ES&H Division

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Radiation Safety Systems

Technical Basis Document

Stanford
Linear
Accelerator Center

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1 Radiological Guidelines for Shielding and Barriers

1 Introduction

During the operation of the accelerators at SLAC, radiation is produced whenever the electron / positron beam interacts with any material in its path. The radiation produced from this interaction is referred to as prompt radiation. Prompt radiation consists primarily of photons, neutrons, and muons, and goes away when the machine is turned off. At SSRL, as the synchrotron radiation travels down the beamline, it can also interact with any material in its path, producing scattered x-rays.

Both the radiation from the accelerators and the synchrotron beamlines can be reduced to acceptable levels. This is done by enclosing the accelerators and the beamlines in housings, or enclosures, such that there is sufficient material between the source of radiation and personnel. This intervening material is referred to as shielding. Different kinds of shielding materials are used for different types of radiation. High atomic number materials such as lead and tungsten are more effective for shielding photons and x-rays. Hydrogenous materials such as concrete and polyethylene are more effective for shielding neutrons.

Since the radiation decreases with distance from the source, barriers may also be used to reduce personnel exposure to acceptable levels. Engineered safeguards such as shielding and barriers are preferred to administrative controls. Administrative controls should only be used when it is impractical to add shielding or barriers. The rest of this section describes the shield design criteria, the shielding configuration, and the protocol for determining shielding requirements.

1.1 Shield Design Criteria

According to Article 128.2 of the SLAC *Radiological Control Manual* (SLAC-I-720-0A05Z-001, current version), henceforth referred to as the *RadCon Manual*:

> "The design objective for controlling personnel exposure from external sources of radiation in areas of continuous occupancy (2000 h per y) shall be to maintain exposure levels below an average of 0.5 mrem (5 microSv) per hour and far below this average as reasonably achievable. The design objective for exposure rates for potential exposure to a radiological worker where the occupancy or duration of the exposure differs from the above shall be ALARA and shall not exceed 20 percent of the applicable standards."

The design objectives are based on exposure of the radiological worker. The annual whole body dose limit (internal + external) for a radiological worker is 5 rem / year. The *RadCon Manual*: defines the radiological worker as " a general employee whose job assignment involves operation of radiation producing devices or working with radioactive materials, or who is likely to be routinely occupationally exposed above 0.1 rem (0.001 sievert) per year total effective dose equivalent ".

Based upon the design objective and definition of a radiological worker, the SLAC Shield Design Criteria are as follows:

1.1.1 Normal Operations

Under normal operating conditions, taking into consideration exposure duration and occupancy, the annual effective dose equivalent to a radiological worker outside the shielding or barrier shall not exceed 1 rem. For continuous occupancy (2000 h of exposure) this criterion corresponds to effective dose equivalent rate of 0.5 mrem / h. For whole body exposures the annual dose equivalent is limited to 1 rem.

For narrow beams (diameter<= 2 inch) only a portion of the body is irradiated. The annual dose equivalent limit for collimated beams is 5 rem (using a conservative weighting factor of 0.25). If a non- radiological worker working in the area is likely to be exposed to an annual effective dose equivalent greater than 0.1 rem, taking exposure duration and occupancy into account, additional shielding may be required or the worker must be reclassified as a radiological worker. Examples of areas where such situations could exist are End Station A (ESA) counting house and the SSRL experimental floor.

1.1.2 System Failure

Under a system failure (defined in 3.8.1.3), the total effective dose equivalent shall not exceed 3 rem for a broad beam or 12 rem for a narrow beam. In this case some protection device such as a burn-through plug or beam shut-off ion chamber (BSOIC)would be expected to turn off the beam within a predictable time period. Under worst-case conditions where the beam would not be turned off by some protection device, but it would require human intervention to terminate the beam, the maximum dose equivalent shall not exceed 25 rem averaged over 1 hour for broad beam exposure or 100 rem averaged over 1 hour for narrow beam exposure. Since mis-steering conditions vary widely from beamline to beamline, the maximum dose equivalent rates are to be determined on a case-by-case basis by the Radiation Physicist.

1.2 Protocol for Determining Shielding Requirements

The SLAC Radiation Physics (RP) Department is responsible for determining the shielding required for a facility and must be consulted prior to the construction of a new facility or the modification of an existing facility. It is the responsibility of the project manager or his / her designee to provide the following information in writing to the responsible Radiation Physicist:

A. Beam parameters.

B. Duration of operation (use factors).

C. Operating conditions.

D. Beam loss scenarios (normal, worst-case and mis-steering).

E. Ray traces.

F. Occupancy factors.

G. Other pertinent information requested by RP.

The Radiation Physicist will then perform the ray trace analysis and calculations based on the above information and specify the shielding configuration (amount, type and location of the shielding). The project manager (or his / her designee) with the assistance of the Radiation Physicist shall submit a proposal including a documentary description of the beamline to the Radiation Safety Officer (RSO) and the Radiation Safety Committee (RSC) for review as needed.

In addition to the shielding, the proposal should include a documentary description of the personnel protection system (PPS, Section 2), the Beam Containment System (BCS, Section 3) and the BSOICs, Section 4. The Radiation Physicist should be involved in the design of the PPS and BCS. The location of the BSOICs shall be specified by the Radiation Physicist. The RSC may recommend acceptance of the design or may recommend additional shielding. The RSO has approval authorization for the shield design.

After construction or modification of the facility, as-built drawings of the shielding should be provided by the project manager and facility and signed off by the project manager or his / her designee and the Radiation Physicist. It is the responsibility of the project manager or his / her designee to verify actual dimensions and materials used in the shielding configuration. The Radiation Physicist is responsible only for doing a visual inspection of the shielding. There may be situations where the shielding is not visible (for example shielding inside penetrations). In these situations the project manager or his / her designee is responsible for verifying that the shielding is in place.

In the case of minor modification of shielding as deemed by the Radiation Physicist and the RSO, the approval by the RSC is not required. Beam time should be scheduled as requested by the Radiation Physicist to conduct or supervise radiation surveys. Based on the measurements additional shielding, barriers or controls may be required.

1.3 Shielding Configuration

The shielding configuration is determined by the responsible Radiation Physicist. All calculations performed by the Radiation Physicist should be reviewed by his or her back-up (as indicated on the Radiation Physics Assignments List). The calculations are performed using the information provided by the project manager. Semi-empirical and analytical methods and codes (e.g SHIELD11, PHOTON - synchrotron radiation and STAC8 - synchrotron radiation etc.) may be used in simple cases and radiation transport codes (e.g. EGS, FLUKA, MORSE, MCNP, HETC, MUCARLO, MUON89 etc.) may be used in more specialized cases. A written memo specifying the final shielding configuration will be issued by the Radiation Physicist.

2 Personnel Protection Systems

2.1 Introduction

A personnel protection system (PPS) consists of electrical interlocks and mechanical barriers that prevent personnel from entering Radiation Safety Enclosures when particle beams may be operating. The interlocks also serve to shut off the radiation source if any of the gates into an enclosure are opened when beams are on. The interlock system must be operated and maintained in accordance with an extensive set of administrative procedures. These ensure that activities such as setting access states, searching an exclusion area, and testing the interlocks are carried out safely and thoroughly.

At SLAC, the personnel protection systems serve primarily as Access Control Systems. This term is favored by the National Council on Radiation Protection. The DOE uses the name Beam Interlock Safety System. In the following description, PPS will be used because of its widespread and long-standing use at SLAC, and because the system does perform safety functions other than control of access. It provides the logic and the hardwired connections to beam shut-off devices that operate in response to signals from burnthrough monitors (BTMs) and beam shut-off ion chamber s (BSOICs). These devices are described in separate documents under the titles “beam containment system” and the “beam shut-off ion chamber system.” In addition, the PPS limits the potential radiation exposure to persons inside the beam housing when access is permitted, by ensuring that beam-blocking stoppers are in place. The stoppers are designed so that the dose rate in the occupied areas remains below that which could result in a dose of 1 rem a year under normal conditions and less than 25 rem in one hour in the event of a system failure.

While the main function of the PPS is to prevent entry to radiation enclosures when beams are operating, and to turn off the beams when a security violation is detected, there are several other important functions that the logic circuits must accomplish. These include:

1. The provision of interlocks for orderly searching of an area before beam turn-on;
2. Interlocks for setting up the various entry states, such as Controlled and Restricted Access;
3. Provision for emergency shut-off;
4. The operation of annunciator signs and audio warning systems; and
5. Control of electrical hazards in tunnel areas — specifically, uncovered magnet terminals operating at 50 V and above.

It should be noted that the PPS is not designed to protect people against residual radiation when the beam is off, although it does present a somewhat formidable barrier against casual entry to tunnel areas when in the Controlled, Restricted, or No Access states. The reason for its relative ineffectiveness in protecting against residual radiation is because every entry door has an emergency entry (and exit) mechanism, and a determined or untrained person could easily gain access. During long shut-down periods, the Control Room is not manned, and an alarm signal indicating a forced entry would not be noticed. The emergency entry / exit devices are fitted with microswitch interlocks such that if beams were operating, the accelerator would be shut off immediately by the emergency entry interlock, and also by the interlocks associated with the door microswitches.

