Experiment Safety Assessment Document (ESAD)
for
The Proton Charge Radius Experiment

October 30, 2015

Contents

Chapter 1

Introduction

This ESAD document describes identified hazards of the PRad experiment and the measures taken to eliminate, control, or mitigate them. This document is part of the CEBAF experiment review process as defined in Chapter 3120 of the Jefferson Lab EHS&Q manual, and will start by describing general types of hazards that might be present in any of the JLab experimental halls. The document then addresses the hazards associated with all the experimental sub-systems of Experimental Hall B and PRad and their mitigation. Responsible personnel for each item is also noted. In case of life threatening emergencies call 911 and then notify the guard house at 5822 so that the guards can help the responders. This document does not attempt to describe the function or operation of the various sub-systems. Such information can be found in the experimental hall specific Operating Manuals.

Chapter 2

General Hazards

2.1 Radiation

CEBAF's high intensity and high energy electron beam is a potentially lethal direct radiation source. It can also create radioactive materials that are hazardous even after the beam has been turned off. There are many redundant measures aimed at preventing accidental exposure to personnel by the beam or exposure to beam-associated radiation sources that are in place at JLab. The training and mitigation procedures are handled through the JLab Radiation Control Department (RadCon). The radiation safety department 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 (Vashek Vylet) can be reached as follows: Office: 269-7551, Cell: 218-2733 or Home: 772-6098.

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

2.2 Fire

The experimental halls contain numerous combustible materials and flammable gases. In addition, they contain potential ignition sources, such as electrical wiring and equipment. General fire hazards and procedures for dealing with these are covered by JLab emergency management procedures. The JLab fire protection manager (Dave Kausch) can be contacted at 269-7674.

2.3 Electrical Systems

Hazards associated with electrical systems are the most common risk in the experimental halls. Almost every sub-system requires AC and/or DC power. Due to the high current and/or high voltage requirements of many of these sub-systems they and their power supplies are potentially lethal electrical sources. In the case of superconducting magnets the stored energy is so large that an uncontrolled electrical discharge can be lethal for a period of time even after the actual power source has been turned off. Anyone working on electrical power in the experimental Halls must comply with Chapter 6200 of the Jefferson Lab EHS&Q manual and must obtain approval of one of the responsible personnel. The JLab electrical safety point-of-contact (Todd Kujawa) can be reached at 269-7006.

2.4 Mechanical Systems

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

Use of ladders and scaffold must comply with Chapter 6231 of the Jefferson Lab EHS&Q manual. Use of cranes, hoists, lifts, etc. must comply with Chapter 6141 of the Jefferson Lab EHS&Q manual. Use of personal protective equipment to mitigate mechanical hazards, such as hard hats, safety harnesses, and safety shoes are mandatory when deemed necessary. The JLab technical point-of-contact (Suresh Chandra) can be contacted at 269-7248.

2.5 Strong Magnetic Fields

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

2.6 Cryogenic Fluids and Oxygen Deficiency Hazard

Not applicable for this experiment.

2.7 Vacuum and Pressure Vessels

Vacuum and/or pressure vessels are commonly used in the experimental halls. Many of these have thin Aluminum or kevlar/mylar windows that are close to the entrance and/or exit of the vessels or beam pipes. These windows burst if punctured accidentally or can fail if significant over-pressure were to exist. Injury is possible if a failure were to occur near an individual. All work on vacuum windows in the experimental halls must occur under the supervision of appropriately trained JLab personnel. Specifically, the scattering chamber and beam line exit windows must always be leak checked before service. Contact Will Oren 269-7344 for vacuum and pressure vessel issues.

2.8 Hazardous Materials

Hazardous materials in the form of solids, liquids, and gases that may harm people or property exist in the JLab experimental halls. The most common of these materials include lead, beryllium compounds, and various toxic and corrosive chemicals. Material Safety Data Sheets (MSDS) for hazardous materials in use in the Hall are available from the Hall safety warden. These are being replaced by the new standard Safety Data Sheets (SDS) as they become available in compliance with the new OSHA standards. Handling of these materials must follow the guidelines of the EH&S manual. Machining of lead or beryllia, that are highly toxic in powdered form, requires prior approval of the EH&S staff. Lead Worker training is required in order to handle lead in the Hall. In case of questions or concerns, the JLab hazardous materials specialist (Jennifer Williams) can be contacted at 269-7882.

