HYCAL manual

March 14, 2016

1 HYCAL Overview

The PRAD Collaboration will perform a high precision *ep* elastic cross sections measurement at very low four-momentum transfer squared, Q^2, from 10^{-4} to 10^{-2} (GeV/c)^2 range using a high resolution calorimeter and a novel windowless cryo-cooled hydrogen gas flow target of thickness $t \sim 1 \times 10^{18}$ hydrogen atoms/cm^2 in Hall B of Jefferson Laboratory. The energies of the electron beam will be 1.1 GeV and 2.2 GeV at a beam current of about 10 nA for production running. The high precision differential cross sections, measured for the first time in this low Q^2 range, will allow a sub-percent and essentially model independent extraction of the proton charge radius.

A multichannel calorimeter, the HYCAL, will be located approximately 7.0 m downstream of the targger magnet. It consists of 1700 lead glass and lead tungstate detector modules, each with photomultiplier tubes. Each module is supplied with high voltage (1100V to 1500V, drawing up to 0.3 mA) and is equipped with readout of dynode and anode signals. Normal operation of the HYCAL will require the doors be interlocked with the high voltage supply system. In addition, an LED based light monitoring system is used to deliver a pulse of light to each module via a fiber optic cable. HYCAL is contained in an enclosure which will seal it both thermally and optically from the surrounding environment. The enclosure has been constructed with access doors on the rear. 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 1.5 m$\times$1.5 m and will be centered on the beamline during production data taking. A 2×2 $PbWO_4$ modules removed at the center of the detector will allow the passage of the primary electron beam to the beam dump.

2 HYCAL High Voltage System

The executable "pradHV" which is used to control the HYCAL high voltage is under password protection. There are separate passwords to log in as an Administrator with full read/write access, User with limited read/write, and as a guest with only read privileges. We will use the Admin configuration during commissioning to calibrate the gains on each of the 1700 HV channels. We will then switch to a specially configured "user" mode for the physics run.

As it is extremely important that the voltages not be inadvertently changed, the Admin password will be restricted to only a few people qualified to change HYCAL HV settings. These people are the expert shift takers.

There is a built in crate definable High Voltage limit that can be set across a whole board. In principle, this can prevent too high of a voltage being placed on a PMT and thus damaging it. However, we are unable to use this feature due to the mixing of lead glass and lead tungstate detectors on the same board. The maximum voltage for a lead tungstate is simply too low for the lead glass PMTs to function. Therefore, a software limit has been implemented. This safeguard is based on our naming convention for our detectors. All channels with a "W" as the first letter of their name have a maximum writable voltage of 1300 V. Lead glass is similarly protected. The light monitoring system voltages will also be protected in this manner. As long as this naming convention is respected and any changes registered with the maintainers of the code, this protection should be adequate.

The CAEN SY1527 universal multichannel power supply system is interlocked to the door, moisture, and chiller interlocks. If an interlocked door is opened, moisture detected, or if the chiller is disabled, the HV is shut down. This prevents damage to the PMTs (w.r.t. the first two interlocks) and prevents rapid heating of the interior of HYCAL (w.r.t. the last interlock), which are vital to the health of the lead tungstate.

HV_status_mon: A (separate from "pradHV") status monitoring program will query all channels every 30 seconds regarding trip, over/under voltage conditions, disconnections, disabled, overcurrent and power on/off status. Errors will be written to a file local to the Linux machine running "pradHV" and to either or both the CVS repository or to the PRAD website for archival and online purposes.

2.1 HYCAL Electrical Hazards and mitigation

One of safety considerations for this experiment involves large number of high voltage channels for HYCAL PMTs.

Although there are no large, exposed terminals inside of HYCAL carrying high voltage, there are solder points which one could come in contact with if sufficient care is not taken. The solder points are on the back of the vertically mounted printed circuit boards (VPCB) accessed from the back of HYCAL.

The PMT high voltage supplies providing power to the internal HYCAL detectors are CAEN 1932A high voltage distributor cards. These cards can supply a maximum current of 0.5 mA per channel. This is only slightly less than the 0.6 mA required for a "slight sensation" as described in section 6210 of the JLab EH&S manual. The largest risk of injury is likely from an instinctual reaction should someone feel such a sensation. Work on HYCAL detectors will require the worker to stand on a stool or platform 1 to 2 feet off of the ground. A sudden reaction could cause loss of balance.

