Personnel Safety System

Operator Training

Table of Contents

Table of Contents 2
Part 1a System Description 4
What is the PSS? 5
What is the Hazard? 6
Basic PSS function 10
PSS Hazard Mitigation 11
PSS as an Administrative Aid 12
Things Not Covered by the PSS 13
PSS Components 14
What is the Safety Interlock System? 16
Attributes of the Safety Interlock System 17
Logic 18
What is the Fast Electronics System? 19
What is the ODH System? 20
What is PSS Configuration Control? 21
Fail -Safe 23
Segmentation 24
Injector Segment 27
North Linac Segment 28

South Linac Segment 28
BSY Segment 29
Hall A Segment 29
Hall B Segment 30
Hall C Segment 30

Part 1a System Description

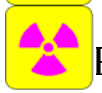
What is the PSS?

The Personnel Safety System is a system of sensors, interlocks, and warning devices that are designed to protect personnel from exposure to prompt radiation, electrocution, and oxygen deficiency hazards that may be present during accelerator operations. The Personnel Safety System also includes non-safety interlock systems such as the accelerator and FEL public address systems, used to announce changes in tunnel states.

What is the Hazard?

The PSS is designed to provide a measure of protection (mitigation) against exposure to the following hazards that can be present during accelerator operation:

Prompt ionizing radiation dose rates in excess of 1 Mrad/hr caused by beam loss.


RF cavity field emission[1] prompt ionizing radiation dose rates in excess of 4 krad/hr.

Electromagnetic prompt non-ionizing radiation in excess of 30 mW/cm^2 caused by open or missing RF waveguide.

Exposed Gun High voltage (≥100 kV) components in the tunnel.

Exposed electrical leads on arc magnets that may have over 800 V and 600 amps.

Oxygen deficient atmosphere (≤ 19.5 % O_2) caused by cryogenic leak or rupture or gas leak into a confined space.

[1] Field Emission is the radiation produced by electrons striped form the cavity surface bombarding the cavity walls.

OK, so what are the prompt radiation, electrical, and oxygen deficiency hazards?

Prompt radiation requires an external energy source to occur. The PSS can shut off a prompt radiation source by shutting off the energy to the device generating the radiation. Prompt radiation at Jefferson Lab comes in two forms:

Ionizing radiation has enough energy to change the chemical properties of matter it encounters. The electron beam is the primary source of prompt ionizing radiation in the accelerators. Secondary prompt ionizing radiation is generated by the operation of the superconducting RF cavities.

Non-ionizing radiation does not have enough energy to change matter but can cause damage through heating. The primary form of non-ionizing radiation in the accelerator is the high power RF microwave energy used to accelerate the electron beam.

Electrical (electrocution) Hazards are present when the large dipole magnets, which bend the beam from one section of the accelerator to another, are powered. The electrical connections to these magnets are not covered and so are exposed to workers in the tunnel. The PSS can shut off the power supplies to these magnets when there is a potential for personnel to be in the tunnel. The terminals of any high voltage magnets not interfaced to the PSS are covered and a red beacon flashes when the magnets are powered.
The high voltage used in the Injector to produce the electron beam can also be an electrocution hazard.

ODH hazards are not normally present when the accelerator is operating. However the potential for a gas or cryogenic spill is great enough to warrant a system that monitors the oxygen level in and around where these gases are used. The ODH alarm system does not shut off the source of the gas but alerts personnel to evacuate an area.

Accelerator devices that have a PSS interface

- Electron Gun or "the gun":

Produces the electron beam
CEBAF electron guns operate at 100kV.
The FEL electron gun operates between 300 and 500 kV. The electron beam produced by these guns is the primary source of prompt ionizing radiation in the accelerators.

- RF High Power Amplifier (RF HPA)

Transfers energy to the beam
Transfers 1497 MHz RF power to the electron beam via a waveguide transmission line and accelerating RF cavity.
There are 43 HPAs powering 338 cavities in the CEBAF machine. The FEL has up to 6 HPAs powering 25 8kW cavities and two 100 kW cavities.