2.9 Lasers

Not applicable for this experiment.

Chapter 3

Hall Specific Equipment

3.1 Overview

The following Hall B subsystems are considered part of the experimental endstation equipment for running the Proton Charge Radius (PRad) experiment engineering run. Many of these subsystems impose similar hazards, such as those induced by high voltage systems and vacuum systems. Note that a specific sub-system may have many unique hazards associated with it. For each major system, the hazards, mitigations, and responsible personnel are noted.

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

3.2 Checking Tie-in To Machine Fast Shutdown System

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

3.3 Beamline

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

The beamline in the Hall provides the interface between the CEBAF accelerator and the experimental hall. All work on the beamline must be coordinated with both physics division and accelerator division in order to ensure safe and reliable transport of the electron beam to the dump.

3.3.1 Hazards

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

3.3.2 Mitigations

All magnets (dipoles, quadruples, sextuples, beam correctors) and beam diagnostic devices (BPMs, scanners, beam loss monitors, viewers) necessary to transport and monitor the beam are controlled by Machine Control Center (MCC) through EPICS [1], except for specific elements which are addressed in the subsequent sections. The detailed safety operational procedures for the Hall B beamline should be essentially the same as the one for the CEBAF machine and beamline.

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

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

These hazards are noted by signs and the most hazardous areas along the beamline are roped off to restrict access when operational (e.g. around the PRad target area). Signs are posted by RadCon for any hot spots. Survey of the beamline and around it will be performed before work is done on the beam line or around. The connection of leads to magnets have plastic covers for electrical safety. Any work around the magnets will require de-energizing the magnets. Energized magnets are noted by read flashing beacons. Any work on the magnets requires the "Lock and Tag" procedures [2].
Additional safety information is available in the following documents:

– EH&S Manual [2];
– PSS Description Document [3]
– Accelerator Operations Directive [4];

3.3.3 Responsible Personnel

The beamline requires both accelerator and physics personnel to maintain and operate. It is very important that both groups stay in contact with each other to coordinate any work on the Hall B beamline. The authorized personnel is shown in table 3.1.

Name (first,last)	Dept.	Call [5]		e-mail	Comment
		Tel	Pager		
F.-X. Girod	Hall-B	6002		fxgirod@jlab.org	*1st Contact*
Stepan Stepanyan	Hall-B	7196		stepanya@jlab.org	*2nd Contact*
Michael Tiefenback	Accel.	7430	757-438-4523+	tiefen@jlab.org	*Contact to Hall-B*
Hari Areti	Accel.	7187	584-	areti@jlab.org	*Contact to Physics*

Table 3.1: Hall B beamline: authorized personnel.

3.4 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.

3.4.1 Hazards

The tagger magnets can present magnetic and electrical hazards when they are energized. The power supplies are potentially lethal electrical sources.

3.4.2 Mitigations

There are plastic covers on the connection panels for power leads on the magnets for electrical safety. Any work around the magnets will require de-energizing the magnets. Energized magnets are noted by red flashing beacons. Any work on the magnets requires a "Lock and Tag" procedure [2]. There will be beacons installed to notify when magnetic field is present. The magnet power supplies will be interlocked to the beam shutdown system (FSD). If any of power supplies will trip, beam delivery to Hall B will be interrupted.

3.4.3 Responsible Personnel

The tagger magnets will be maintained by the Hall B engineering group. The authorized personnel is shown in table 3.2.

Name (first,last)	Dept.	Call [5]		e-mail	Comment
		Tel	Pager		
Tech-on-Call	Hall-B				*1st Contact*
Doug Tilles	Hall-B	7566		tilles@jlab.org	*2nd Contact*

Table 3.2: Hall B beamline: authorized personnel.

3.5 PRad Target System

The PRad target system consists of a thin windowless cell hung from a linear feedthrough. Target position is remotely adjustable vertically allowing it to be inserted into the beam.

3.5.1 Hazards

There are hazards related to moving the target frame into the beam or overheating the target foils. The stepping motor linear actuator will be operated using EPICS controls. The GUI for operation of the target will have preset coordinates for each target foil. The tungsten targets are intended to operate with beam currents up to 500 nA, which produce strong local heating. The strength of tungsten drops by an order of magnitude with temperature increases in the range of 1000 C. In addition, the material re-crystallizes above this range, which increases the tendency for cracking where thermal expansion has caused temporary dimpling.