The HYCAL PMTs use voltage dividers which require external, additional power supplies (APS). There are 6 APSs that provide between 300 V and 500 V DC. These voltages are distributed to the PMTs via a common bus which runs along each of the VPCBs. The traces which form the bus are coated so there is no risk of contacting the high voltage via casual contact with the trace itself, only the solder points present such a hazard as described above. The APS supplies present the largest risk to personal since they can supply at least 300 mA of current.

A small risk of equipment damage also exists for the PMTs should a large voltage be applied while a bright light source is shining on the detectors.

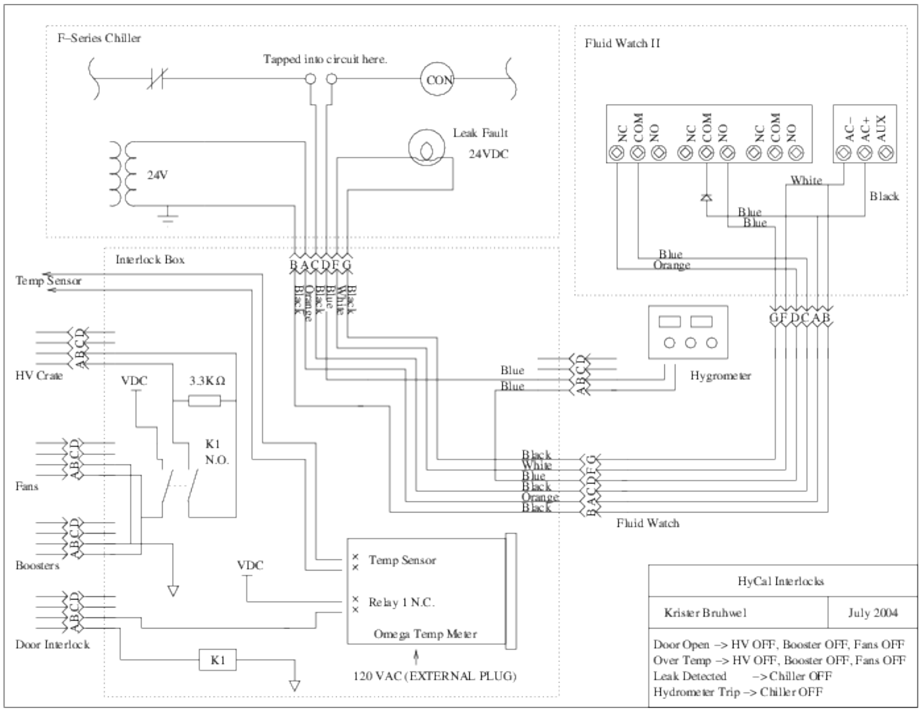


Figure 1: HV interlocks

Administrative measures will be taken to mitigate the risk of injury due to high voltage from the APS. These include:

A rope barrier will be maintained across the back of HYCAL with posted signs warning of the high voltage hazard. The barrier will remain in place whenever the high voltage is on, or has the potential of being turned on.

To minimize the risk of injury from falling off a foot stool or work platform while working on HYCAL, the area directly behind HYCAL (3 foot perimeter) should be kept clear of any items which could potentially cause injury. This includes things like broom handles, or similar large hard objects which a worker could land on should they fall unexpectedly. In addition, the floor must be kept clear of all items, such as screws and tools that could cause a person to lose their balance were they to step on them.

The CAEN SY1527 universal multichannel power supply system is interlocked to the door, moisture, and chiller interlocks. If an interlocked door is opened, moisture detected, or if the chiller is disabled, the HV is shut down. This prevents damage to the PMTs (w.r.t. the first two interlocks) and prevents rapid heating of the interior of HYCAL (w.r.t. the last interlock), which are vital to the health of the lead tungstate. The diagram of HV interlock system is shown in Fig. 1.

3 HYCAL Transporter

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

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

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

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

3.1 HYCAL transporter Hazards and Mitigation

There are two risks associated with the motion system.

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

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

The details of the HYCAL motion system interlocks re described in following sections.

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

3.2 HYCAL Motion Control

3.2.1 Overview

The purpose of this section is to describe the theory and operation of the Hall B HYCAL transporter control system. Although the system will be controlled via EPICS software, this document will only cover the electronic hardware used to control and interlock the system. There is a distinction made between software (EPICS) and hardware (electronic) control of the transporter. All hardware interlocks will supersede any software limits that may be implemented. A basic overview of all components involved, theory of operation, and a detailed breakdown of each item that a technician may use to repair or modify the system is provided in this document.

