
<td>2.445</td>
<td>819.14</td>
</tr>
<tr>
<td>3.245</td>
<td>1090.78</td>
</tr>
<tr>
<td>4.045</td>
<td>1366.17</td>
</tr>
<tr>
<td>5.045</td>
<td>1733.95</td>
</tr>
<tr>
<td>6.045</td>
<td>2338.60</td>
</tr>
</tbody>
</table>

Table 3: Nominal tagger currents for various beam energies.

3.7.2 Normal Operation

The magnet will be used for its designed purpose during all photon beam runs in Hall B,
and may also be used for beam steering and tune-up during electron beam runs. During all
beam runs, the power supply is controlled exclusively from MCC via EPICS.

During short controlled accesses to the hall the power supply may remain energized.
During longer controlled accesses (longer than 4 hours) or when the Hall is in a state of
restricted access, the power supply shall be turned off, or the current set to zero, unless an
authorized person is present in the magnet area.
3.7.3 Special Procedures

The power supply may be run under local control by authorized personnel for the purpose of making magnetic field measurements, testing the interlock systems, or de-gaussing the magnet, under local control. The power supply shall be energized only while authorized personnel are present in the magnet area.

3.8 Toroidal Magnet

3.8.1 General Orientation

The CLAS toroidal magnet is the primary momentum analyzer for the spectrometer. Its most commonly used configuration is such that negative particles bend toward the beam line (i.e. “inbending electrons”). The magnet was designed to operate at up to 3861 amperes, however, an administrative limit of 3375 amperes has been imposed to reduce the probability of premature mechanical failure. This is an iron-free, superconducting magnet.

The device is activated through the CLAS slow controls “Magnets” gui, which is available from the clas, epics gui. Its power supply is located on the first elevated level of the Space Frame, adjacent to the stairs. There are red beacons located at several points in the hall that indicate that the magnet is activated or may be remotely activated.

This magnet produces a toroidal field. Such a field is intrinsically well-confined, so that fringe fields are not large, even though the maximum field may exceed 1 Tesla. Normal precautions should be used for people with pacemakers and medical implants. More information is available in the Jefferson Lab EH&S manual. Before energizing the magnet, a sweep should be performed to ensure no unintended magnetic materials can be dislodged by activating it. Any work performed near the interior of the magnet while it is energized must be pre-approved by the Hall Work Coordinator, Doug Tilles, and may require additional advance approvals such as obtaining a TOSP (Temporary Operating Safety Permit).

3.8.2 Reversing Polarity on the Oxford Magnet Power Supply

Reversing the polarity on the torus magnet requires a hall entry to mechanically disconnect and re-connect electrical contacts. This operation can only be performed by authorized members of the Hall B Engineering Group.

4 Detector Operation

4.1 Crate Power Supplies

CLAS uses several low voltage, high current power supplies, specified by VME, VXI, FAST-BUS standards, and JLab-designed ADB crates. The operation of all these is in accordance with the new “High Current Power Supply Systems” Section of the EH&S Manual 6240. Special precautions are taken to protect exposed leads from accidental contact. The crates are protected from an over-current condition by means such as a fuse or circuit breaker. Each type of powered crate in CLAS has been specified to include over-temperature protection circuits that will remove crate power in the case of an over-temperature condition.
4.2 PMT High Voltage

4.2.1 Detectors and Environment

There are four systems in CLAS that use photomultiplier tubes (PMTs) to detect low levels of light produced by ionizing particles. These are the gas Cerenkov counters, Time-of-Flight (TOF) scintillation counters, electromagnetic calorimeters (EC), and tagging spectrometer. The last three detector systems use plastic scintillators based on polyvinyltoluene (PVT) purchased from Bicron Corporation (BC-408 and BC-412). The scintillators are attached to the PMTs via acrylic or polystyrene plastic light guides.

There are six Cerenkov detectors, one per sector in CLAS, each with 36 5" Hamamatsu PMTs and approximately 380 ft$^3$ of non-flammable gas (C$_4$F$_{10}$). The voltage divider is inside the gas-filled volume, with signal and high voltage cables patched through the detector walls to the outside.

4.2.2 High Voltage Supply

The high voltage (HV) for the PMTs of the CLAS detector$^1$ is provided by the LeCroy 1450 Modular High Voltage System. The power is provided by the 1458 Mainframe that houses up to sixteen vertical 1461 high voltage cards that supply the actual high voltage to the PMTs. All subsystems require negative voltage (supplied by 1461N cards), except for the Cerenkov detector, which requires positive voltage (supplied by 1461P cards). The mainframe can supply a maximum of 1440 W (60 A at 24 V) to all cards. Each card has twelve channels that generate a voltage between 0 and 3 kV and a maximum current of 2.5 mA per channel at 3 kV (7.5 W per channel). Details of the PMTs for the TOF and calorimeter as interfaced to the HV system can be found in CLAS-Note 96-010.

Table 4 gives a breakdown of the number of HV channels per subsystem. The HV mainframes for the forward-angle TOF, calorimeters and Cerenkov counters are on the forward carriage (deck 3). The HV for the tagging hodoscope is located on the floor of Hall B below the spectrometer. The mainframes for the large-angle calorimeters are located on the south clam shell. The mainframes for the large-angle TOF are located on the north and south clam shells, and one on the space frame.

4.2.3 Cables

Each PMT is connected to a LeCroy 1461 HV card with a red RG-59 cable (except for the tagging spectrometer which has black cables) and SHV connectors. Two PMT signals are connected to the electronics, one to the readout and the other to the trigger, with coaxial cables. All cables have a fire rating of CL2X or equivalent.