At SLAC, the PPS is implemented using relay logic. Fail-safe circuits are used wherever possible. For relay systems, this means that for the beam-on condition, all relays in the safety logic circuits are in the operated or energized state. Dual, redundant paths or chains are used to reduce the likelihood that a single unsafe failure would completely disable the protection system. An example of an unsafe failure would be a sticking contact on a relay or switch that failed to open when the relay was de-energized or the switch operated. The dual redundancy is carried from the input devices, such as door microswitches, through duplicate wiring to the dual chains in the logic. The logic output connects to redundant shut-off devices. At least two independent devices are used to ensure positive shut down of beams, but typically three and sometimes four devices are used.

2.1.1 Design Features

The PPS has been designed in accordance with guidelines that are in common usage in other accelerators, and at similar facilities where a life-threatening situation might arise if inadvertent entry were made to a restricted area. The guidelines have been heavily influenced by publications such as The American National Standard N43.1 [1] and the National Council on Radiation Protection and Measurements Report, NCRP 88 [2]. Many of the principles listed below are described in SLAC-327 [3] and are now incorporated in the guidance section of the DOE Accelerator Safety Order [4].

2.1.1.1 High Quality Components

Materials and components are of high quality for dependability and long life. Materials that resist radiation are used for components located in areas where radiation levels are high enough to cause radiation damage.

2.1.1.2 Fail-safe Circuits

Fail-safe circuits and components are used whenever practicable. Fail-safe design includes consideration of the effects of open-circuited or short-circuited cables, the failure of primary AC or DC power, and the loss of pressurized air that feeds air-actuated solenoids. In each case, the safety interlock system reacts to render the area safe. To achieve fail-safe operation, the logic has been implemented using relays that are maintained in the energized state for the normal running (beam on) condition. Thus, all normally open contacts are in the closed condition. Abnormal conditions such as a power loss, cable disconnection, or a conductor short or open circuit, will cause the relay to de-energize and the logic to go to the fault (safe) state. The relays operate at 24 V DC.

2.1.1.3 Redundancy

Duplicate circuits or redundant components are used in critical applications where the failure of a single circuit or device could lead to a hazardous condition. Most tunnel entrances have two doors, and doors used for routine entry have two microswitches. Double or triple redundancy is used for beam absorbers or magnets that serve as beam stoppers when entry is required into a downbeam area. In the case of logic wiring and circuits, two independent chains, or circuit paths, are used. The failure or activation of any one or both chains results in a beam shut-off and the removal of power to tunnel magnets operating at 50 V or above.

2.1.1.4 Protection of Equipment

Circuits, equipment, and connecting cables are protected against inadvertent modification, disconnection, or tampering. Logic equipment is located in locked racks or cabinets. All cables have been protected by armor covering or conduit, except for long cable runs where tray cable has been used in metal trays. When the cable leaves the tray, protective conduit has been installed.

2.1.1.5 Test Features

To the maximum extent possible, "press-to-test" switches and status indicators have been incorporated into the equipment to permit efficient testing and certification. Thus the use of clip leads and bypass boxes for testing individual chains has been reduced significantly.

2.1.1.6 Location of Control Panels

Wherever feasible, control and status of the PPS logic for a specific enclosure are available both at the radiation enclosure itself and at the operations control room. This is to permit maximum flexibility for operational efficiency.

2.1.1.7 Use of Computers

In some instances, the general purpose control system computer that is used to monitor and control the accelerator, may be used for monitoring the status of a remote PPS logic chassis. However, if an operator response is necessary to maintain safety, status signals that are defined as alarms and warnings are also communicated by audible or visual indicators that are not generated by software (SLAC Guidelines for Operations, [5]). Control signals to a remote PPS logic chassis may operate through the general-purpose control computer, provided an additional hardwired permissive signal is also transmitted in parallel (logic AND). The control computer is not permitted to perform any PPS logic function because there is not adequate configuration control over hardware or software.

2.1.1.8 Interlocks for Safe Entry

Interlocks, such as door microswitches, are not used to shut off the beam for routine entries. Beams must be shut down, or stoppers inserted, in an orderly sequence. Entry to a beam housing is prevented (except in an emergency) until the PPS logic circuitry confirms that all machine-generated radiation sources and electrical hazards are turned off, or that the required beam stoppers are inserted or off. Only then is it possible to release a key, operate the electric door latch, and gain entry.

2.1.1.9 Stopper Integrity

When entry is permitted in an area that is protected by beam stoppers, beams in the up-beam area must be shut off immediately if there is any indication that a stopper is not properly positioned or if it is damaged.

2.1.1.10 Reset Requirement

If an interlock trips during normal beam operation, the accelerator cannot be restarted until the operator has reset the interlock at the PPS panel in the control area. In the situation where the security of an enclosure has been lost, or when an Emergency Off button has been pushed, a complete search of the area is required before the interlocks can be reset.

2.1.1.11 Search and Warning Provisions

Interlocks have been provided to ensure complete and effective searching of an enclosure. The interlocks consist of push button or key switches for:

1. Search Preset (search start),
2. Search In Progress, and
3. Search Complete.

The interlock circuits prevent beams from being turned on until the search has been completed and the audio and visual warnings are finished.

The audio warning is a voice recording that instructs persons who may have been overlooked in the search that they must push the nearest emergency-off button and exit immediately. In some areas, a siren is used as the audible warning. The visual warning is given by the flashing of the overhead lights. At the end of two minutes, the lights are left in the dim condition.

2.1.1.12 Emergency-off Switches

Emergency shut-off switches have been installed in all tunnel enclosures. The switches are large, clearly labeled, and easily accessible. A large red light is mounted on each switch assembly.

2.1.1.13 Radiation Warnings

Radiation signs and lights, or large annunciators have been installed outside all entrance doors.

2.1.1.14 Emergency Entry/Exit Provisions

Most doors have emergency exit and entrance mechanisms. These may consist of a crash-bar, a key kept in an adjacent key-box, or a pull-ring.

2.1.1.15 Access State

In addition to No Access and Permitted Access, many enclosures have Controlled Access and Restricted Access states. These are described in the following section.

2.1.2 System Description

A block diagram of a typical personnel protection system is shown in Figure 2-1. The PPS logic circuits receive information from the accelerator about the status of doors, key banks, emergency-off switches, and other devices. Depending on the safe (or unsafe) state of these components, “permissive” or “enable” signals are generated (or withdrawn) to allow control of safety devices such as beam stoppers. The logic also issues control signals to release keys at remote doors, and to operate warning systems at entrance doors and in accelerator tunnels.

The operator interface to the logic circuits of the PPS may be achieved through a hardware or software control panel. Frequently, both types of panels are provided — a hardware panel near the entrance to the enclosure and a computer touch screen in a central control room area.

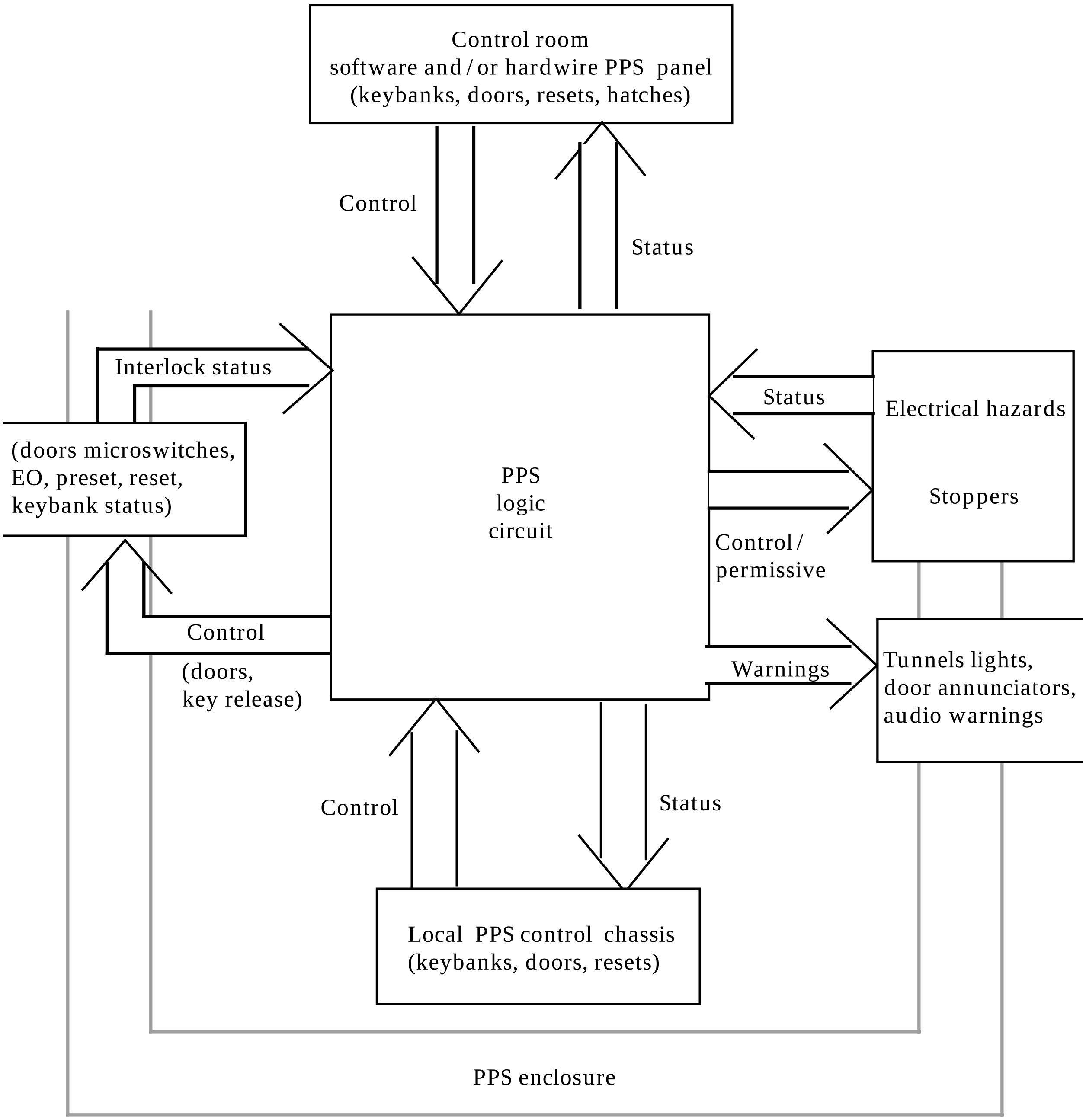


Figure 2-1. Block Diagram of Typical PPS System

2.1.2.1 Stoppers

The term “stopper” refers to any device used to block the beam or prevent it from reaching occupied areas. Thus a stopper could be a mechanical assembly, a deflecting magnet, or the modulators that drive the klystron tubes. SLAC policy requires at least two beam stoppers for protection of personnel, but typically three, and sometimes four, are used. The specific requirements for stoppers are contained in the *SLAC Beam Containment Policy and Implementation* document, available from the Radiation Physics Department. In summary, the current requirements are:

- If the beam line is designed to permit beam to be incident on the first stopper when access is permitted to the beam line downbeam of the stoppers, two additional PPS stoppers (for a total of three) are normally required. If fewer stoppers are used, the design must be justified on the basis of adequate safety.
- If the beam line is designed so that the beam cannot be incident on the first PPS stopper unless a prior failure occurs, then at least one additional PPS stopper (for a total of two) is normally required. If fewer stoppers are used, the design must be justified on the basis of adequate safety.
- One or more magnets can function as one of the stoppers.

2.1.2.2 Entry Requirements

Stoppers must be inserted in a beam line before entry is allowed to a downbeam area. The PPS logic requires two status signals from each stopper confirming the “in” status before the area can be set to an entry state. In the case of mechanical stoppers, such as slits, collimators, dumps or scatterers, two microswitches are used to determine the “in” position. For magnets used as stoppers, the magnet power supply provides two independent status signals to the PPS logic to confirm that the supply is off. In the case of the linac, the Variable Voltage Substations (VVSs) that power the klystron modulators serve as stoppers. Each VVS provides two “off” status signals to the PPS logic.

2.1.2.3 Security Violation

A security violation of any zone must immediately shut off all machine produced radiation and electrical hazards in the area. The internal PPS logic circuits respond within about 10 to 100 milliseconds to the opening of any gate or the pushing of an emergency-off button. This delay is due to the drop-out characteristics of the relays that constitute the logic elements in the PPS. Beyond this internal delay, there is an additional delay due to the time taken for mechanical devices to drop into the beam line or for large electromechanical contactors on power supplies or VVSs to release. This second delay could add as much as one or two seconds to the internal delay of 10 to 100 milliseconds.

Note that the logic circuits generate two permissives for each stopper and that both permissives are removed when there is a security violation.

2.1.2.4 Damage to Stoppers

Mechanical stoppers are protected from overheating and damage from accelerator beams by Protection Ion Chambers and Temperature Sensors. BTMs are also used to give an early warning of potential damage to stoppers. The BTM is a pressurized chamber placed in the beam line that ruptures when struck by a beam or beam shower. A pressure switch on the chamber acts through the PPS logic to shut down all beams. The protection of stoppers is covered in more detail in a companion report describing the Beam Containment System, and in the *SLAC Beam Containment Policy and Implementation* document.

2.1.3 PPS Access States

The PPS design provides for up to four access states — No Access, Restricted Access, Controlled Access, and Permitted Access. In some locations, such as the linac, only two states are available — No Access and Permitted Access.

2.1.3.1 No Access

Allows operation of the beam in that area and electrical hazards to be on. No personnel are allowed in the area.

2.1.3.2 Restricted Access

Allows electrical hazards to be on but no beam. No personnel are allowed in area except under Restricted Access Safety Key (RASK).

2.1.3.3 Controlled Access

No beam and no uncovered electrical hazards may be on. Personnel access is allowed by contacting the control room. Each person entering must be logged-in by an operator, take a key from a keybank, and be in possession of the key at all times while in the radiation enclosure. In Controlled Access, searching of the area is not required before establishing the No Access state, and resuming of beam operation.

2.1.3.4 Permitted Access

No beam and no uncovered electrical hazards may be on. Personnel access can be made without restriction. Keys are not required. The area must be searched by operators before beams or electrical hazards can be turned on.

2.1.3.5 Restricted Access Safety Key (RASK)

This is a special operating mode that permits personnel to occupy a radiation enclosure with electrical hazards on. Beam operation is prevented by ensuring, through the PPS logic circuits, that the upbeam stoppers are inserted (or off) and that they cannot be removed (or turned on). This special operating mode is used when voltage or polarity measurements must be made on beam line magnets, or when it is necessary to check the integrity of bus and terminal connections on magnets. In this case, temperature probes are used to detect hot spots at connection points.

RASK mode testing is done in the Restricted Access state of the PPS (except for the linac). In this state, beam operation is prevented by the insertion of stoppers as noted above, housing lights are on at full brightness, and key release at entrance door key banks is prevented once the test team has entered the enclosure.

Testing is done in strict conformance with approved procedures. The procedures are somewhat different for each area, depending on the nature of the electrical hazards, and the particular design of the PPS logic, which in the recently constructed systems, provides more interlocked safety features than the earlier designs. For example, because there is no Restricted Access state available for the linac, RASK testing is done in the “Sector Secure” condition, with each team member required to carry an ODD-sector key. Sector Secure is the logic state for the linac PPS that is reached when the sector has been searched and reset; the gates, door, and hatch closed; and the light timer has completed its two-minute time-out.

2.1.4 Warning Lights and Signs

Each entry point to a beam enclosure has a warning light, or annunciator, and a radiation sign. In the klystron gallery, large yellow and magenta warning lights are mounted above the manway door. When the yellow light is on continuously, the linac is off, but there may be residual radiation in the tunnel. A steady magenta light means that the area has been searched and is ready for beam. A flashing magenta light means that dark current may exist or that the beam is actually running in the accelerator tunnel. In other areas, each entry point has a large annunciator which indicates the access state for that area (No Access, Restricted Access, Controlled Access, Permitted Access).

2.1.4.1 PPS Control Panels

PPS controls and status are available to operators as either a software-generated display with a touch screen overlay, or as a conventional hardware panel with lamps and switches. For many areas, both hardware and software panels are available.

Hardware Panels

A typical hardware panel includes the following features:

- A key switch to enable the panel; the key is kept in the control room key safe
- Stopper status and controls
- Electrical hazards status and controls
- Access state status and controls
- Door / gate status
- Warning tape status and control
- Interlock status and reset control for Emergency Off Circuits, doors and BSOICs where applicable
- Search preset status
- Search reset status and control
- TV monitor for remote monitoring of the zone entry doors
- Intercom or phone to communicate with persons entering or leaving an enclosure
- Control for release of key bank key
- Key bank status
- Control for release of door solenoid

Software Panels

Software-generated panels emulate all of the control and status functions provided by hardware panels, with the exception that no control function to a remote PPS logic chassis is active unless a hardware enable button is also pushed simultaneously with the computer software command.

This additional safeguard, the use of a hardware enable in conjunction with a computer-generated control function, is mandated by the Radiation Safety Committee and by the requirements of the *SLAC Guidelines for Operations*. The reason is that the computer control system is an open system, with no configuration control and no redundancy. Programming errors or software bugs introduced into a beam control program might inadvertently affect safety control programs. Hence the requirement for a hardware backup circuit whenever a safety control function is being exercised through a computer path. Remote key release and door solenoid control are examples of safety control signals requiring hardware backup.

2.1.4.2 Typical PPS Enclosure

Following is a description of a typical PPS enclosure at SLAC. Figure 2-2 shows such an enclosure. It consists of a shielded beam area with a main entrance module and another gate leading to an adjacent beam enclosure.