3.2.2 Theory of Operation

The system is composed of two stepper motors that move a large transporter in the X and Y axis (see Fig. 2. Each axis has hardware switches that limit its path of motion. In addition to end limit switches at the edges of axis travel, there are home switches in mid travel that will facilitate easy positioning during an experiment. To determine the exact location of the transporter, digital and analog encoders are used to transmit its position. The transporter is controlled by our standard EPICS software interface, and there are hardware interlocks installed to prevent unwanted movement of the transporter.

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

3.2.3 System Requirements

During normal operation, the system must stay within set boundaries in the beam-line area. This area will be kept clear during an experiment, minimizing the damage risk to personnel and equipment.

During transporter storage, operator alertness is essential. The transporter will traverse the height of the space-frame and an operator must ensure that the path is clear at all times.

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

3.2.4 Hardware Interlocks

There are two modes of operation, normal mode and storage mode. The main difference between the two modes is the height of the transporter in the Y axis. Above a certain height, an operator must be more alert to the movement of the transporter. A different set of hardware interlocks is used in each of the two modes.

The following hardware interlocks are used during normal mode:

1. Pitch and roll tilt sensors
2. Emergency stop buttons
3. Analog Y-axis encoder

The following hardware interlocks are used during storage mode:

1. Pitch and roll tilt sensors
2. Emergency stop buttons
3. Dead-man switch
4. X center limit switch

During normal operation, all transporter movement will stop in the event of a tilt sensor alarm, an emergency stop button is depressed, or the analog encoder goes above a predetermined Y-axis range.

During storage operation, all transporter movement will stop in the event of a tilt sensor alarm or emergency stop button is depressed. The transporter must have the dead-man switch depressed and the X-axis centered for any movement in the Y-axis.

See Fig. 4 for a logic diagram.

3.2.5 Hardware Layout

The main transporter system is located on the space-frame. Its normal operating range during an experiment is limited to travel around the beam-line area, and

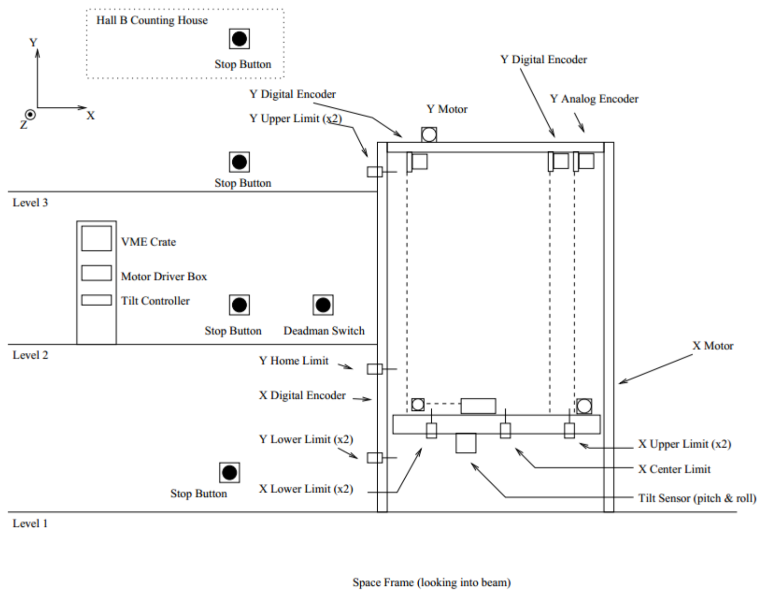


Figure 2: Transporter overview

when stored it is positioned much higher in Y and limited to a centered position on the X axis. The control system is located on level 2, North-East side of the space-frame. A rack contains the VME crate and the Motor Driver chassis. All hardware interlocks are housed in the Motor Driver chassis. When an interlock has been generated, power to the axis X and/or Y motor is removed via an All Windings Off (AWO) selection at the driver. This prevents motor movement at the end of the control chain. Hardware interlocks supersede any other control logic used. Please see Fig. 2 for the hardware layout.

Listed below are the major hardware components of the system:

- Stepper for motors X and Y motion.
- Dual upper and lower limit switches per axis.
- Home limit switches, X and Y axis.
- Emergency stop buttons.
- Dead-man switch.
- X center limit switch.
- Tilt sensor box.
- Analog encoder for position monitoring and interlocking of the Y axis.

- Two digital encoder for positioning on Y axis and one on the X axis.
- Motor Driver Chassis.
- VME crate with IOC.
- VME Motor Driver control board.
- VME Motor Driver ADC board.

3.2.6 System Components

A schematic diagram of the connections among the following system components is shown in Fig. 3.

VME Crate
The VME crate is located on level 2 of the space frame NE side. It contains the Input Output Controller, Motor Driver Board, and the Analog Input Module.