- Cathode Power Supply (CPS)

Powers the RF HPAs
Provides up to 12 kV of D.C. voltage to the RF HPAs. Each HPA has one cathode power supply.

- Magnet Box Supply

Powers the large arc dipoles
Operate at up to 800 V and 600 amps. Magnets are required to bend beam from one area to another.

Basic PSS function

None of these hazards are significant outside of the tunnel, so one function of the PSS is to maintain the tunnel as an "exclusion area" during beam operations, i.e. people are excluded from the tunnel when these devices are operable.

Conversely, the PSS will not allow the Gun, RF HPA, or Magnet Box supplies to operate when people could possibly be in the tunnel. In this mode the tunnel is an "occupied area".

Sometimes it is possible to have access to one section of the tunnel while beam is operating in another, adjacent section. The PSS "segments" the tunnel such that people in the occupied areas are kept safe from hazards in the adjacent section. Later we will talk about PSS "Critical Devices" which are used to make sure beam cannot travel between an exclusion and occupied area.

PSS Hazard Mitigation

The PSS automatically acts to protect personnel against the following hazards:

- Personnel entry into an exclusion area
- Excessive radiation dose rate in an occupied area.
- Beam transport from an exclusion area to an occupied area.
- Beam burn through of beam stopping devices.
- Operation of radiation producing devices while an area is occupied.
- Exposure to high power RF EMI.
- Electrical shock from powered arc dipoles.
- Beam current in excess of the CEBAF safety envelope.

PSS as an Administrative Aid

The PSS logic helps the SSO and personnel around the accelerator conduct some administrative operations…

- Tunnel sweep sequence
- Tunnel Controlled Access
- PSS emergency crash switches
- Voice announcements
- Audio/visual status and warning indicators.
- Automated door locks
- ODH alarms
- ODH logging

Things Not Covered by the PSS

The PSS does not protect against:

- Exposure to residual radiation due to activation.
- Electrical shock hazards other than from the operation of the large arc dipole magnets.
- Protection of the general public from radiation doses less than that for trained Jefferson Lab radiation workers.
- Beam damage to non-PSS equipment.
- Damage to Beam Dumps.
- Beam Loss.
- Malicious intent to defeat or circumvent the PSS.
- Explosive gas hazards.
- ODH by automatically activating exhaust fans.
- Exposure to cryogen hazards.
- Exposure to Laser Hazards.

PSS Components

The major blocks of the PSS are the Safety Interlock System, the Fast Electronics System, the Oxygen Deficiency Hazard (ODH) monitoring system, the external interfaces, and configuration control. Typically, when an SSO speaks of "The PSS" they are talking about the Safety Interlock System (SIS).

Figure 1 shows the breakdown of the PSS for the CEBAF accelerator. The breakdown for the FEL is similar, except the FEL does not have critical devices or fast electronics systems.