Its features include:

- An interlocked outer door, with electric strike or magnetic lock, and an emergency exit/entry mechanism
- An interlocked and unlocked inner gate. In some locations, the inner barrier is a movable concrete shielding block or hatch.
- Key bank with 8 or 16 keys
- Door release key switch and push button
- Search preset button inside the enclosure
- Search reset button outside the enclosure
- Emergency-off buttons
- TV camera
- Intercom or telephone
- PPS annunciator sign
- Loud speakers for audio warning
- Flashing lights

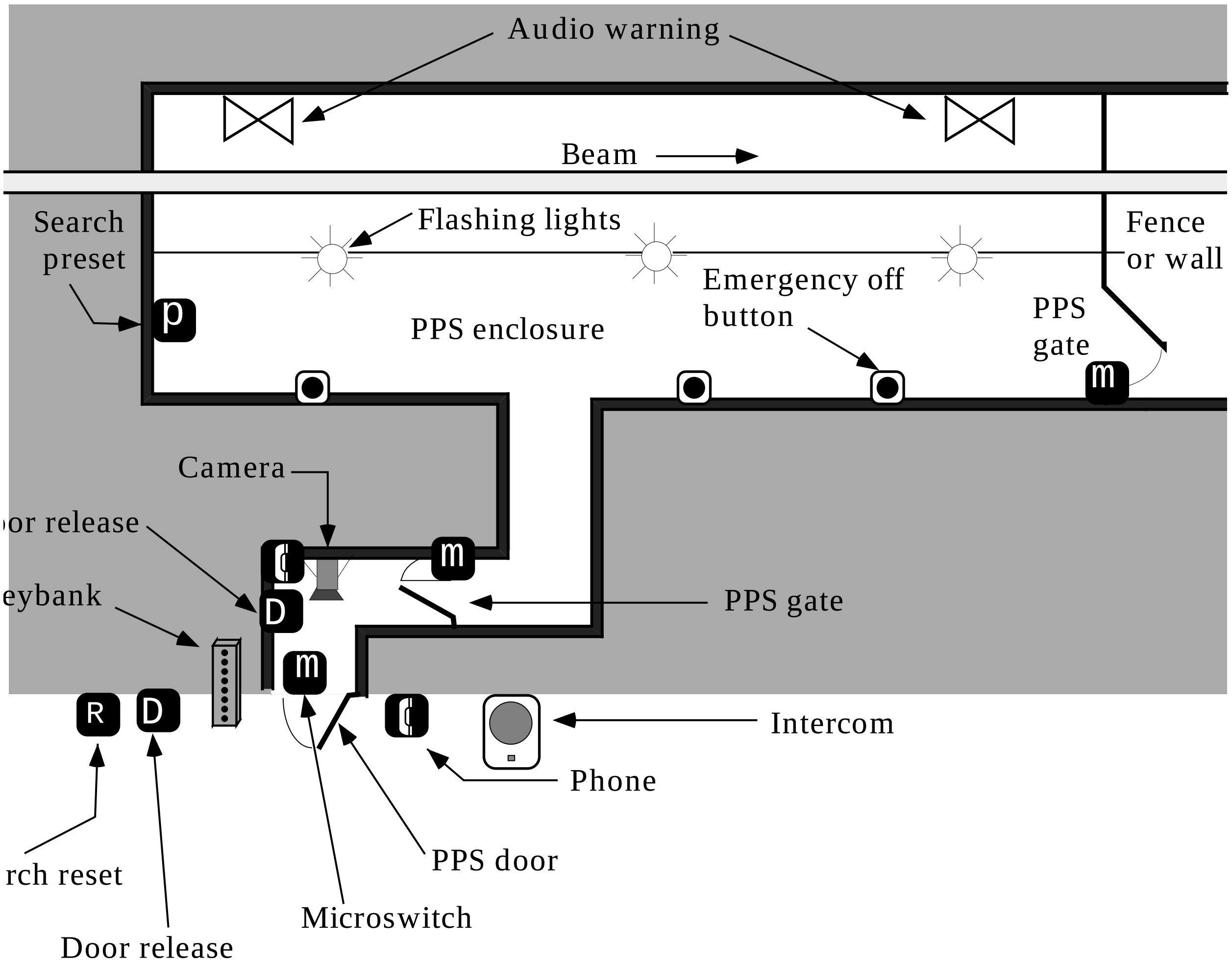


Figure 2-2. Typical PPS Enclosure at SLAC

2.1.4.3 Searching and Securing an Enclosure

Entry and exit procedures, and procedures for searching and securing a PPS area are fully documented for each of the SLAC facilities. Operators are required to be familiar with the procedures and to follow them meticulously.

A general description of the steps necessary to bring an area such as the one shown in Figure 2 from Permitted Access to beam operation is as follows. (For a specific enclosure, searchers would follow the documented procedures for that area.)

1. The PPS operator in the control room makes an announcement over the paging system that the area is about to be searched and that personnel should prepare to leave.
2. The operator sets the area to the Controlled Access state, and releases a key from the local key bank to each member of the search team after

logging the entry in the control room security logbook for the specific area. In simple enclosures such as the one shown, it would be possible for one operator to safely search the area.

3. One member of the search team inserts the key into the door release box, and turns it clockwise, while the control room operator releases the electric door latch.
4. The searchers enter the enclosure, closing the outer door behind them but leaving the inner gate open. (The microswitches on the open door serve as an additional pair of interlocks that prevent the beam from being turned on when an enclosure is occupied). The control room operator checks on the remote TV that each person entering has a key. One searcher goes to the far end of the enclosure, checks that the gate is closed and that the emergency entry mechanism is not faulted, and then pushes the Search Preset switch. Pushing the Search Preset sets a latch in the logic circuit, and in some areas, starts a timer that sets the maximum time allowed for the search.
5. The searcher starts the search at the area adjacent to the Search Preset button and walks back toward the entrance gate, making sure that there is no one on the far side of the beam line. The searchers complete the search, close the inner gate, and contact the control room operator who releases the latch on the outer door. The searchers leave the enclosure, close the outer door, and return all keys to the key bank.
6. The control room operator may now reset the interlocks. Alternatively, in many locations, this may be done at the local control panel outside the enclosure. Resetting interlocks sets latches, or memory circuits on all momentary contacts that connect to the PPS logic circuitry. Momentary contacts are associated with door microswitches, emergency shutoff buttons and emergency entry / exit mechanisms. Providing memory circuits for these contacts ensures that all interlock trips must be acknowledged and reset by an operator. Also, troubleshooting is much easier because momentary failures can be easily detected even if the transient fault disappears.
7. To complete and confirm the search, one of the searchers pushes the Search Reset button outside the door, simultaneously with the control room operator who pushes the Search Reset button for that area. This sets the state called “Search Reset Complete,” assuming that all Emergency-off switches and Emergency entry / exit circuits are in the normal state. Simultaneous operation of the Search Reset function is to ensure that the control room operator remains fully aware that an area has been searched.
8. When Search Reset has been set, the area may now be raised to the Restricted Access or No Access state.
9. Once in the No Access or Restricted Access state, the operator activates an audio warning system which provides a siren sound alternating with a voice warning to the effect that either radiation hazards or electrical hazards may be coming on in the zone concerned. There is also an instruction to push the nearest emergency-off button and to call the operations control room. In addition to the audio warning, the housing lights are flashed from bright to dim for two minutes. They remain in the dim state until the area is set to one of the access states, or until an interlock trip causes loss of security.

10. When the visual and audio warnings are complete, the area is ready for beam and permissives are generated by the PPS logic to allow the beam stoppers to be removed or the electrical loads to be energized.

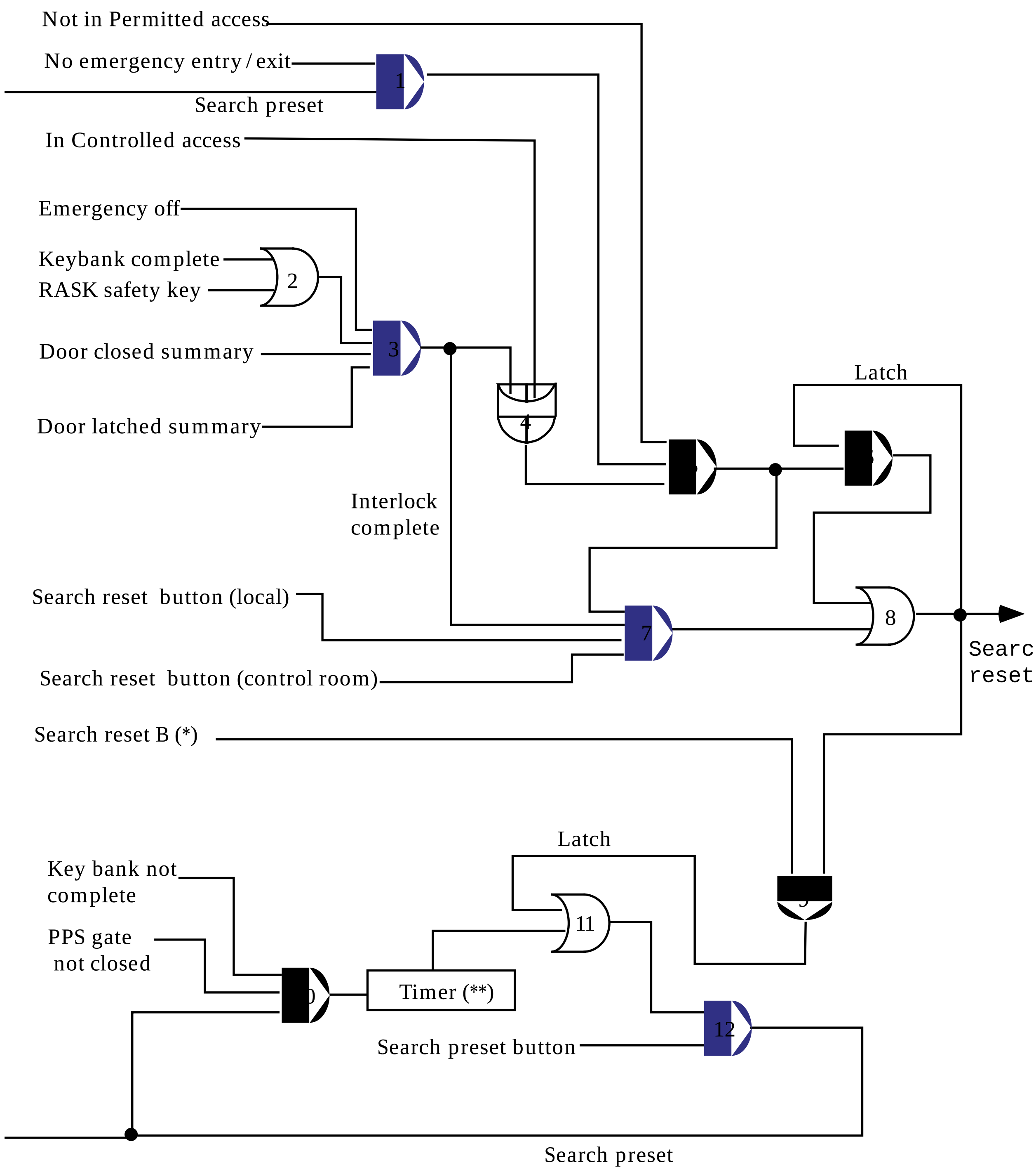
2.1.4.4 Circuit Logic Description

There are several major logic blocks that make up a typical personnel interlock system. These include the:

- Search and secure logic
- Stopper permissive logic
- Electrical hazard logic
- Access state change logic
- Key and door release logic
- Annunciator and warning system logic
- RASK logic

Formal circuit schematics show the detailed interconnections of relay coils and contacts that comprise each logic block and that join logic blocks together. These circuit schematics and wiring diagrams are essential for the construction and maintenance of the system. They are not so useful if only a quick overview of the logic is required. It is often difficult to locate a specific switch or contact on one of the five or six large circuit schematics that describe the logic of a typical zone. For this reason, shorthand methods are often used to describe PPS logic functions. One common method is to use AND / OR logic symbols.