4.2.4 PMT Voltage Dividers

The voltage divider networks for the TOF, calorimeter, and tagger T-counters are based on a University of New Hampshire low-power design, which typically draws 0.5 mA at an operating voltage of 2000 V (1 W), independent of load. Failures that result in the divider

$^1$The Large-Angle Calorimeter uses the CAEN SY527 HV System.
<table>
<thead>
<tr>
<th>System</th>
<th>Channels</th>
<th>Polarity</th>
<th>Operating Voltage (V)</th>
<th>Operating Current (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward-Angle TOF</td>
<td>276</td>
<td>Negative</td>
<td>2000</td>
<td>0.35</td>
</tr>
<tr>
<td>Large-Angle TOF</td>
<td>408</td>
<td>Negative</td>
<td>2000</td>
<td>0.5</td>
</tr>
<tr>
<td>Forward-Angle calorimeter</td>
<td>1296</td>
<td>Negative</td>
<td>2000</td>
<td>0.5</td>
</tr>
<tr>
<td>Large-Angle Calorimeter</td>
<td>512</td>
<td>Negative</td>
<td>2000</td>
<td>0.5</td>
</tr>
<tr>
<td>Cerenkov</td>
<td>216</td>
<td>Positive</td>
<td>1600</td>
<td>1</td>
</tr>
<tr>
<td>Tagging E-counters</td>
<td>384/4</td>
<td>Negative</td>
<td>2000</td>
<td>1</td>
</tr>
<tr>
<td>Tagging T-counters</td>
<td>122</td>
<td>Negative</td>
<td>2000</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Table 4: Number of high voltage channels required by each subsystem. Note that the large-angle calorimeter uses the CAEN SY527 HV system.

network drawing more than 2.5 mA will trip the high voltage channel. In very unusual circumstances, failures could result in drawing up to a maximum of 2.5 mA at 3000 V, or 7.5 W. These conditions, however, should be flagged by the slow control system that monitors the current draw and operating voltage of each PMT.

4.2.5 HV Shock

If the HV connections to the PMT voltage divider are improperly attached, it is possible to receive an electrical shock. To avoid shock, the following precautions shall be taken upon initial operation of the system:

- Check grounding of support frame to carriage;
- Check grounding of High Voltage supply to carriage.

The grounding scheme for the forward carriage is shown in Fig. 2 (similar schemes are implemented for the north and south clam shells). All racks and cable trays are grounded with a 4/0 copper ground strap to the grounding grid in Hall B for safety and to minimize sources of noise.

Additional special circumstances for particular detectors include:

1. TOF Scintillators

   The TOF PMTs are enclosed in cylindrical μ-metal shields that are connected through a 8 MW resistor to the HV on the voltage divider to minimize noise. Accidental exposure to the pigtail or shield could result in a shock. However, the current is limited to 0.4 mA by the resistor. Under normal circumstances, the HV is completely covered by the light-tight plastic enclosure for the PMT.

2. Cerenkov Detector

   The Cerenkov counters use 5″ Philips XP4500B/03 photomultiplier tubes. The signals are capacitatively coupled to positive HV, with the PMT cathode at ground potential. The voltage divider is a rugged commercial design. However, care must be taken as failures in the divider network can cause the signal pin to float to high voltage.
3. Large-Angle Calorimeter

The scintillator, based on polyvinyltoluene (PVT), was supplied by NE technologies (NE-110A). The voltage divider is a commercial base with properties similar to those reported in Section 4.2.4. The high voltage is supplied by the CAEN SY527 HV System. The power is provided by a mainframe that hosts up to 10 cards with 16 channels each. Each card generates a voltage from 0 to 3.0 kV with a maximum current of 3.0 mA per channel at 3 kV. The mainframe can supply a maximum of 1.6 kW.

4. Tagging Hodoscope

The tagging hodoscope is located below the tagging magnet in the alcove at the entrance to Hall B. All scintillator detectors are contained in a single light-tight enclosure that is protected against accidental exposure by connections to the fail-safe interlock connection on the LeCroy 1458 Mainframe (for details see CLAS-Note 96-021).

4.2.6 Fire

The largest fuel supply in Hall B consists of the inventory of plastics. Most of the plastic is in the cables, although a significant fraction is found in the scintillator detectors. (For more information refer to the Fire Hazard Analysis for Hall B.) Therefore, a concern is any fire that originates in a voltage divider or any electronics connected through cables to the PMT detector. The detector system was designed to minimize the potential for ignition or spread.
of fires by using low-powered bases (see above), fire retardant cables, and safe connections (SHV). However, the detector material itself, especially of the TOF system, is covered by thin sheets of plastic and aluminum foil to achieve the desired physics objectives.

We therefore require that for HV equipment installed in Hall B the following procedures must be followed:

- The LeCroy 1458 Mainframes shall be powered fully loaded with HV cards and burned in for a minimum of 30 hours before installation.
- The detectors will be not be left on without supervision for at least two days prior to routine operation. During this time there will be a visual inspection of energized detectors as they are plugged in and hours after first energized. Look for smoke, distorted plastic, and other signs of heat to whatever extent visible.

4.3 Drift Chamber Operation

Drift chambers require low voltage (6 V) power for the on-board pre-amplifiers, high voltage (~2000 V) for biasing the sense and field wires, and a source of high-purity gas. Here we discuss the safety aspects of these three utilities.

4.3.1 Low Voltage

There are eighteen low voltage supplies, one for each chamber. The supplies are located in Hall B in racks on each level of the “space frame”. Below each supply is a distribution box that contains the power bus and two fuses for each pair of power cables (outgoing and return).