MVME 2306 IOC Board
The IOC controls the entire crate and serves variable to EPICS so that a software interface may be used to control the transporter.

OMS VS-040 Motor Driver Board
This board receives command from the IOC and transmits motor movements to the Motor Driver Chassis. As well, it receives inputs from the digital encoders via the Motor Driver Chassis for use by EPICS.

XVME-560 Analog Input Module
The XVME-560 board is used to convert signals from the analog encoder and the tilt switches into a format usable to EPICS. This is for EPICS use only. In addition, both the analog encoder and the tilt switches are hardwired to the interlock system.

Motor Driver Chassis
The Motor Driver Chassis houses two motor driver modules for the X and Y axes, a VME break-out board, and a hardware interlock board. All system hardware interlocking is implemented through this chassis. All hardware interlocks override any software interlocks that may be in place. A triggered interlock will remove power from its associated motor by using the All Windings OFF (AWO) selection at the driver module. Please see Figs. 3, 4, 5, and 6.

Interlock Board The Interlock Board in the Motor Driver chassis is the heart of the interlock system. This board controls two relays that supply power to the X and Y axis motor driver modules. If the interlocks are not made, no power will be available to drive a motor in any direction. The board has bypass switches and indicating lights so that it may be easily modified by a technician to meet non-standard system interlock requirements. Please see Fig. 6.

Stop Buttons
Four stop buttons are provided that will prevent movement of the transporter in

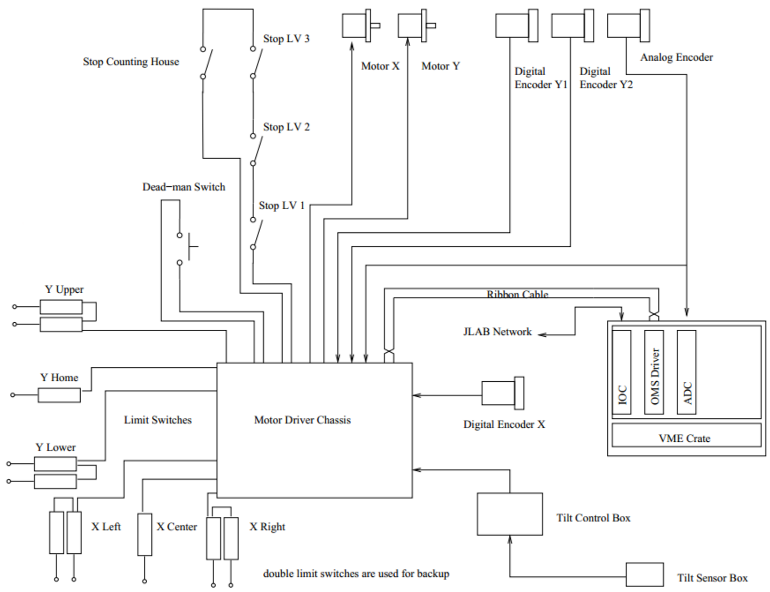


Figure 3: Motor driver chassis connections

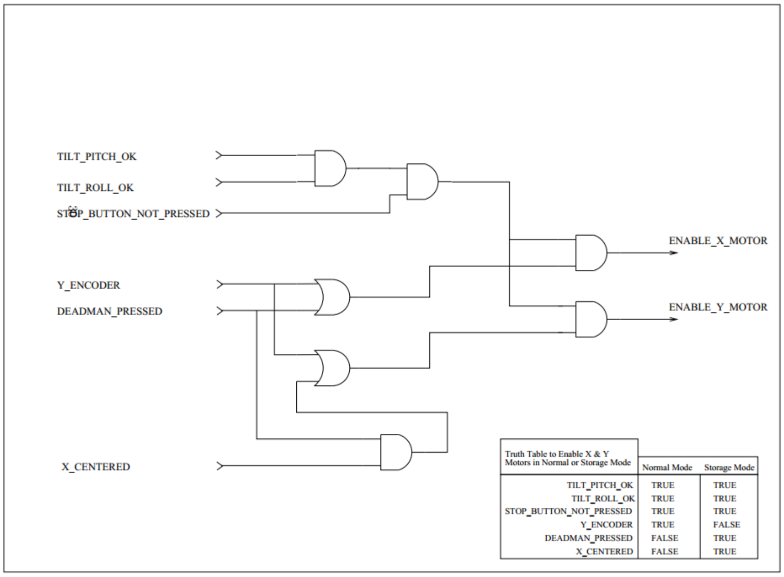
the X and Y axis. The switches must be pulled back out to reset the interlock. There is one switch per level of the space-frame and one in the Hall B Counting House. The stop switches enable a constant high voltage level to the Interlock Board. If it is removed, power to the X and Y drives will be disabled. If the cabling for the stop switches is unplugged, the interlock will automatically disable the drives.