3.5.2 Mitigations

There will be limit switches (hard stops) that will prevent the motion of the target ladder outside of allowed range if EPICS set values are wrong. To keep the temperature rise less than about 1000 degrees, we adjust the optics to produce an adequately large beam spot and limit the maximum current incident on the target. There will be overall beam current limit of 500 nA for the experiment.

3.5.3 Responsible personnel

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

Name	Dept.	Phone	email	Comments
Tech-on-call	Hall-B			1st contact
D. Tilles	Hall-B		tilles@jlab.org	2nd contact
C. Keith	JLab Target Group		ckeith@jlab.org	contact

Table 3.3: Personnel responsible for the target.

3.6 Vacuum Systems

The Hall B vacuum system consists of three segments, all interconnected. The beam transport line consisting of 1.5 to 2.5 inch beam pipes, the Hall B tagger magnet vacuum chamber, and for the PRad experiment a large ∼5m long vacuum chamber extending from the target to the PRad detector system. There is a 1.7m diameter 63 mil Al. window at one end of the vacuum chamber, just before the PRad detectors. The tagger vacuum chamber also has a large window, 8 inches over 30 ft Kevlar-Mylar composite window. The vacuum in the system is provided by a set of rough, turbo, and ion pumps and it is maintained at the level of better than 10^{-5} Torr.

3.6.1 Hazards

Hazards associated with the vacuum system are due to rapid decompression in case of a window failure. Loud noise can cause hearing loss. Also, there is a hazard related to the GEM chamber being sucked into the vacuum chamber in case of an accidental puncture of the vacuum window.

3.6.2 Mitigations

All personnel working in the vicinity of the tagger vacuum chamber window and the PRad vacuum chamber window are required to wear ear protection. Warning signs must be posted in those areas. All personnel working in the vicinity of the PRad vacuum chamber will also be required to wear safety glasses. To mitigate a possible window failure and/or accidental puncture, when not under vacuum the PRad vacuum window will be covered with a plastic protective cover. When under vacuum the adjoining area will be roped off and additional warning signs limiting access will be posted.

3.6.3 Responsible personnel

The vacuum system will be maintained by the Hall B engineering group. The authorized personnel is shown in table 3.4.

Name (first,last)	Dept.	Call [5]		e-mail	Comment
		Tel	Pager		
Tech-on-Call	Hall-B				*1st Contact*
Doug Tilles	Hall-B	7566		tilles@jlab.org	*2nd Contact*

Table 3.4: Hall B beamline: authorized personnel.

3.7 GEM Tracker

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

3.7.1 Hazards

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

3.7.2 Mitigations

Hazards to personnel are mitigated by turning off HV and LV power before disconnecting cables or working on the chambers and internal electronics.

3.7.3 Responsible personnel

Individuals responsible for the system are:

Name	Dept.	Phone	email	Comments
Kondo Gnanvo	UVa			First contact
Nilanga Liyanage	UVa			2nd Contact
Krishna Adhikari	MSU			3rd Contact

Table 3.5: Personnel responsible for the GEM tracker.

3.8 Electromagnetic Calorimeter

The Electromagnetic Calorimeter (HYCAL)will be located approximately 7.4m (run configuration) or 8.7m (calibration configuration) upstream of the center of the CLAS12. It consists of 1700 lead glass and lead tungstate detector modules, each with photomultiplier tubes with readout enclosed inside a temperature controlled enclosure. Each module is supplied with high voltage and is equipped with readout of dynode and anode signals. In addition, an LED based light monitoring system is used to deliver a pulse of light to each module via a fiber optic cable. The HYCAL will sit in two positions along the beamline. In the run configuration HYCAL will sit on a stationary cart, and in the calibration configuration it will be mounted on a transporter which will enable motion in the horizontal and vertical directions. The detector has overall dimensions of 1.5m 1.5m and will be centered on the beamline during production data taking. A 4cm 4cm hole at the center of the detector will allow the passage of the primary electron beam to the beam dump. Additionally, a Total Absorption Counter (TAC) will be placed approximately 1m downstream of the HYCAL (when it is in run position). These will be placed on a common cart which has the capability of moving them in and out of the beam with horizontal motion.