The system is set up such that there are FEW SAFETY ISSUES (to persons or equipment) during operation. The supplies cannot exceed 7.5 V by design; thus, they cannot harm the on-chamber voltage regulators. Each output and return line is separately fused with a maximum 2.5 A fuse, where the nominal current draw is about 1.5 A. Any unaccounted-for power draw must be less than about 10 Watts (7.5 V x 1 A) thus posing a negligible fire risk. Furthermore, software limits are set about 2 A above the nominal current draw for each supply as a whole. If the total current draw exceeds the limit, the supply is shut off. The only plausible hazard arises from improper placement of fuses. The following are the RULES of SAFE OPERATION:

1. Do not change the voltage.
2. Reset the supply if necessary and record the current.
3. If necessary, replace fuses ONLY with ones with the SAME RATING.
4. Notify Mac Mestayer or Amrit Yegneswaran if fuses repeatedly trip.
4.3.2 High Voltage

The high voltage power is supplied by CAEN modules that are arranged as 10 boards of 24 channels each per crate. Three crates power all of the CLAS chambers. The CLAS shift personnel will be required to turn channels ON and OFF, as well as monitoring the system for tripped channels that will require RESETTING.

Although there is NO DANGER OF ELECTROCUTION from these supplies (the maximum output current on a channel is 40 μA) damage to the drift chambers can occur if they are not used properly. Details of how to run the drift chamber control program, DCHV, are contained in the Drift Chamber section of the Operations Manual. The following are the RULES of SAFE OPERATION:

1. In normal operation, it will not be necessary to change the voltage setting. If you must initialize the settings, do not exceed the standard voltage setting as described in the Drift Chamber section of the Operations Manual unless authorized by Mac Mestayer or Amrit Yegneswaran.

2. Do not increase the current trip level setting beyond the nominal value for the target and beam luminosity in question as indicated in the Operations Manual.

3. During extended periods without beam, set the current trip level to the beam-off value as indicated in the Operations Manual.

4. Do not reset a channel more than three times in an hour without consulting Mac Mestayer or Amrit Yegneswaran.

4.3.3 Gas System

The gas used in the drift chambers is a mixture of Argon and Carbon Dioxide. The gas is mixed and filtered and the flow controlled by apparatus located in the gas shed and in Hall B at the gas panel (on deck 2 of the “space frame”). The system is set up such that there are FEW SAFETY ISSUES (to persons or equipment) during operation. The gas mixture is non-flammable, and there is no high-pressure (< 1 bar PSIG) gas within the Hall. The gas pressure in the Hall is high enough to harm the chambers’ gas bags, however.

To guard against harmful pressure excursions, the gas system is designed with two levels of protection: a hardware protection system that will automatically bypass flow to the chambers in the event of a number of error signals (e.g. pressure at the chamber too high or too low) and a software system with looser limits that reports error conditions through an EPICS alarm handler.

During normal operation the shift personnel ONLY need to respond to the ALARM HANDLER. These are the corresponding RULES of SAFE OPERATION:

1. For a minor YELLOW ALARM, acknowledge the alarm handler and note the occurrence in the logbook as described in the Operations Manual.

2. For a major RED ALARM, acknowledge the alarm handler and call or page George Jacobs immediately. Although the system is set up to avoid damage to the equipment, a major alarm may indicate a condition in which the data is corrupted.
4.4 Cerenkov Gas System

This gas system is designed to purge the six Cerenkov detectors, recirculate and filter the radiator gas, and recover the gas for storage. The gases used are Nitrogen, as a purge gas, and Perfluorobutane ($C_4F_{10}$), as the radiator gas. Liquid nitrogen is used as the source of the purge gas and is also used as a coolant for the system’s distillation unit. $C_4F_{10}$ is a very dense, non-flammable, non-toxic, colorless gas with no discernible odor. Its commercial use is as a fire extinguishing agent. $C_4F_{10}$ is easily liquefied and is delivered as a liquid in 25 psig tanks. This system is split between the Hall B gas shed (96B) and the in-hall equipment mounted on the forward carriage. The system features two supply lines and two return lines. The two supply lines deliver nitrogen and $C_4F_{10}$ to the hall. A three-way valve upstream of the flow control valve selects which gas is fed to the detector. The outlet from the each detector is fed to a three-way valve that selects whether the effluent from a detector is directed to the recirculation loop or to the distillation system. Flow rate into each detector is controlled by a mass flow control valve downstream of the three-way supply valve. The mass flow control valves are controlled by a MKS 647B controller in the gas shed control room. Pumps in the gas shed draw the gas from the hall. The system is protected from over- and under-pressure by three systems. The primary system, two electronic pressure controlled proportional valves downstream of each buffer tank, act as pump throttle valves for the recirculation and distillation lines. The second protection is a set of pressure switches that measure the pressure in both buffer tanks. The position of these pressure switches is shown by indicator lights on the door to the by-pass switch box on the second level of the forward carriage. An over-pressure in either tank will shut-off the $C_4F_{10}$ supply in the hall. An under-pressure in either buffer tank will close the solenoid valve in the return line from that tank to the gas shed. The third protection is over- and under-pressure bubblers mounted on the second level of the forward carriage.

4.4.1 System Operation

In normal operation the detectors are brought on-line one at a time. The detectors are purged of air by flowing nitrogen through the detectors. The nitrogen is vented through vent valves in the hall. Caution: The over-pressure pressure switches do not shut-off the nitrogen supply. The nitrogen purge is intended to be used only when the system is manned. After the detector is adequately purged, the flow into the mass flow control valve is switched to the $C_4F_{10}$ supply and the return should be directed to the distillation system. The distillation pump must be turned on before switching the detector to the distillation return line. The $C_4F_{10}$ will be trapped in the distillation unit, the nitrogen will pass through it. When the detector is filled with $C_4F_{10}$, the return line should be switched to the recirculation loop. The recirculation pumps must be turned on before switching the detector to the recirculation line.

4.4.2 Safety Considerations

**Oxygen Deficiency Hazard and Cryogens.** Liquid nitrogen is used as the source of purge gas and is also used as a coolant for the system’s distillation unit. Both of these are supplied from 160 liter dewars that are mounted outside the gas shed. A
small amount of nitrogen and liquid nitrogen passes through gas shed. The gas shed features an active ventilation system. Refer to the Jefferson Lab Safety Manual for information on handling cryogens. The detectors themselves represent a large volume of gas. C$_4$F$_{10}$ is approximately 10 times the density of air. In the event of a catastrophic failure of all six detector windows simultaneously, an ODH hazard would be created to a depth of 2 inches on the floor of the hall. Special attention would be needed for low points within the hall such as the Photon Tagger Beam Dump in the event of such a failure. Refer to the Jefferson Lab Safety Manual for information on Oxygen Deficiency Hazard.