Dead-Man Switch

The dead-man switch is used to insure an operators physical presence when moving the transporter in the storage mode. It is a momentary on push button that must be depressed to meet the interlock requirements of the Motor Driver Chassis.

Tilt Switches

The Tilt Switches sense pitch and role of the transporter. There is a sensor box on the transporter and a control module in the control rack on the second level of the space frame. The control module provides input to EPICS and interlock inputs to the Motor Driver chassis that must be made to meet interlock requirements for system operation. It is wired in a similar fashion as the Stop Switches in that an unplugged cable will prevent motor driver operation.



Truth Table to Enable X & Y Motors in Normal or Storage Mode	Normal Mode	Storage Mode
TILT_PITCH_OK	TRUE	TRUE
TILT_ROLL_OK	TRUE	TRUE
STOP_BUTTON_NOT_PRESSED	TRUE	TRUE
Y_ENCODER	TRUE	FALSE
DEADMAN_PRESSED	FALSE	TRUE
X_CENTERED	FALSE	TRUE

Figure 4: Interlock logic

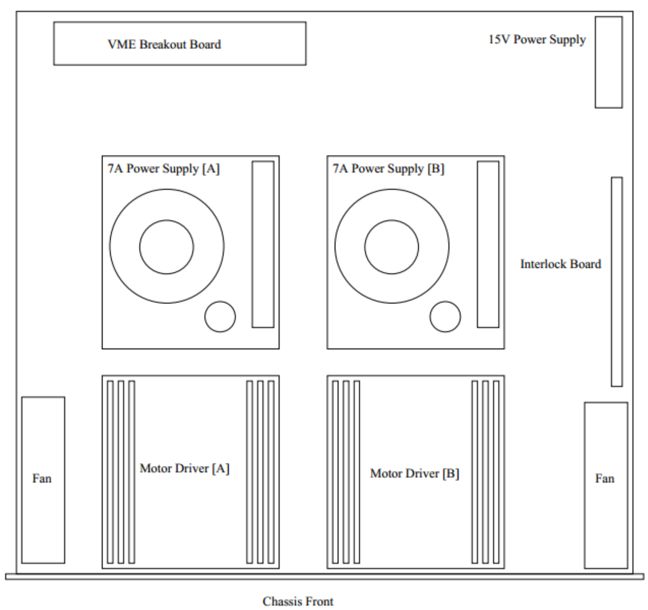


Figure 5: Motor driver chassis

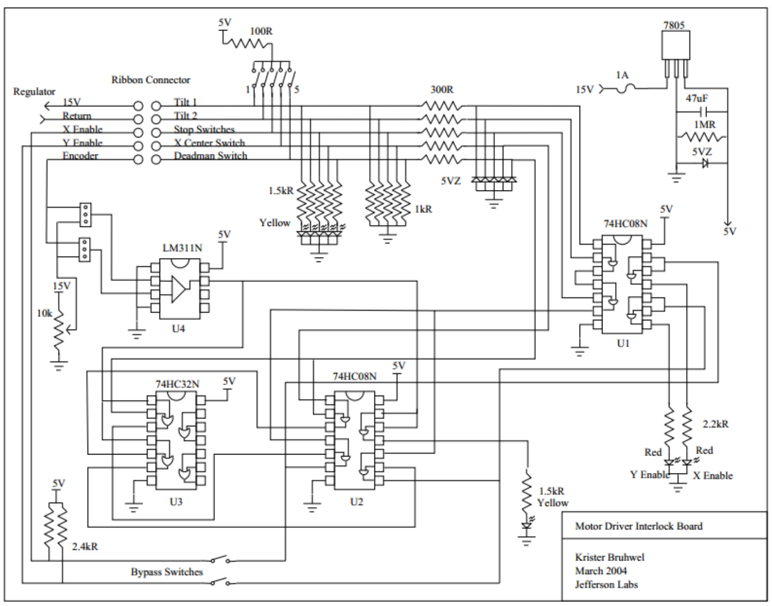


Figure 6: Motor driver interlock board

3.2.7 Summary

While the operators of the transporter must be trained in its use, there are important measures designed into the system to prevent damage to personnel and the system. The hardware interlocks supersede any software interlocks that may be put into place, and will ensure the system is in a safe state in the event of an error or malfunction.