Figure 2-3 is an and / or diagram that shows the Search and Secure functions (Search Preset and Reset) for the enclosure described above. It illustrates the level of complexity contained in a typical logic block. Other functions such as electrical hazard and stopper permissive circuits, key bank key release, door release and access state change circuits (so-called bailing circuits) can be described on similar logic diagrams.



(*) Redundant circuit
(**) Most timers have been disabled

Figure 2-3. Search and Preset Functions

Operation of the search logic circuit is as follows:

- The Search Preset is made up by pushing the preset button which sets an electrical latch or holding circuit shown on the bottom of Figure 2-3. The latch is set when the signal labeled “Search Preset Cmd, S/Pc” is “high” or “true.” The momentary command signal is held at the output of OR Gate 12 if the output of OR Gate 11 is “true.” This signal is “true” when the output of AND Gate 10 is “true.” This AND Gate is satisfied when the key bank is incomplete, which it must be because the searcher has a key, and when the inner PPS Gate is open. This gate would be open for a Controlled Access entry. Note that there is a timer at the output of AND Gate 10. The timer output is initially “true,” and remains “true” for about two minutes after the inner Gate is closed. If the Search Reset has not been made up before this time, the Preset drops out.
- To make up the Search Reset, the searcher closes the inner gate and outer door, returns all keys to the key bank, resets the interlocks and pushes the Search Reset button (S/R C{L}) simultaneously with the control room reset button (S/R C{R}). At this time, all inputs to AND gates 5 and 7 are “true,” and the Search Reset state is “true” at the output of OR Gate 8. This state is held by the latch formed by AND Gate 6.
- The loss of any of the input signals such as emergency-off, key bank complete, etc., will drop the latch and cause the reset to be lost. This in turn, unlatches the preset circuit which remains in the “false” state until the search process is repeated.
- If a beam had been operating in the enclosure when security was lost, the PPS logic would withdraw permissive signals from the radiation stoppers. Loss of these signals causes the mechanical stoppers to drop into the beam line, the electrical stoppers (magnets) to turn off, and other radiation sources, such as klystrons, to be shut down. Electrical hazards would also be turned off.

2.1.4.5 Zone Entry Requirements

A planned entry into a zone may be made in the Permitted Access state or in Controlled Access, depending on the number of people requiring entry and the time that the area is expected to be open. In either case, the stoppers required for entry to the area must be in place before the PPS logic can generate permissives to release keys and to operate door latches. In addition to the requirement that stoppers be inserted, all electrical hazards in the area must be turned off before door latch and key permissives are given.

2.1.4.6 Security Violation

A security violation in any zone that is receiving or is ready to receive beam, must immediately turn off electrical hazards and remove beam-related radiation by inserting the upbeam stoppers and turning off the klystron modulator power sources (VVSs). Thus while normal entry to an area requires only that the appropriate beam line stoppers be inserted and electrical hazards be off, a security violation turns off the electrical hazards, inserts stoppers, and turns off VVSs.

2.1.5 Administrative Procedures

Even the most carefully engineered interlock system can fail to provide protection if not augmented by administrative rules and procedures covering operation, testing, and modifications. These are summarized below.

2.1.5.1 Training

Operators and other users of the PPS are trained by the ES&H Division in the Radiation Worker Training course. Further guidance and reference material is provided in the SLAC *RadCon Manual* and the *SLAC Guidelines for Operations*. Operators receive advanced training in the use of the PPS by senior personnel, and the progress and status of their training is carefully monitored and recorded in PPS Certification Workbooks for each area.

2.1.5.2 Search Procedures

These are formal documents that must be rigidly followed. All unusual or unsafe conditions must be reported to the Accelerator Department Safety Office and these must be corrected or mitigated before beam operation.

2.1.5.3 Validation

Validation of the PPS is done semiannually, following detailed procedures and checklists prepared by the Controls Department and approved by the Accelerator Department Safety Office. The procedures include radiation interlock tests, electrical hazard tests and system tests.

2.1.5.4 Testing

Whenever an area is searched, specific tests must be done on door microswitches and emergency-off buttons by members of the search team. These tests are described in the Accelerator Department PPS Interlock Checklists. Also, whenever an area is open, a safety inspection of the radiation protection devices must be made in accordance with written procedures. These are described in the Safety Inspection Checklists issued by the Accelerator Department.

2.1.5.5 Configuration Control

Procedures that control the modification and retesting of PPS systems are described in the *SLAC Guidelines for Operations*. All changes must be carefully reviewed and approved, and retesting must be done in accordance with an approved procedure.

2.1.5.6 Beam Authorization Sheets

For each beam running cycle, specific safety instructions on beam parameters, the operational safety envelope, and required safety devices, including any special requirements for the PPS operation, are given in the Beam Authorization Sheet (BAS). This is a formal document prepared by the Radiation Physics Department and approved by the Accelerator Department Safety Office. It specifies the operational requirements for a particular beam cycle as authorized by the Radiation Safety Officer (RSO). Operations are constrained to levels which may be significantly below the Accelerator Safety Envelope.

2.1.5.7 Electrical Hazard Testing

Procedures for testing energized magnets in tunnel areas are issued by the Accelerator Department. All personnel involved in high voltage testing must adhere to these procedures.

2.1.6 References

1. "Radiological Safety in the Design and Operation of Particle Accelerators." American National Standard N43.1 1978.
2. National Council on Radiation Protection and Measurements. Radiation Alarms and Access Control Systems, NCRP Report No. 88, December 1986.
3. Health Physics Manual of Good Practices for Accelerator Facilities. SLAC-327 R. C. McCall, April 1988.
4. "Safety of Accelerator Facilities," US Department of Energy, DOE 5480.25, November 3, 1992.
5. SLAC Guidelines for Operations, Chapter 19, "Use of Software-Based Control Systems."
6. SLAC Guidelines for Operations, Chapter 14, "Configuration Control of Radiation Safety Systems."

3 Beam Containment System

3.1 Introduction

Radiation safety at an accelerator requires that beams deposit their energy at pre-selected locations. If beams diverge from their proper channels, high radiation levels can occur in unprotected areas. The Beam Containment System (BCS) prevents accelerated beams from diverging from the desired channel, and detects excessive beam energy or intensity that could cause unacceptable radiation levels in occupied areas.

Containment of beams is usually accomplished by a combination of passive devices such as collimators, that are designed to absorb errant beams, and active devices, such as electronic monitors, that shut off beams when out-of-tolerance conditions are detected. The combination of these mechanical and electronic devices is called the Beam Containment System.

Beam containment may be lost for a number of reasons. In one instance, a magnet was connected backwards in a new beamline. This was discovered during the initial radiation survey. In another case, a beamline component was significantly damaged by the beam. Following the discovery of this damage, tests were conducted on 13 different devices. These were irradiated at various beam power levels, and the time for burn-through was recorded. As an example, a copper cylinder, 15 cm in diameter and 38 cm long, burned through its length in 22 seconds when struck by a 360 kW beam (Reference 1).

Given the destructive power of SLAC beams and the possibility of excessive radiation in occupied areas as illustrated above, formal guidelines and procedures have been adopted to ensure that appropriate protective devices are installed to contain beams. These guidelines, and the devices that are used to provide protection, are described in the following sections.

It should be noted that the Beam Containment System (BCS) is distinct and separate from the Machine Protection System (MPS). The BCS protects personnel against elevated radiation levels in occupied areas. One of the means by which this protection is achieved is to prevent damage to beamline devices that have been designated as having a safety function. The MPS also protects beamline components from damage due to high power beams, but in this case, the components being protected do not have a personnel safety function. Thus even if there were to be significant damage to an MPS device, there would be no increase in radiation levels in occupied areas. The MPS uses many of the same protection techniques and instruments as the BCS, but there is less redundancy and less rigid administrative control compared to the BCS.

3.1.1 Beam Containment Principles

We can define a properly contained beam as one that terminates on a device that can absorb either:

1. The maximum credible beam or
2. The allowed beam power indefinitely.

In this latter case, the device must be protected by appropriate means. (See Glossary, page B-10, for definition of the terms in italics.)