3.8.1 Hazards

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

3.8.2 Mitigations

Whenever any work has to be done on the calorimeter, whether it will be opened or not, HV and LV must be turned off. Turn chiller off if enclosure will be opened for maintenance. Any large (more than couple of degrees in C) must be investigated to make sure that there are no leaks.

3.8.3 Responsible personnel

Name	Dept.	Phone	email	Comments
A. Gasparian	NC A&T		gasparan@jlab.org	1st contact
E. Pasyuk	Hall-B		pasyuk@jlab.org	2nd contact

Table 3.6: Personnel responsible for HYCAL.

The authorized personnel is shown in table 3.6.

3.9 CLAS12 Construction work

The main 12 GeV activity in Hall-B during the PRad run will be assembly of the CLAS12 Torus magnet. Beam running would occur during evenings, nights, and weekends or during other periods when it would not conflict with the regularly scheduled assembly of the CLAS12 Torus coils.

3.9.1 Hazards

There are no personal hazards associated with the running over evenings, nights, and weekends, and continue with torus assembly during the normal work hours. The only hazard is possible delays of start of the torus work after beam the delivery due to possible activation of beamline parts close to the torus assembly fixtures.

3.9.2 Mitigations

Every time Hall will switch from beam running to torus assembly, a fully survey of the hall will be conducted and Hall will be brought to "Restricted Access". Normally this will happen very early in the morning of work day (6am). If elevated radiation near torus assembly fixtures are found, work on torus must be delayed until conditions are acceptable.

However, we do not expect any excess radiation in the Hall or activation of any beam line components near the torus assembly area. The PRad target is located ~ 10 meters upstream of the assembly area and it is a very thin gas flow target. Only tuned electron beam with less than 10 nA current, will be transported in vacuum through hall to the target. If beam conditions are not acceptable, which may result excess radiation, beam tune will be performed. Every time beam tune is required the Hall-B tagger magnet will be energized and beam will be dumped on the Hall-B tagger dump, shielded hole in the floor ~ 15 meters upstream of the torus assembly area.

3.9.3 Responsible Personnel

Individuals responsible for the coordination of the torus assembly and PRad run:

Name	Dept.	Phone	email	Comments
PDL	Hall-B			1nd contact
E. Pasyuk	Hall-B		pasyuk@jlab.org	contact
D. Kashy	Hall-B		Kashy@jlab.org	contact

Table 3.7: Personnel responsible for coordination of the PRad run and the torus assembly.

Chapter 4

PRad Specific Addendum

4.1 Running Conditions

The PRad experiment will perform a high precision measurement of the proton charge radius. The energy of the electron beam will be 1.1 GeV and 2.2 GeV, the beam current for production running 10 nA. A photon radiator of thickness 10^5 radiation lengths will be used at currents of 0.1 nA. A very thin hydrogen gas flow target with a thickness of 10^{18} atoms/cc will be placed in the electron beam. These targets will be located approximately 15m upstream of CLAS12 center. The CLAS12 will not be used for this experiment. A multichannel calorimeter, the HYCAL, will be located approximately 7.4m (run configuration) or 8.7m (calibration configuration) upstream of the center of the CLAS12. It consists of 1700 lead glass and lead tungstate detector modules, each with photomultiplier tubes. Each module is supplied with high voltage and is equipped with readout of dynode and anode signals. In addition, an LED based light monitoring system is used to deliver a pulse of light to each module via a fiber optic cable. There will be a pair of GEM chambers for charged particle tracking on the upstream side of the HYCAL. The HYCAL will sit in two positions along the beamline. In the run configuration HYCAL will sit on a stationary cart, and in the calibration configuration it will be mounted on a transporter which will enable motion in the horizontal and vertical directions. The detector has overall dimensions of 1.5m 1.5m and will be centered on the beamline during production data taking. A 4cm 4cm hole at the center of the detector will allow the passage of the primary electron beam to the beam dump. Additionally, a Total Absorption Counter (TAC) will be placed approximately 1m downstream of the HYCAL (when it is in run position). These will be placed on a common cart which has the capability of moving them in and out of the beam with horizontal motion. This experiment requires a standard operation condition for the photon tagging system.

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[5] Jefferson Lab, (12000 Jefferson avenue, Newport News, VA 23606). URL http://www.jlab.org. Telephone numbers: (757)-269-XXXX, Pager numbers: (757)-584-XXXX. 9, 10, 12