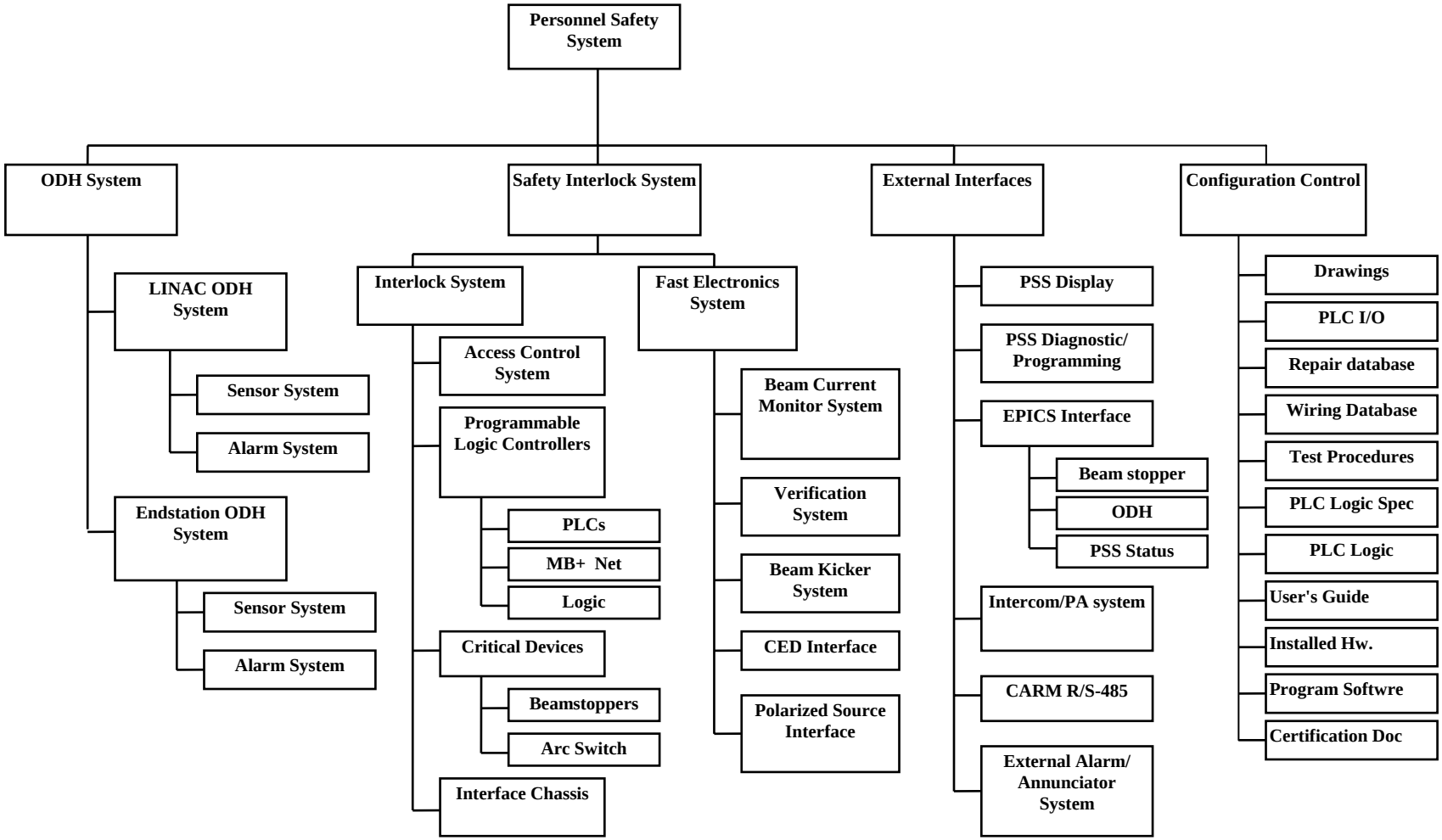


Figure 1. PSS Family Tree

What is the Safety Interlock System?

- The CEBAF Safety Interlock System is the part of the PSS designed to ensure that personnel are not exposed to prompt radiation exceeding the CEBAF administrative limits. This is accomplished by maintaining “exclusion” areas for accelerator operations.

- It includes the tunnel door switches, equipment interlocks, radiation monitors, Run/Safe boxes, PSS console equipment, and the programmable logic controller system.

- It is composed of two independent parallel systems, labeled System - A and System - B. If either one of the systems senses an unsafe condition it will turn off the electron gun and any other potentially hazardous device the PSS has control over.

- If an exclusion area is violated, such as if a tunnel entrance door is opened, the interlock system will immediately shut off the beam and any other device that could present a prompt radiation or shock hazard.

Attributes of the Safety Interlock System

Each hazardous device interfaced to the safety system has special control points where the PSS can turn off the device if required. The PSS cannot turn on a device, just turn it off and keep it off.

This interface is called the PERMIT. The PSS "permits" the device to operate.

Each device interfaced to the safety system also has fail-safe on/off status indicators that are read by the PSS. The PSS monitors these signals to confirm that the device is OFF when the PSS Permit is OFF.

These signals are called OFF/SAFE. The signals are fail-safe in that if the OFF/Safe signal is not powered or disconnected the PSS will read this as the device being ON or UNSAFE.

Both the PERMIT and OFF/SAFE signals are fully redundant. There are two independent signals for every device.