For example, the maximum credible beam that could be delivered to a particular beamline might be as high as 100 kW if all the beam power-limiting interlocks failed. If the dump at the end of the line could absorb 100 kW indefinitely, then the beam would be safely contained at the dump. If, however, the dump had a rating of 50 kW, then it would have to be equipped with a burn-through monitor (BTM) and protected by devices such as ion chambers or temperature detectors that would shut off the beam when the power exceeded 50 kW. (A BTM is a pressurized container that ruptures when excessive beam power causes damage to a mechanical beam containment device.)

Now take the situation where a 50 kW beam is targeted on a 50 kW dump, and the beam is diverted from its proper trajectory in the beamline by either a steering mis-adjustment or a magnet failure. If the beam hits a safety collimator that is rated for 50 kW, no additional protection is needed. If the collimator is rated for less than 50 kW, it must be protected by BCS devices in a similar manner to the dump protection.

These two examples illustrate the need for an electronic protection system in addition to the mechanical devices. The electronic system serves three basic functions:

1. To monitor and limit the beam power in a beamline to the allowed value,
2. To limit the losses along a beamline that is operating at its allowed power, and
3. To protect safety-related beamline components from damage.

Thus we can arrive at a definition of beam containment as follows:

BCS is a combination of mechanical devices (e.g., collimators and beam dumps) and associated protection devices (e.g., current toroids or ionization chambers) that assure that a beam is confined to an approved beam channel at an approved allowed beam power.

3.1.2 BCS Policy and Implementation

The SLAC Beam Containment Policy and the Implementation Guidelines are given on page 3-7. These are formal documents that are used by the Radiation Safety Officer (RSO) and the Radiation Safety Committee (RSC) to ensure that all safety requirements are incorporated into the design of new or modified beamlines.

3.1.3 Mechanical Beam Containment Devices

3.1.3.1 Failure Mechanisms

Mechanical devices that are used to contain beams are subject to damage or destruction from either loss of coolant or when design specifications are exceeded. (See Reference 1 for a detailed discussion of this topic.)

3.1.3.2 Loss of Coolant

Most SLAC power absorbers that are designed to dissipate more than a few hundred watts of beam power on a regular basis are water-cooled. Their safe operation depends heavily on the proper functioning of the cooling system. Malfunctions in this system such as loss of coolant due to a leak, loss of flow due to pump failure, or excessive inlet water temperature due to loss of heat exchanger capacity can have disastrous consequences for the heat dissipating areas of the power absorbers, even though the beam power may be within the rating of the absorber. Failure is generally due to melting in the areas of high beam power deposition, but other mechanisms, such as plastic deformation and/or fracture due to thermal stresses exceeding the yield and tensile properties of the material, may also contribute. The latter may occur in combination with thermal fatigue due to the pulsed nature of the beam.

3.1.3.3 Design Limits Exceeded

Since not all power-absorbing devices are called upon to dissipate the maximum allowed beam power for indefinite periods of time, there are a wide range of design limitations for the devices in each beam line. For example, there are protection collimators with an average power absorption limit of 5 kW in beam lines that are operated at power levels up to maximum machine output. These collimators are protected against excessive power deposition by means of ionization chambers and temperature detectors in the water system, and are equipped with BTMs that shut off the beam if the collimator is damaged.

3.1.3.4 Device Descriptions

The specific mechanical devices used for containment are:

Protection Collimators

These are placed in strategic locations to intercept a mis-steered beam and prevent it from entering another beam port or from striking a shielding barrier. These devices are either cooled or un-cooled, depending on whether they intercept beam on a regular basis. They are typically at least 20 X0 (radiation lengths) long. They offer good protection, except where a high-power beam impinges at grazing angles along the aperture. Typically they are equipped with a BTM and protected by devices such as ionization chambers, temperature sensors and flow switches. If the electronic protective devices fail to shut off the beam, collimator burn-through could occur within a few seconds at power levels of 100 kilowatts. In this event, the BTM would turn the beam off within one to two seconds after the detection of damage to the collimator.

Beam Dumps and Beam Stoppers

These are designed to absorb a beam of specific power for an indefinite period. If they are designed to absorb the maximum credible beam, no protection devices are needed.

Burn-Through Monitors

BTMs are used to detect the onset of damage to collimators, dumps and stoppers. BTMs are pressurized cavities, usually located at or near shower maximum, that are designed to rupture when the device being protected absorbs greater than its allowed beam power. A pressure switch connected to the cavity turns off the beam through the personnel protection system (PPS). The switch acts through energized relays that de-energize on either a BTM fault, the loss of power, or a short or open circuit on any connecting cable.

Blow-Out Fuses

These fuses are an integral part of the stopper assembly. When excess power is absorbed by the stopper, the fuse melts, allowing air to enter the beamline vacuum pipe, resulting in beam scattering.

3.1.4 Electrical Beam Containment Devices

Bending magnets are frequently used as protective devices in the containment system. Typically the magnet polarity, the magnet current, and the on / off status of the power supply are monitored and interlocked, such that when an out-of-tolerance condition is detected, the beam is deflected into a safe location, or is prevented from entering a beamline that has an inadequate power rating.

3.1.5 Electronic Beam Containment Devices

If mechanical containment devices could be designed to absorb the maximum credible beam power, there would be no need for additional electronic protection or for the installation of BTMs. However, cost and physical space limitations preclude such an approach in most beamline designs. The alternative is to provide fast electronic protection for devices and beamlines. The electronic devices in the BCS provide this protection. (As noted earlier, the BTMs do not act through the electronic shut-off circuits of the BCS. They operate directly through the PPS to shut-off beams.)

3.1.5.1 BCS Electronics

Each electronic protection path or system, from the sensor (ion chamber, flow switch, etc.) to the processing electronics, is designed to be as fail-safe as possible, with self-checking signals that serve to confirm the correct operation of the sensor and electronic module. This continuous self-checking coupled with formal administrative procedures, provide a protection system that has both high reliability and high availability. (See Reference 4 for more information.)

3.1.5.2 Design Philosophy

- All systems incorporate continuous self-checking features to ensure integrity of the transducer, the cabling, and the electronic processing unit.
- All pulsed equipment, with the exception of ion chamber electronics, utilizes narrow window gating (5-10 µs) at beam and test time to reduce the effects of noise that may be introduced into the electronic modules via the cable plant.
- The protection devices in each beam line are independent of each other and are different whenever possible. For example, one protection channel might monitor the average beam current while another monitors the beam repetition rate. Type diversity such as this reduces the chances that a common mode failure would disable both channels simultaneously. In practice, three or more independent devices are used for protection in most beamlines.
- Beam power is monitored by measuring beam current. Beam energy is known because the number of klystrons accelerating the beam is known, or the field strength of bending magnets (or the magnet currents) can be measured. Beam current is typically measured by beam line current transformers (toroids).
- The requirement for verification that a beam has reached its proper destination without significant beam loss is met by using toroid comparators that measure and compare beam current on a pulse-to-pulse basis at two locations in a beam line.

- Beam loss in a beamline may also be measured by discrete ionization chambers placed near mechanical devices or by long ion chambers that protect a section of the beamline or the whole beamline.
- When a fault is detected, beams are shut off by three independent methods.
- Equipment and cabling is protected in locked racks.
- Operation of the equipment is checked daily using formal procedures.

3.1.5.3 Beamline Sensors

Typical sensors, or transducers, used in the BCS include ionization chambers, beam current toroids, flow switches and temperature detectors.

3.1.5.4 Processing Electronics

Signals from transducers are processed in electronic modules that shut off the beam when out-of tolerance conditions are detected.

Processing modules measure:

- Average current
- Charge per pulse
- Beam repetition rate
- Beam loss between two beamline sensors (toroid comparator)
- Beam loss along a beamline (long ion chamber)
- Beam loss at a point (discrete ion chamber)
- Temperature of devices or water systems
- Position of stoppers and other mechanical devices

3.1.5.5 Beam Shut-off Paths

Beam shut-off for a BCS fault has the following characteristics:

- High speed — within a few beam pulses
- Redundant — three shut-off methods are used
- Diversity — each shut-off method is different