**Window Failure.** The windows of these detectors, front and rear, have a large area and are very thin. They have very little pressure differential tolerance. The high density of this gas creates a significant head pressure within the detectors themselves. In addition, while the pressure safety equipment is as close as possible to the detectors, due to space restrictions, it is not connected directly to the detectors. There is a pressure drop, albeit small, between the detectors and the point where the pressure is measured. This pressure differential increases with flow rate. The large volume of these detectors makes responses to changes in operating conditions very slow. One should not increase flow rates to the detectors unless the detectors can be monitored for several hours afterward to insure a safe equilibrium has been reached at the new flow rate. There are several possible indications that the detectors are in an over- or under-pressure condition. An over-pressure or an under-pressure would indicate a failure in the pressure control systems or too high of a flow rate into the detectors. The possible indications of an out of range pressure are:

1. The pressure read-outs on the buffer tank pressure controllers indicating too high.
2. The displacement of the liquid in the bubblers is too high. (The bubblers can be monitored from a camera mounted on the forward carriage.)
3. The detector windows are either bowed out more than normal or go inward.
4. Any pressure switch indicator light on the forward carriage is off.

**Over- or Under-Pressure Conditions.** Follow these steps if a pressure-control problem is suspected.

1. Check the pressure indicator lights. An over-pressure in either buffer tank will cut off the C$_4$F$_{10}$ gas supply. This can happen if the distillation loop is off-line and the pressure rises in that tank. If this occurs, the buffer tank over-pressure light will be off and all actual flow rates as read at the 647B mass flow valve controller will read zero. To solve this, run the distillation pump for a few minutes to lower the pressure in the buffer tank. The pressure switch will reset and allow gas to flow.
2. Check that the flow rates set on the 647B in the control room are not too high for this system.
3. Check that the pumps are operating.
4. Check that the handles of the three-way valves (supply and return) are fully in the desired position. These valves do have a off position in the center.

**Liquid in the System.** $\text{C}_4\text{F}_{10}$ is easily liquefied, so an effort must be made to insure it does not liquefy where undesired. Of particular importance is the outside tank and the raceway connecting the gas shed to the hall. Both are insulated and heated. One must insure those heaters are operating to prevent the gas from liquefying. If the liquid reaches the mass flow control valves in the hall, unstable operation of those valves will result. There are also heaters upstream of the pumps to prevent liquid incursion into the pumps. The $\text{C}_4\text{F}_{10}$ tanks have both liquid and gas withdrawal ports. The ports are unmarked and they differ in type and position from tank to tank. The regulator must be connected to the gas side only. If the system is connected to the liquid side of the tank, liquid will enter the make up pump, which will cause immediate damage. The only way to insure that the system is connected to the gas side is to slightly open each port to find out if liquid or gas comes out.

**Leak Checks.** This system should be periodically rechecked for leaks. Per the manufacturer of the $\text{C}_4\text{F}_{10}$, Freon leak detectors have a five times increase in sensitivity, relative to Freon, when used with $\text{C}_4\text{F}_{10}$. Several hand held leak detectors are available in the gas shed for this purpose.

## 5 Beamline and Dumps

### 5.1 Tagger Vacuum Window

This section describes the hazards and corresponding safety measures of the Hall B Tagger Vacuum System. The tagging magnet hangs from a steel support gantry in the upstream alcove in Hall B. The Magnet is a C magnet with a 2" gap. A large vacuum tank is welded directly to the magnet steel, giving a total vacuum volume of approximately $0.6 \text{ m}^3$.

The lower surface of the vacuum tank is covered by a thin (less than $20 \text{ mg/cm}^2$) Kevlar-Mylar composite window of width 8 in and length 30 ft. Vacuum is maintained by a 1500 l/s turbo pump at the downstream end of the vacuum tank. The vacuum is continuous with the vacuum in the main hall beam line and with the tagger-dump beam line, which runs from the downstream end of the vacuum box into the floor of Hall B (the tagger beam dump is located beyond the end of this line, approximately 20 ft beneath the floor). The window faces the interior of the tagger hodoscope box, a mesh-walled box about 3 ft by 4 ft in cross section and 40-ft long.

A shutter system, consisting of 24 interlocking plates of 3/16-in-thick aluminum that slide on two Teflon-covered channels, can be inserted immediately outside the window, at a distance of about 1 in from the window frame. This shutter system is intended to protect detectors and personnel in case of a sudden window failure. The shutter plates are inserted and removed by one or two persons standing at the bottom end of the hodoscope box, at a distance of more than 6 ft from the closet point of the window and not in direct line of sight of the window.
5.1.1 Hazards

All potential hazards are due to window implosion. They are

- Being pulled towards the window by rushing air directly after an implosion, and impacting detector structures or the vacuum tank itself.
  
  For example, if an arm were directly across the window, working on a detector, when the window imploded, then that arm could possibly feel a pressure of 15 psi, or perhaps 150 lb pushing it against the hodoscope.

- Ear drum damage and/or hearing loss. Ear damage might result from a pressure wave due directly to the imploding membrane, or to loud noise generated by ringing of the vacuum tank, caused by sudden release of the membrane tension.

Experience among members of the CUA and GWU groups exposed to the noise from imploding membranes identical to the current window and a 10-mil mylar window on a 4-ft-long prototype showed that regular safety ear muffs offer good ear protection even within 3 ft of the failure point. During the failure of the mylar window, an observer approximately 20 ft from the failure experienced no temporary hearing loss even though NOT wearing ear protection. Finally, calculations performed at BNL for a window with larger surface area and volume indicated that people at least one meter from the window would be safe wearing ear protection, and that people 6 m from the window would be safe if unprotected.