Logic

The logic of the safety interlock system is programmed into programmable logic controllers (PLCs). The PLC logic resolves into determinate "states" which permit or deny operation of equipment.

The SSO can switch between the states using the key switches on the PSS console.

Every segment of the accelerator has 2 PLCs that run programs that are functionally the same. However, the programs are written by two separate individuals and vary in the implementation.

What is the Fast Electronics System?

- Fast electronics system is composed of active sensors such as beam current monitors as well as fast beam shutoff devices such as clamps and beam kickers. The Fast Electronics system is designed to detect and shut off the beam much faster than the safety interlock system.

- The Fast Electronics system is implemented using two independent parallel systems, like the safety interlock system. Both systems can independently eliminate an unsafe condition. However, because of the nature of the system, it is not intrinsically fail-safe. Therefore, extensive self-test and fault detection capability is built into the system.

What is the ODH System?

- The ODH System is a network of oxygen sensors and warning devices in the tunnel and service buildings.

- The system will set off horns and blue beacons in an area where the oxygen level drops below 19.5%.

Oxygen Deficiency Hazards (ODH) may occur whenever a cryogenic system is present. In an enclosed area a cryogenic leak can displace oxygen in a manner of seconds. ODH conditions are sensed in the FEL, linac tunnels, endstations, and service buildings immediately above the linacs. ODH alarms are located throughout the accelerator tunnel and service buildings.

The ODH system does not act to prevent or mitigate ODH conditions but alerts personnel to a possible oxygen deficient area.

What is PSS Configuration Control?

Because of the critical nature of the Personnel Safety System, strict controls over changes to the system are maintained. The Jefferson Lab PSS Configuration Control Policy outlines the requirements for making changes or repairs to any part of the system.

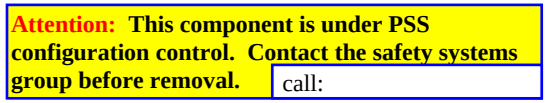
PSS equipment, hardware and software are categorized by the severity or criticality of the subsystem or equipment. There are five categories, or levels, with 5 being the most critical and 0 the least critical.

Most Safety Interlock Systems fall within level 4 or 5. Administrative subsystems such as the ODH and PA systems fall within levels 2 or 3. Level 0 and 1 equipment is for PSS group use only. An example of a level 1 device is one of the PSS test stands.

All level 2-5 systems are audited twice a year to certify functionality.

Example of PSS configuration control sticker. These are mounted on all PSS equipment and wiring conduit.

Example of PSS Critical Device control sticker. These are mounted on PSS accelerator equipment such as beam stoppers.



PSS Configuration Control sticker. This is mounted on the PSS controlled circuits of non-PSS equipment. An example would be a safety interlock system controlled relay inside an HPA.

Fail -Safe

The concept of Fail-Safe is very important in understanding PSS operation and troubleshooting. The PSS should always be deterministic - i.e. it should never wind up in an ambiguous state. The system is designed such that a sensor must be energized to indicate a “safe” state and a control must be energized to permit an “unsafe” state. The de-energized position for a sensor is assumed to be “unsafe.”

This is an extension of the concept of passive protection. Passive is interpreted as no energy input required for the safety function. In the PSS we require that no energy (electrical or mechanical) be required to reach the “safe” state.