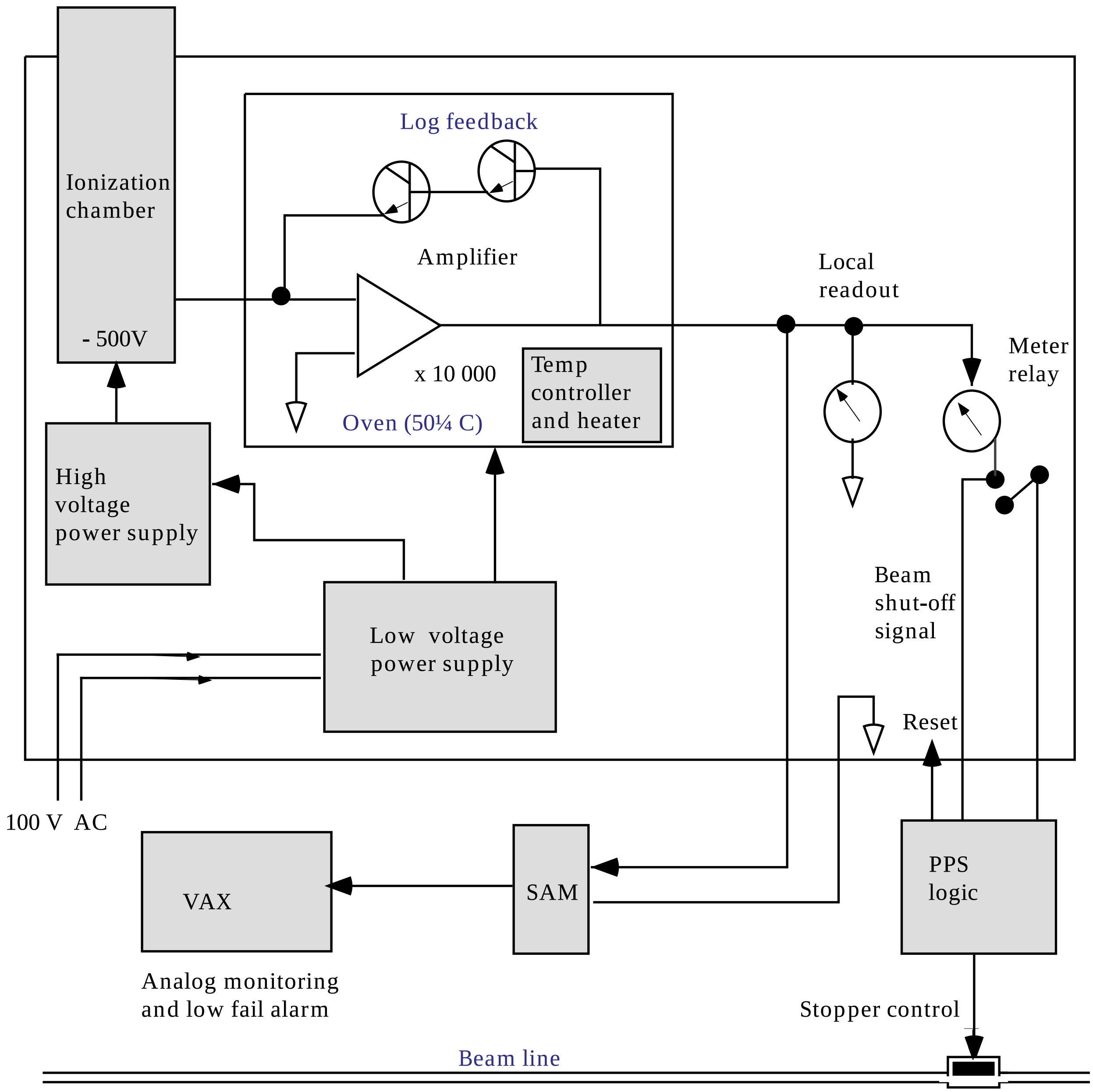


Figure 3-1. Typical BCS Signal Distribution

3.1.6 Beam Containment Policy

The SLAC policy for containing beams requires all three of the following to be met:

1. Primary beams must be prevented from escaping Beam Containment.
2. Secondary beams must also be confined if they are of sufficient power to exceed SLAC radiation design limits.
3. Primary and secondary beams must be prevented from striking beamline components or the shielding enclosing the Radiation Containment Area if this results in radiation levels in occupied areas that exceeds SLAC radiation design limits.
4. Primary and secondary beams must be turned off if excessive radiation levels occur in occupied areas or if the beam power striking a device, which is designated to contain the beam, exceeds the power limit of the device.

3.1.7 Implementation Guidelines

To achieve the goals stated in the policy, the following guidelines have been adopted:

Beamlines are designed by beamline engineers or physicists:

- With advice from Radiation Physics.
- Using these Beam Containment guidelines.
- With consultation from the RSO for variances.
- With the advice from RSC before construction starts.

Design of beamline includes an estimate of the maximum credible beam power that can be delivered, and the specification of the locations of mechanical containment devices with their power absorption capabilities. Ray traces should be included that demonstrate the normal beam path and the consequences of beam mis-steering. Shielding calculations must be made for potential beam losses.

In the description below, unless otherwise stated, the radiation levels in occupied areas must not exceed the allowable levels for normal beam operation.

3.1.7.1 Equipment Requirements

1. The beam power in a beamline must be limited to the allowed beam power by each of three independent protection devices if the allowed power is less than the maximum credible beam power.

   Beam losses in Radiation Containment Areas may need to be limited by two protection devices to prevent radiation levels in occupied areas from exceeding those given in Section 3.1.7.3 on page 3-9 for normal beam operation.

2. Mechanical Beam Containment devices, such as dumps, collimators, and stoppers must either:
   - Be capable of intercepting the maximum credible beam power for an indefinite time period, or
   - If not able to absorb the maximum credible beam power, must be protected by at least two protection devices.

   These devices must turn off the beam to prevent exceeding the power limit of the mechanical device. If the mechanical beam containment device is capable of intercepting the allowed beam power, the protection devices in Point 1 may serve this function.

If the protection devices mentioned in Points 1 or 2 fail and the maximum credible beam strikes a mechanical device, the radiation levels in occupied areas must not exceed the allowable levels for accident cases given in Section B.8.1.3 on page B-9.

3. Mechanical beam containment devices as described in Point 2 must also be equipped with a BTM over as large an area as the beam can be steered if the device cannot absorb the maximum credible beam indefinitely.
4. Beam containment devices, such as magnets, and mechanical and electronic protection devices, must be designed or implemented to fail in a safe manner.
5. PPS stoppers are considered to be beam containment devices in that their function is to “contain” the beam upstream of a secured area when access is permitted. The required redundancy of PPS stoppers depends on the beamline design.
   - If the beamline is designed to permit beam to be incident on the first stopper when access is permitted to the beamline downbeam of the stoppers, two additional PPS stoppers are normally required. If fewer stoppers are used, the design must be justified on the basis of adequate safety.
   - If the beamline is designed so that the beam cannot be incident on the first PPS stopper unless a prior failure occurs, then at least two PPS stoppers are normally required. If fewer stoppers are used, the design must be justified on the basis of adequate safety.
   - One or more magnets can replace one of the stoppers.

   These stoppers must meet the criteria for beam containment devices as indicated in Points 2, 3, and 4 above.
6. Beam shut-off ion chambers (BSOIC) should be associated with each beamline unless it is proven that they are not needed. The BSOIC is responsive to radiation levels, and is not considered as one of the electronic protection devices for limiting beam power or losses.
7. Primary beams must be prevented from entering secondary beam channels unless the secondary beam channels are also completely confined. This may be accomplished by one or more of the following:
   - All bends in the primary beam line must be in different planes than the secondary beam channels.
   - Failure of magnets or the most radical steering, at all energies, must not send the primary beam into the secondary beam channels.
   - Secondary beam channels must be plugged or shadowed with a beam containment device meeting the criteria in Points 2, 3, and 4 above.
   - A redundant system of permanent magnets must prevent the primary beam from entering the secondary beam channels. The permanent magnets must be protected from beam related damage.
   - Charged particle secondary beams can be controlled by proper secondary transport magnet polarity and / or transport energy. The polarity must be properly controlled and / or interlocked into the Beam Containment Shut-Off System.

3.1.7.2 Administrative Requirements

1. All devices described must be certified to function properly before the beamline is operated.
2. Sufficient scheduled accelerator time must be provided for adequate beam containment checkout as prescribed by the responsible Radiation Physicist and the Accelerator Department Safety Office, or the Stanford Synchrotron Research Laboratory (SSRL) Safety Office. To ensure that this time is allocated, line items may be included on the Beam Authorization Sheet (BAS).
3. All protection devices must be protected against unauthorized modification or bypassing. Wherever possible, appropriate fail-safe and self checking features are to be included in the design.
4. Protection devices should be reviewed by the RSC.
5. The burden of proof for the safety of the beamline design lies with the designer. It is not the responsibility of the RSC to prove the safety.

3.1.7.3 Maximum Allowable Radiation Design Levels

The maximum allowable radiation levels in potentially occupied areas are limited to the following:

1. Normal beam operation — The total integrated dose equivalent to an individual outside secured area must not exceed 10 millisievert (1 rem) in a year when running the allowed beam power and the beam is fully contained. This limit shall include radiation levels caused by normal beam losses and occasional mis-steered beam conditions.
2. System Failures— In the event of a BCS failure, the total integrated whole body dose equivalent to an individual outside secured area shall not exceed 30 millisievert (3 rem) for broad beam exposure. Narrow beam, ð2 inch diameter, exposures shall not exceed 120 millisievert (12 rem). With dose rates on the order of 250 millisievert / hr. (25 rem / hr) under accident conditions, the beam must be turned off in approximately 1 / 10 hour to meet these criteria. BTMs must be used to limit the duration of the accident.

   System failures are defined as follows:

   - All the beamline containment protection devices have failed, thereby permitting the maximum credible beam to enter the beamline. Loss of this maximum credible beam at any point shall not cause radiation dose exposure levels to exceed those stated in Point 2, above.
   - If any beam containment device or its associated protection devices fail, such that the beam is no longer properly contained, the resulting radiation levels must be limited as in Point 2, above. Since PPS stoppers are categorized as beam containment devices, the above criteria applies in the event of the failure of any stopper. As long as one stopper remains the above criteria applies.

3.1.7.4 Documentation (For presentation to the Radiation Committee)

1. A documentary description of each beam line should be prepared and circulated to the RSC. Its preparation should be the responsibility of the beam line engineer and the responsible Radiation Physicist.
2. The documentation should contain the following elements:
   - A general beam layout drawing showing all elements of the beam and the adjacent equipment.
   - Ray traces of areas of interest.

- A list of all safety components and a quantitative description of their function.
- A statement of assumptions.
- A description of the accidents envisioned in the design.
- A list and description of routine inspections required to insure integrity of the safety system.
- Description of tests or presentation of calculations that support performance claims of safety features or devices.
- Description of conditions and limitations of the design analysis, i.e., what conditions were not covered in the analysis.