5.1.2 Hazard Mitigation

The most important consideration is the very small probability of a window failure. All installed windows are tested with a positive pressure of two atmospheres. In each case the windows are tested three times, for 30 min each time. Thus, installed windows are known to be free of manufacturing defects or weak spots that might cause failure.

Failure due to puncture has been investigated with several prototypes. Even a large puncture, such as from a screwdriver or a knife, will not cause a catastrophic failure (implosion).

Finally, a prototype was kept under vacuum for over a year. Monitoring results show that the Kevlar extension will not reach the manufacturer’s predicted break point for many years.

Given that the installed windows are pre-tested for defects, and that windows with no defects are expected to last for many years, the chance of an implosion during the time when a person is in close proximity is small. One can minimize this probability by minimizing the time spent near the window when it is under vacuum.

Physical damage due to rushing air is not possible unless a body part is very close to the window and the shutter is not installed. Installing the shutter and wearing eye protection to guard against small debris caught in the stream rushing around the shutter edges will eliminate this hazard. Noise and pressure wave hazards are mitigated by ear protection and distance. One also expects the shutter to provide substantial buffering of the pressure wave. Finally, since the window points downward, people above it will see only a reflected pressure wave. This decreases the hazard for people working on Level 2 in the hall or in the tunnel.
5.1.3 Operating Safety Requirements

1. Ear protection is required for people spending more than a few seconds in the following areas when the window is under vacuum:
   
   (a) In the tagger alcove.
   
   (b) In the upstream beam tunnel.
   
   (c) On the floor of Hall B, in the area limited by the tagger racks on the south, the stairs to Level II on the north, and the downstream end of the tagger racks on the west.

2. When working inside the hodoscope box when the window is under pressure, workers will wear ear and eye protection.

3. The shutter will be installed if anyone needs to work inside the box for more than 15 min.

4. The shutter will be installed whenever practical. For example, if beam tests are being performed that will not suffer due to the energy degradation of the electrons passing through the shutter.

5.1.4 Posting Requirements

When the window is under vacuum, signs will be posted in the following areas that say “Caution, tagger window under vacuum, ear protection required for work beyond this point”

1. On the Hall B floor, at the entrance to the area between the tagger racks and the Level 2 access stairs.

2. On the landing of the Level 2 access stairs, at the entrance to the alcove.

3. On Level 2 at the top of the stairs leading to the passageway through the tagger alcove.

4. In the upstream beam tunnel, facing the door passing the upstream shield wall.

When the window is NOT under vacuum, signs saying “Attention: Tagger window is NOT under vacuum, hearing protection NOT required” will be posted at the same locations.

5.2 Tagger Dump and Faraday Cup

Hall B has two beam dumps, the tagger beam dump and the Faraday cup. When the tagger magnet is on, the electron beam is transported to the tagger dump otherwise the beam is to be transported to the Faraday cup. Both dumps are not cooled, and therefore have relatively low power limits. The maximum power that can be deposited into the tagger dump is 1 kW. The maximum power that can be deposited into the Faraday cup is 1 kW. Power near these ratings should not persist for more than one hour. The Faraday cup is located downstream of the last shield wall. This shield wall has a movable lead door that must be in place if
the electron beam is being transported to the Faraday cup. This door has a lock on it so that the area is not accessible during a controlled access. The tagger dump, which is located in the floor underneath the CLAS detector, is not accessible, and the hole in the floor has coverings and railings around it to prevent workers from falling into the hole. The position of the beam at the entrance to the dump can be monitored by a fluorescent screen viewed by a CCTV camera.

5.3 Cryogenic Target

The cryogenic target system was built by Saclay for Hall B electro- and photo-production experiments. It was placed inside CLAS in May of 1997 and operated during commissioning runs during the summer. The target consists of three main separate units:

1. The control rack containing all automated control and readout devices is installed on the Level 2 platform in Hall B.
2. The target chamber with its refrigeration vessel and target cell is attached to the installation cart.
3. The target gas handling system consisting of bottle supplies and two storage tanks (one for H₂ and one for D₂) installed permanently in the hydrogen storage area outside of the Hall, and a small storage tank for ³He located in the electronics rack.

The entire system is powered by a single 3-phase cord plug coming from the rear of the control rack, and a UPS. All valves are operated by compressed air available in the Hall. Permanent gas lines and signal cables run from the outside gas shed to the control rack. From there, transfer lines and signal cables run to the target chamber. All relief valves are connected to a common exhaust line.

The target cell is surrounded by a 120-mm thick Kapton foil. The cell has been tested by cycling it 50 times between normal pressure and vacuum. The target vacuum system is connected upstream of the tagger vacuum, and downstream of the alcove beam pipe vacuum. Fast acting valves will isolate the target in case of increased pressure in either the upstream or downstream volumes. A detailed description and procedures can be found in Appendix A.

5.4 Solid Target

The solid target system, was designed and built at Jefferson Lab. Target holders are mounted on the support rails of the modified scattering chamber. Pneumatic actuators, which operate by compressed air, are used to move targets in and out. Electronics that controls the actuators are designed in to prohibit simultaneous movement of more than one solid target. There is additional software protection against simultaneous movement in the EPICS software to drive the electronics control box. Work of the target movers, control electronics, and the software were tested under the working conditions. The system responded as designed.

Current assembly of the solid target system has three solid target holders and the target foils that are mounted on them are: ¹²C, ⁵⁶Fe, and CH₂. All three targets are positioned and aligned against to the center of the scattering chamber.
6 Operating Procedure for the Hall B Beam Tunnels

There are two tunnels, the upstream tunnel that contains the beam elements that transport the beam to the hall, and the downstream tunnel that contains the elements that transport the beam to the Faraday Cup. At the transition between each tunnel and hall is an alcove. The tunnels present unique work environments.