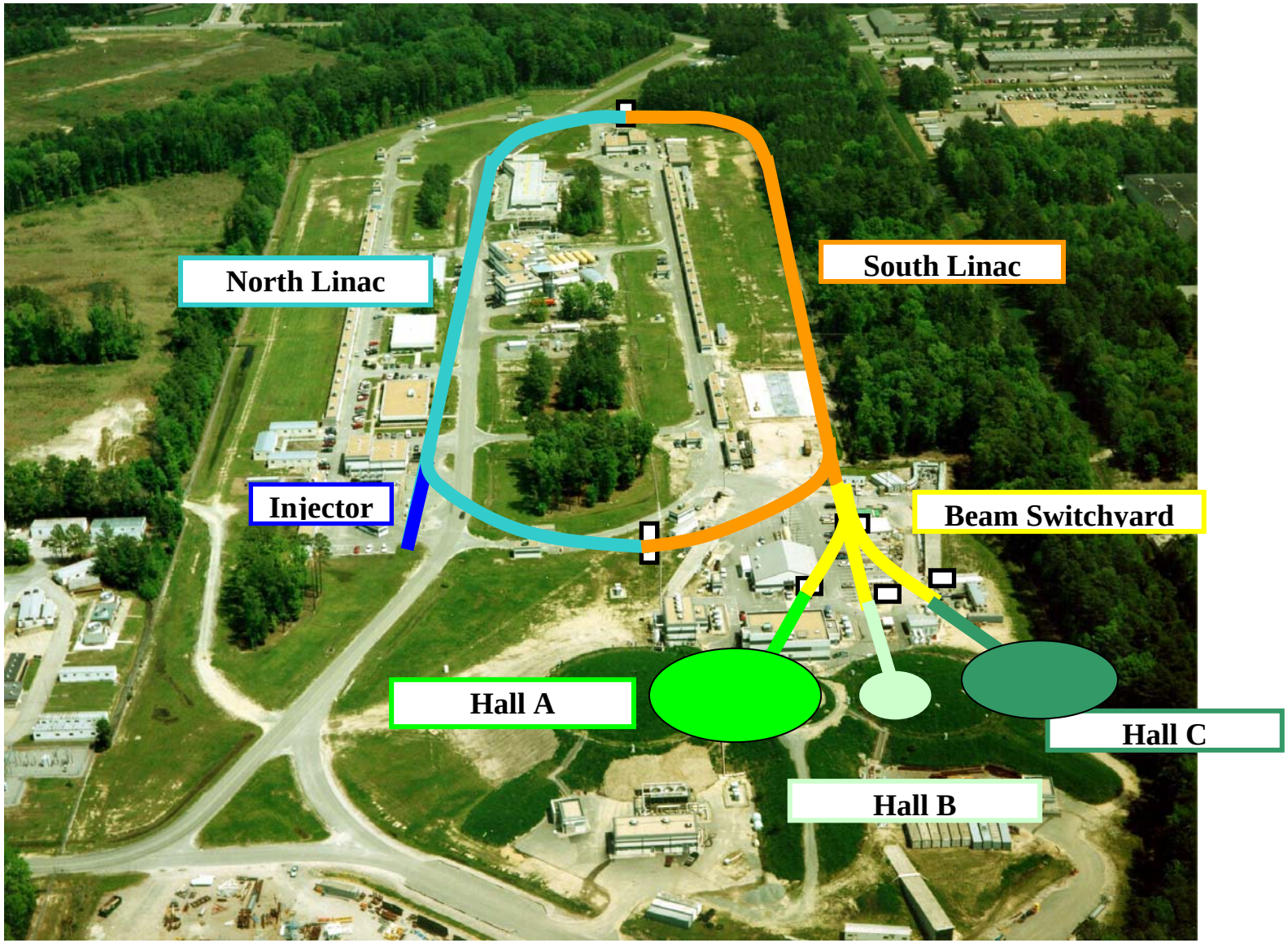
Segmentation

The safety system is segmented into 7 geographical areas.