3. All drawings and sketches should contain SLAC drawing numbers and all components should be clearly identified.

3.1.8 References

1. "Tests and Description of Beam Containment Devices and Instrumentation — A New Dimension in Safety Problems." D. Walz et al. IEEE Trans. Nuclear Science. March 1973. NS-20, 465.
2. "Safety of Accelerator Facilities." DOE 5480.25, November 1992.
3. "A Precision Actuator and Shaft Encoder for a High Radiation Environment and Other Beam Component Developments at SLAC." L. R. Lucas and D. R. Walz. SLAC Pub 879, March 1971. IEEE Trans. Nuclear Science, June 1971. NS-18 #3, June 71.
4. "Operational Experience with SLAC's Beam Containment Electronics." T. Constant, K.F. Crook, D. Heggie. SLAC Pub. 1901, March 1977. Particle Accelerator Conference 1977.

4 Beam Shut-Off Ion Chamber System

4.1 Introduction

Beam shut-off ion chambers (BSOICs) are radiation detectors that have been installed in a number of locations around the SLAC site. Their function is to measure beam-related radiation outside the shielded areas and to turn off the accelerator beams if radiation levels exceed design limits. Typically, the limits are set to either 10 millirem / hr or 100 millirem / hr, depending on the location of the BSOIC.

4.1.1 BSOIC Description

4.1.1.1 Ionization Chamber

The ionization chamber and associated electronics are housed in a watertight cylindrical can, 10 inches in diameter by 28 inches high. The ionization detector is a 10-liter aluminum chamber filled with ethane at one atmosphere. Aluminum and ethane are approximately tissue-equivalent for photons in the energy range from 200 KeV to 10 MeV. Ethane was selected to enhance the response to fast neutrons. The chamber response to neutrons is about 20% less than its response to the same dose of photons. Since warning and trip levels are adjustable, this under-response can be calibrated out.

The chamber is designed to produce one pA / mrad / hr at 10-liter-atm with a collecting potential of 500 V. It has been checked for saturation in fields up to 100 rads / hr. The nominal operating range is from one to 1000 mrad / hr.

4.1.1.2 Electronics

The entire unit is AC-powered and the electronic processing is all solid-state. The collecting potential is provided by a 500 V internal power supply. The log converter consists of two base-to-emitter junctions in series as the major part of a feedback network in an operational amplifier. This amplifier has a dual MOS-FET input and has an open loop gain of the order of 10,000. Primarily because of the temperature dependence of the log converter, the entire circuit is enclosed in an oven operating at approximately 50°C. The proportional controller for the oven uses a thermistor for temperature sensing. Within 1 / 2 hour from a cold start, the oven stabilizes to within ±0.1°C. The entire oven temperature control circuit is also located within the oven housing.

The oven housing measures approximately 3 1 / 4 x 3 1 / 4 x 2 1 / 4 inches. The log converter uses two 2N2913 transistors. These exhibit an almost ideal logarithmic characteristic (i.e., base-to-emitter voltage versus base-to-emitter current) over the range of 10–5 to 10–12. The complete electronic diagram including oven control, is shown on drawing SD-123-823-00, available from SLAC Document Control.

4.1.1.3 Fail-safe Design (Self-Test)

To provide fail-safe operation, a 0.4 -µCi90 Sr. source is incorporated within the chamber. The source produces a current corresponding to about 2 mrads/hr. This “housekeeping” current generates a continuous analog voltage at the output of the integrator. When the output signal drops below a preset level, indicating either a deterioration of the source, a fault in the electronics, or an open circuit or short circuit on the wire pair to MCC, an alarm is generated and the BSOIC is replaced or repaired.

4.1.1.4 Power Disconnection

In addition to the fail-safe operation provided by the internal source, the BSOIC is fail-safe when AC power is disconnected. To prevent inadvertent disconnection, and thus the shutting down of the accelerator, the AC plugs are protected by locking collars.

4.1.1.5 Cable or Connector Disconnection

When the signal cable that connects the BSOIC to the external safety devices (stoppers) is disconnected or short circuited, the accelerator is immediately shut down.

Glossary

Term	Definition
Allowed Beam Power	The highest primary power permitted for the beamline in question by administrative and / or electronic restraints. The Radiation Physicist responsible for the beamline determines the allowable beam power.
Beam Containment System (BCS)	A beam channel defined by a system of devices, i.e., shielding, dumps, collimators, stoppers, magnets, or electronic restraints, designed to "contain" the beam and / or limit the beam power and / or beam losses to prevent excessive radiation in occupied areas. The BCS confines a beam to an approved channel at an approved Allowed Beam Power.
Beam Containment Shut-off System	This system utilizes two electronic summary modules that shut off the beam by three independent methods.
Beamline Engineer	The engineer responsible for the design of the beamline, including the provision of all safety devices such as collimators, dumps, ion chambers, and other containment devices.
Beam Shut-Off Ion Chamber (BSOIC)	A device wired into the PPS to put in beam stoppers (or turn off gun High Voltage) if radiation is detected above a pre-set level.
Blowout Fuse	A thermal plug that is part of a stopper assembly. It is designed to rupture when the beam power absorbed by the stopper exceeds the design value. Air enters the accelerator vacuum pipe and the beam is scattered.
Burnthrough Monitor (BTM)	A device wired into the PPS to turn off the VVSs if the BTM mechanical beam containment device has melted. BTMs are presently limited to pressure or vacuum release. The BTM must turn off the VVSs in less than 1 / 10 of the calculated burn-through time of the beam containment device when the device is absorbing greater than the specified beam power.
Radiologically Controlled Area (RCA)	Areas that may contain potential radiation hazards. In these areas, a dosimeter must be worn at all times.
Ion Chamber	A beamline device that responds to beam-related ionizing radiation. It consists of a gas-filled chamber with an inner electrode at high voltage. The output signal current is transmitted on coaxial cable to an integrating circuit in one of the support buildings. The integrator output trips a comparator circuit when the ionization level exceeds a pre-set level.

Maximum Credible Beam — The highest credible beam power the accelerator can deliver to the point in question assuming all protection devices have failed.

Normal Beam Operation — Beamlines operated within the allowed beam power, and with well-steered beams.

Personnel Protection System (PPS) — A combination of devices and logic systems that includes access control and warning systems and beam stoppers. The PPS prevents access to Secured Areas when beam is possible or present and prevents the radiation dose rate from exceeding the shielding design criterion, 10 mSv / y (1 rem / y), inside Secured Areas when access is permitted.

PPS Stopper Beamline Design — The required redundancy of PPS stoppers depends on the beamline design. The requirements are:

1. If the beamline is designed to permit beam to be incident on the first PPS stopper when access is permitted to the beamline downbeam of the stoppers, two additional PPS stoppers are normally required. If fewer stoppers are used, the design must be justified on the basis of adequate safety.
2. If the beamline is designed so that the beam cannot be incident on the first PPS stopper unless a prior failure occurs, then at least two PPS stoppers are normally required. If fewer stoppers are used, the design must be justified on the basis of adequate safety.
3. One or more magnets can replace one of the stoppers.

Properly Contained Beam — A beam that terminates on a device that can absorb the Maximum Credible Beam indefinitely, or one that can absorb the Allowed Beam indefinitely, provided it is protected by appropriate means such as ionization chambers, and is equipped with a BTM. The beam must be Properly Contained when the BCS and PPS are functioning properly.

Protection Devices — Electronic circuits or modules connected to beamline transducers such as toroids, flow switches, or ion chambers that prevent the beam rate, beam power, temperature, or beam losses from exceeding specified values. When out-of-tolerance conditions are detected by these electronic modules, beams are shut off by the Beam Containment Shut-Off System.

Radiation Accident — A Radiation Accident occurs when a System Failure of the BCS or PPS allows:

1. The Safety Envelope to be exceeded, such as a radiation dose rate existing outside Secured Areas or inside Secured Areas where access is permitted so that an individual could receive more than 250 mSv (25 rem) in one hour.

2. A person to gain access to, or remain inside a Secured Area when access in not permitted, such as a No Access State.
3. Because the radiation level inside a Secured Area when access is not permitted could exceed 250 mSv / h (25 rem / h), a System Failure of the PPS would be classified as a Radiation Accident.

Radiation Containment Area
: An area designed to confine hazardous radiation and prevent personnel access by means of shields, fences, procedures, etc. The adequacy of such enclosures must be approved by the Accelerator Department Safety Office or the SSRL Safety Office and the Radiation Physics Department.

Responsible Radiation Physicist
: That member of the Radiation Physics staff assigned to the design and operation of a specific beam line.

Safety Envelope
: The administrative guideline for facility design limits the dose to an individual to 30 mSv (3 rem), or the dose rate to 250 mSv / h (25 rem / h).

Secondary Beam Channels
: A beamline in which the incoming beam is the result of an interaction of the primary beam with a target or a synchrotron radiation beamline.

Secured Areas
: Radiation containment areas whose doors or gates are locked with strictly controlled keys or are interlocked in the PPS.

BCS System Failure
: System failure of the BCS occurs when:

1. All the beamline containment protection devices have failed, thereby permitting the Maximum Credible Beam to enter the beamline.
2. When any beam containment device or its associated protection devices has failed such that the beam is no longer Properly Contained.

PPS System Failure
: System failure of the PPS occurs when there is a failure of any PPS access control, warning, or beam containment where:

1. Personnel can gain access to, or remain inside Secured Areas when beam is possible or present.
2. The beam is no longer Properly Contained, or system redundancy is degraded.