6.1 Upstream Tunnel

The upstream tunnel under the scope of this document starts at the green shielding wall that separates the accelerator domain from the physics division domain, and continues to the tagger magnet. This region contains both accelerator components and physics division equipment.

6.1.1 Emergency Exits

There are two ways out of the upstream tunnel. The most direct route is to pass the tagger magnet onto level 1 of the space frame and exit the hall. The other route is to go around the green shielding wall and follow the beamline upstream to the Beam Switch Yard and exit there. At each exit there are fire extinguishers in case there is a fire in the tunnel.

6.1.2 Magnetic Fields

The upstream tunnel holds the final focusing quadrupoles and dipole correctors controlled by the accelerator. Also in this region are the Müller raster magnets, Müller quadrupoles, target rasters, and the Tagger magnet. All physics division magnets can be operated while personnel are present in the tunnel. Red flashing beacons will indicate if the magnets are turned on in the tunnel. If any red beacon is on, it is safest to assume that all the magnets are energized. If work is to be done around any magnet in the tunnel, the breaker or power supply for the magnet should be locked and tagged. This will prevent any remote excitation of the magnet. All bus work in the tunnel is not accessible by the casual worker, and the energized magnets pose no safety risks. As a matter of convenience, the casual worker might want to make sure they are not carrying any magnetic credit cards on their possession when working in the tunnel. Care should be taken not to work with magnetic material near the magnets when they are or can be energized.

6.2 Downstream Tunnel

The downstream tunnel begins after the downstream alcove and continues to the end of the tunnel. Located in this tunnel are several beam diagnostic devices maintained by Hall B. The downstream tunnel also holds the beam dump, which for Hall B is a Faraday Cup. Background from the Faraday cup is blocked by two shielding walls, the first shielding wall is at the entrance to the tunnel, and the second shielding wall is after the beam diagnostic equipment but upstream of the Faraday cup. This second shielding wall has a removable lead door that is locked shut during data taking.
6.2.1 Emergency Exits

Since the downstream tunnel terminates at the end of the tunnel or at the second shielding door if it is locked, there is only one way out of the downstream tunnel. It is recommended that all workers in this area follow a two man rule since the area is not visible from outside of the tunnel. All workers in the tunnel should have a working flashlight in case of power failure.

6.2.2 Magnetic Fields

The pair spectrometer magnet can be powered while personnel are in the tunnel. There is no exposed bus and no risk to personnel when this magnet is excited. Care should be taken not to work with magnetic material near the magnet when it is or can be energized.

6.2.3 Confined Space

The region beyond the exhaust tube in the tunnel downstream of the Faraday cup is classified as a confined space and any entry into this region requires a written Confined Space Work Permit before entering.
A Hall B Cryogenic Target

A.1 Description of the Overall Procedure

The $^4$He that is used as a cooling refrigerant is delivered by the helium buffer dewar located on the deck next to the target. The target cell can be filled with LH$_2$, LD$_2$, L$^3$He, or L$^4$He. When not in use, the target is filled with nitrogen.

A.1.1 Operational Procedure

All of the procedures to run the target are performed by an industrial control system. Each procedure corresponds to a button on the menu screen on the control PC. They have to be performed in the order listed below. Hereafter, we give a short summary of the procedures. The detailed list can be found in the CLAS Cryo-Target Expert Manual that is available in the Hall B Counting House.

**Conditioning of the Refrigeration Circuit and Leak Test.** First, the refrigeration circuit gets pumped down and tested for leaks. Then it is rinsed three times with $^4$He drawn from the helium buffer dewar, and then gets filled with $^4$He at a pressure of 1050 mb, and again leak tested. If everything checks out, it is then disconnected from the helium buffer dewar by closing valve FCV.LHE. The valve to the warm return line, FC.RECUP, is always open.

**Gas Choice.** Open manual valves MV.D2T (MV.H2T) and MV.H2D2T.

**Conditioning of the Target Circuit.** The target gets pumped out using pumps VPT, VPS, and VST (the prerequisite is that the vacuum chamber is pumped out, if not, the target cell will break), and leak tested. Pumping proceeds until the process called “target conditioning” is stopped by the user. A vacuum of $3 \times 10^{-2}$ mb is acceptable.

**Cooldown of the Refrigeration Unit.** During this process, the cryostat is filled with L$^4$He drawn from the helium buffer dewar, and the whole refrigeration circuit is cooled down. At the end, the cryostat is 85% full, and the target has reached a temperature of about 50 K. The process “cryostat regulation” will refill the cryostat each time the level falls below 20%.

**Cooldown and Filling the Target.** Once the cryostat is full, the condenser and the screens get cooled down. Heaters are turned on as needed to regulate their temperature. When the condenser is cold enough, the gas in the target circuit starts cooling further, and the pressure in the tanks drops. Heaters in the condenser avoid getting below 19 K when H$_2$ or D$_2$ gas is used. Level sensors indicate when the target is full.

**Regulation of the Target Temperature.** Both a LakeShore regulator, acting on a heater located in the condenser, and a PID program acting on the opening of the Joule Thompson valve, serve to stabilize the target temperature.
Heating the Target. Once the experiment is finished, the heaters are switched on to warm up the target, and the gas flows back into the tank. When the target is at room temperature, the manual valves MV_D2S and MV_D2T are to be closed.

Filling the Target with Nitrogen. The last operation is to empty the target circuit from its gas, and to replace it with nitrogen. The automated process “N2 target” pumps out the target circuit (manual valve MV_H2D2T must be open). Then the pump is stopped, and the operator has to open the nitrogen bottle and to introduce 1120 mb in the target circuit and in the vacuum chamber. Once this pressure is reached, the process closes all of the valves.