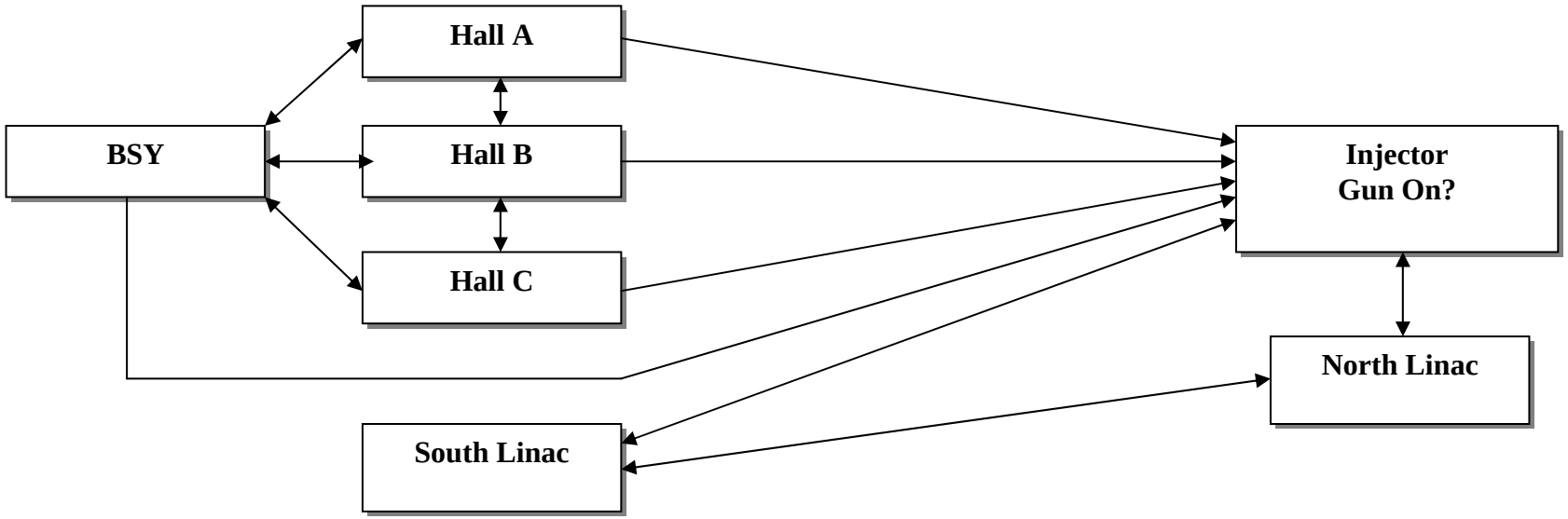
- **Injector**
- **North Linac**
- **South Linac**
- **Beam Switchyard**
- **Hall A**
- **Hall B**
- **Hall C**

Segmentation of the Safety System allows operation and test of the accelerator in logical pieces. Each segment contains two independent PLC systems and is electrically isolated from other segments. This allows separate maintenance and auditing of each segment.

Each segment can operate independently up to the point where operation of a device within one area may present a hazard in another area. At that point the areas must agree that it is safe to operate the hazardous device.



Accelerator Site Layout and Tunnel Segmentation



PSS Segment Intercommunication

Injector Segment

The Injector segment is the "Master" PSS segment. It receives a status input from all other segments in the machine and makes the determination if a permit to the gun is allowed. This segment also provides "Power Permit" permissive to the Capture HPA and pre-accelerator HPAs.

North Linac Segment

The North Linac segment controls permissive to the 20 North Linac RF HPAs, the east dogleg and septa box supplies and the east and west arc magnet Box supplies.

This segment also provides "Power Permit" permissive to the 1/4 Cryo and pre-accelerator HPAs.

South Linac Segment

The South Linac segment controls permissive to the 20 South Linac RF HPAs, the East Arc beam stopper, and the west dogleg and septa box supplies.

BSY Segment

The BSY segment controls permissive to each endstation arc dipole supply, the BSY dump dipole supply, the Lambertson magnet power supplies, and each endstation beam stopper.

Hall A Segment

The Hall A segment controls the Hall A Beam stoppers as well as the Hall A beam transport line Box Power Supply.

Hall A has two large spectrometer/detector systems labeled the electron arm and hadron arm. Each of these areas is considered a sub-segment within Hall A. Once the detector hut Run/Safe box is armed and the hut door closed it will remain armed until the door is reopened.

Hall B Segment

The Hall B segment controls the Hall B Beam stoppers as well as the Hall B beam transport line Box Power Supply.

Hall B does not have any movable detectors or independent detector hut areas. However, Hall B equipment is contained on several multi-level structures. Hall B also contains equipment in the beam dump tunnel, which has a Run/Safe box in the sweep pattern.

Hall C Segment

The Hall C segment controls the Hall C Beam stoppers as well as the Hall C beam transport line Box Power Supply.

The Hall C H.M.S. detector hut is a sub-segment within the Hall. Once the detector hut Run/Safe box is armed and the hut door closed it will remain armed until the door is reopened.