A.2 Identification of Potential Hazards

Two H$_2$/D$_2$ gas detectors are installed, one above the right hand side of the electronics rack and another above the cryostat. In case of a detected leak, the control system will immediately warm up the whole system and empty the target cell. Relief valves installed in parallel with all the remote control valves ensure that the safety system is entirely passive.

In case of an increased pressure in the vacuum chamber, the cryotarget controller will stop all vacuum pumps on the cryotarget, close the valve FV_D2T (FV_H2T) and all $^4$He valves. Additionally an alarm will sound in the Hall B Counting House. The volumes upstream and downstream of the cryotarget are protected separately: the turbo pump on the tagger magnet will shut off when its speed drops below 90% of its nominal value (around $10^{-3}$ Torr), and vacuum valve will close. This will isolate the target in case of hydrogen/deuterium escaping into the beamline vacuum system.

Two kinds of leaks can occur, described as “Internal” (target cell failure) or “External” (vacuum chamber of $^4$He failure). To know if it is an internal or external leak, one has to examine the pressure in the tank PT_D2S (or PT_H2S).

- $PT_{D2S}$ (or $PT_{H2S}$) $\approx$ 1.5 bar: External Leak. The liquid D$_2$ (or H$_2$) has vaporized and has returned to the tank; the pressure is roughly the nominal pressure of $\approx$1.5 bar.

- $PT_{D2S}$ (or $PT_{H2S}$) $\approx$ 1 bar: Internal Leak. The liquid has vaporized in the vacuum chamber and the pressure in the tank is $\approx$1 bar.

In case of an external leak, no prompt action has to be taken. This will leave the target filled with $\approx$0.5 l of D$_2$ (or H$_2$) gas. In the case of an internal leak, $\approx$500 l of D$_2$ gas is left in the vacuum chamber, and the operator then has to remove the gas. In front of the control rack there is a panel with a key. The operator has to turn the key in the lock to 1, then in the lock 2 to open the valves FV_PS and FV_VP. The VPS pump then starts and empties the chamber through the exhaust line.

Some brief notes with regards to safety:

- The target cell cannot explode. If there is a D$_2$ (or H$_2$) air mixture in the target circuit during the cooling procedure, due to a safety interlock, the target will never be filled.
• The Saclay controller is set up to detect increased pressure in the vacuum space. Should that happen, all vacuum pumps are automatically shut down, supply valves are closed, and an alarm will sound in the Counting House. An explosion-proof pump located outside is used to manually pump out the trapped gas volume. In addition, there are Accelerator Division installed gauges in place that close the fast beam line valves upstream of the target in case of a target rupture (senses increased pressure in the vacuum space). There are also flammable gas leak detectors located in the bore of the torus and the gas control panel that close the beam line and gas supply valves. That system is tested periodically.

• There is a mylar pipe around the target that holds the aluminized Kapton superinsulation. If there is a leak from the target cell, this pipe allows the liquid to flow down to the aluminum pipe shielding, where it vaporizes. In this case, the pressure will rise due to cold gas in the vacuum chamber, and the carbon fiber pipe will freeze around the pipe, but there is no shock wave and no hazard that can induce severe damage.

• The area around the target is restricted to authorized and escorted personnel only, and no hot work on Level 2 and 3 should be done.

B CLAS Calibration Lasers

B.1 Detectors and Environment

The highest level of the forward carriage in Hall B contains two identical class-3b lasers used for calibrating equipment for the CLAS detector. The lasers are used to provide light sources for photomultiplier tubes of the CLAS Time-of-Flight (TOF) and calorimeter systems. The locations of the lasers on the forward carriage are shown schematically in Fig. 3. Three additional lasers for calibration of the TOF scintillators are located on the north clam shell, south clam shell, and space frame. All laser setups are similar, so the same precautions must be taken for each. This section gives a description of the lasers, the hazards present, requirements for personnel, and procedures for operation.

B.2 Authorized Personnel

Daniel Carman is the Hall B Laser System Supervisor and no work shall be done on this system unless authorized by him. The lasers may only be operated by personnel that have:

• Completed a laser safety course administered by the safety officers at JLab.

• Read the Laser Safety section of the EH&S Manual (6410);

• Completed and passed an ophthalmological exam that has been reviewed and approved by the JLab occupational health physician;

• Sign list of authorized operators.
JLab personnel or outside visitors who have not completed the required training, may enter the laser control area under the following conditions:

- Use required safety glasses (see below);
- Be accompanied by a laser operator;
- Keep out of beam path.

or when

- Lasers are setup for calibration under Class-1 conditions.

Figure 3: Locations of the lasers in Hall B on the forward carriage, south clam shell, north clam shell, and space frame.

B.3 Laser

Table 5 lists the characteristics of the Laser Photonics LN203C Nitrogen laser.
Table 5: Specifications for Photonics LN203C nitrogen laser.

<table>
<thead>
<tr>
<th>Specification</th>
<th>LN203C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral Output</td>
<td>337.1 nm</td>
</tr>
<tr>
<td>Spectral Bandwidth</td>
<td>0.1 nm</td>
</tr>
<tr>
<td>Pulse Width (FWHM)</td>
<td>600 ps</td>
</tr>
<tr>
<td>Energy/pulse</td>
<td>100 mJ</td>
</tr>
<tr>
<td>Energy Stability</td>
<td>3%</td>
</tr>
<tr>
<td>Maximum Average Power</td>
<td>5.0 mW</td>
</tr>
<tr>
<td>Maximum Repetition Rate</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Beam Dimensions (hor x ver)</td>
<td>5.5 x 3.1 mm²</td>
</tr>
<tr>
<td>Beam Divergence (hor x ver, half angle)</td>
<td>6.2 x 2.5 mrad²</td>
</tr>
<tr>
<td>Gas Consumption (99.995% pure N₂)</td>
<td>1 l/min @ 10 Hz</td>
</tr>
<tr>
<td>Dimensions</td>
<td>28.5 x 8.5 x 5.25 in³</td>
</tr>
<tr>
<td>Weight</td>
<td>20 lbs</td>
</tr>
</tbody>
</table>

B.4 Hazards

B.4.1 Laser Beam Hazards

Class-1 eye-safe laser conditions exist except during alignment procedures. During alignment procedures, the primary beam hazard associated with class-3b lasers consists of eye injury caused by viewing the beam either directly or by specular reflection. 99% of the laser light (337 nm) entering the eye is absorbed in the cornea, aqueous, and lens. The primary adverse effect from accidental viewing is the production of cataracts. To minimize the laser beam hazard associated with alignment procedures,

- supplied laser safety goggles must be worn;
- laser shroud must be placed between the access to the work area and the laser beam. The laser is not a fire hazard, so any UV absorbing material would suffice. A dark cloth is used to cover the area where laser light could escape.

B.4.2 Non-Beam Hazards

The following non-beam hazards exist:

- trip/fall: access to several of the CLAS nitrogen lasers is limited to an extension ladder. To minimize hazards associated with the use of the ladder:
  - All personnel must wear safety shoes
  - One person on the ladder at a time

Nothing is to be carried up the ladder. Anything that is to be brought up to the laser work area must be lifted up. Small items can be lifted with a rope.
• bump hazard: To minimize the bump hazard associated with the use of the extension ladder, post a danger sign on the ladder noting the hazard and the requirement for a hard hat.

• electric shock: If interlocks are bypassed and high voltage is exposed, there is potential for electric shock. No interlocks are to be bypassed, except by qualified service representatives.

• Fire: a portable fire extinguisher is located in the work area.

• Lighting: Most of the emergency lighting for the Hall is located at lower levels and would not be of benefit in the event of a power outage; a standby flashlight is needed.

B.5 Laser Environment

The locations of the LN203C nitrogen lasers are shown in Fig 3. During normal operation, the laser beam is extracted via a fiber bundle array. These measures prevent unintentional interception of the beam, either directly or by specular reflection. Under special circumstances, detailed below, the laser beam is exposed, and precautionary measures must be taken. The laser light is confined to the RF-shielding box except during alignment. During alignment, the light is confined by draping a laser shroud over the end of the Plexiglas fiber-optic box. Before laser work begins, personnel should make sure that they have a clear path to an exit.

B.6 Remote Control and Operation

The laser can be remotely controlled during routine operation by using specifically designed circuits for the laser. The remote functions including power, pulse rate, enable, and disable functions that can be used to automatically shut down operation in case of emergency. An emission time delay is built into the remote control: the yellow beacon energizes when the laser power is turned on, and lasing is delayed by 5 minutes. Once the laser yellow beacon is energized, goggles must be worn.

B.7 Procedures

In this section we review the various procedures that are required to operate the laser. Hazards are least likely to occur during normal operation. During maintenance and alignment, the laser box is open and beam and non-beam hazards are present. The manual for the LN203C laser details installation (Section III), normal operation (Section IV), maintenance (Section V), and trouble-shooting (Section VI) of the laser.

When working with the lasers, the personnel must not wear jewelry or clothing that can present a specular reflection hazard. Protective eye wear must be worn with a minimum optical density OD = 1.4 at 337 nm. Safety UV-absorbing glasses that meet this requirement are available in the immediate area of each laser.
B.8 Maintenance and Initial Alignment

For laser alignment and some maintenance operations, the RF-shielding box is open, the on/off switch is activated, the N₂ gas flow rate is adjusted, and the warm-up period is initiated. To prevent optical hazards, the beam stop should remain closed for this operation except during the initial alignment period. Standard electrical hazard prevention procedures should be followed. To minimize optical hazards, no one will be allowed in the laser control area except trained and qualified personnel who are wearing UV-absorbing safety glasses.

B.9 Scintillator Calibration (Class-1 Conditions)

The laser beams are directed to fiber bundle arrays at the exit of the RF-shielding boxes. The fibers in the bundle are connected to the TOF scintillators or directed to scintillators on the calorimeters. Under these circumstances, the lasers shall be considered to pose a Class-1 hazard, as no portion of the beam is exposed.

B.10 Controls

The laser control area will be posted with a danger sign describing the tests being conducted. The key that turns the laser on shall be kept separate when the laser is not in use, to avoid unintentionally enabling operation. Eye-wear is provided and shall be used during maintenance, alignment, and any activity that allows viewing of the laser beam. A high voltage safety cover interlock is located on the rear panel of the laser. Removal of the top access panel is required for servicing and will automatically break the interlock. Any interlock interruption will require the high voltage enable switch to be re-engaged to resume operation.

B.11 MPE Calculations

We calculate the optical density, \( D_\lambda \), of protective eye wear required for laser operation assuming the laser is continuous. The optical density is given in terms of the radiant exposure, \( H \), and the maximum permissible exposure, MPE, by:

\[
D_\lambda = \log \left( \frac{H}{\text{MPE}} \right),
\]

\[
H = \frac{4E_p N}{\pi a^2},
\]

\[
\text{MPE} = 0.56 \times \left( \frac{N}{f} \right)^{1/4},
\]

where \( a \) is the limiting aperture (1 mm), \( f \) is the maximum operating frequency (50 Hz), \( E_p \) is the maximum energy per pulse (100 mJ), and \( N \) is the number of pulses (frequency times observation time). With these parameters we calculate that:

\[
D_\lambda = -1.22 + \frac{3}{4} \log N
\]
For an observation time of 10 s, \( N = 500 \) and \( D_\lambda = 0.8 \). For an observation time of 1 min, \( N = 3000 \) and \( D_\lambda = 1.4 \).

Next, an MPE was calculated using the pulse width as exposure time as directed by Dr. John Leonowich, a consultant for JLab. This calculation yielded a required O.D. of 1.23. We use the more conservative estimate of 1.4.

\(^2\text{John Leonowich, Battelle Laboratories engineering worksheet, Feb. 2, 1995.}\)