

SLAC-TN-93-3

May 1993

(TN)

**THE PERSONNEL PROTECTION SYSTEM FOR A
SYNCHROTRON RADIATION ACCELERATOR FACILITY:
RADIATION SAFETY PERSPECTIVE**

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ABSTRACT

The Personnel Protection System (PPS) at the Stanford Synchrotron Radiation Laboratory is summarized and reviewed from the radiation safety point of view. The PPS, which is designed to protect people from radiation exposure to beam operation, consists of the Access Control System (ACS) and the Beam Containment System (BCS). The ACS prevents people from being exposed to the very high radiation level inside the shielding housing (also called a PPS area). The ACS for a PPS area consists of the shielding housing and a standard entry module at every entrance. The BCS prevents people from being exposed to the radiation outside a PPS area due to normal and abnormal beam losses. The BCS consists of the shielding (shielding housing and metal shielding in local areas), beam stoppers, active current limiting devices, and an active radiation monitor system. The system elements for the ACS and BCS and the associated interlock network are described. The policies and practices in setting up the PPS are compared with some requirements in the U.S. Department of Energy draft Order of Safety of Accelerator Facilities.

Works Supported by Department of Energy Contract DE-AC03-76SF00515.

INTRODUCTION

The Stanford Synchrotron Radiation Laboratory (SSRL) is located within the site of the Stanford Linear Accelerator Center (SLAC). Although they are operated independently, SSRL conforms to the same requirements as SLAC with regard to environment, safety, and health issues. Figure 1 shows that SSRL complex consists of an Injector and a storage ring called SPEAR (Stanford Positron Electron Asymmetric Ring). The Injector is comprised of a 2.5 MeV RF (radio frequency) gun, a linear accelerator capable of accelerating the electrons up to 150 MeV, and a 3 GeV Booster synchrotron. There are three beam transport lines. The Linac-to-Diagnostic room (LTD) line transports the beam from the Linac room to the Faraday cup in the Diagnostic room for beam diagnosis. The Linac-to-Booster (LTB) line directs the beam from the Linac room to the Booster for further acceleration through a 760 keV maximum RF cavity. The Booster-to-SPEAR (BTS) line transports the beam from the Booster to SPEAR. Barrier D and gate E are used to separate the Booster from SPEAR. SPEAR is also capable of accelerating its stored beam ($100 \text{ mA}, 4.9 \times 10^{11} \text{ e}^-$) through its two RF cavities. Note that the beam parameters (energy and intensity) shown in Figure 1 are design limits, not physical limits. Figure 1 also shows the nine main synchrotron radiation beamlines: the synchrotron radiation in beamline numbers 1, 2, 8, and 3 are generated from bending magnets, the synchrotron radiation in beamline numbers 7, 10, 6, and 4 are from wigglers, and the synchrotron radiation in beamline number 5 is from an undulator.

The possible radiation protection problems for the workers and the general public from the SSRL operation are shown in Figure 2. The problem for the general public outside SLAC is mainly the neutron-photon skyshine radiation to the site boundary, which are monitored continuously with six active peripheral monitoring stations at SLAC. The x-ray radiation hazard is mainly from the klystrons, which provide RF power to the Linac cavities for electron acceleration. However, the x-ray has been reduced to an acceptable level with

local lead shielding, which was placed around the collector as part of the klystron structure. Minor problems for the workers include the induced activity, ozone in the insertion device beamlines, radioactive gases, and muons, and some has been described in a comprehensive report (1). This paper will only discuss the Personnel Protection System (PPS), which is designed for the major radiation protection problems for the workers. The major problems for the workers/users at SSRL are the very high neutron, photon, and electron radiation levels inside the shielding housing (called a PPS area), the neutron-photon radiation outside the PPS areas, and the synchrotron radiation and the gas bremsstrahlung problems in the beamlines.

Recognizing the radiation protection problems between accelerator and nuclear facilities are different, the US Department of Energy (DOE) is preparing an Order of the Safety of Accelerator Facilities (SAF) (2) and the associated implementation guidance document (3). Some of the radiation protection policies and practices used in setting up the PPS at SSRL are compared with the requirements in the draft Order of SAF.

PERSONNEL PROTECTION SYSTEM (PPS) FOR THE WORKERS

The PPS is defined in this paper to be a system protecting people from exposure to beam radiation (this is the prime purpose) and electrical hazards. Figure 3 shows that the PPS's two major systems and the associated interlock network: the Access Control System (ACS) which keeps people from being inside a PPS area where beam may be running, and the Beam Containment System (BCS) which not only limits the beam power, but prevents beam from escaping from its prescribed channel.

There are four major PPS area classifications at SSRL: the Linac and Diagnostic rooms (called the Linac here), the Booster, SPEAR, and the synchrotron radiation experimental hutches. The beam can be in one or more PPS areas, while the remaining PPS

areas are in safe-access states. Figure 1 also shows the six entry points to the three PPS areas of the Injector and SPEAR.

There are generally four access states for a PPS area (see Table 1):

1. Permitted Access (PA): The PA state allows unlimited and uncontrolled entry, and both the radiation and electrical hazards are interlocked to be off.
2. Controlled Access (CA): The CA state allows limited and controlled entry, and both the radiation and electrical hazards are interlocked to be off.
3. Restricted Access (RA): The RA state allows very limited and controlled entry, and only the radiation hazards are interlocked to be off. Persons are allowed into a PPS area with electrical hazards on to perform special electrical tests with the Restricted Access Safety Key (RASK).
4. No Access (NA): The NA state allows no one in a PPS area, and both the radiation and electrical hazards can be on.

The change of the access state of a PPS area is always in the sequence of PA-CA-RA-NA or NA-RA-CA-PA. A search of a PPS area, following a well-defined procedure, is required after the area has been in PA state. In the CA and RA states, everyone entering the area is required to take a key from the keybank and carries it with him/her during the period of access. There are no CA and RA states for the Linac and the x-ray beamline hutch PPS areas. The personnel protection system for the x-ray beamline hutches is called the Hutch Protection System (HPS) at SSRL. However, for our discussions in this paper, it will be called PPS since the HPS has functions similar to those of a PPS.

Access Control System (ACS)

The DOE Order 5480.11 (4) requires that the entry control system for very high radiation areas shall function automatically to ensure that no people are inside a PPS area where a very high radiation level exists. The radiation levels inside the PPS areas of SSRL

could be much higher than 0.05 Sv h^{-1} (definition of a very high radiation area) ⁽⁴⁾ and, therefore, require the use of ACS. The ACS consists of the shielding housing (concrete structure for accelerator housing and lead-wall housing for hutches) and the entry modules at the entrances of a PPS area (see Figures 3 and 4).

The shielding housing itself is also a physical barrier which makes the access to a PPS area possible only through the entry points. The typical features of the entry module of a PPS area (e.g., see the PPS area A in Figure 4) include:

1. An interlocked and lockable outer door with emergency entry and exit capabilities.
2. An interlocked and unlocked inner gate and a maze. This is the situation for SPEAR entrances. For the Injector, a movable concrete shielding block is used at each entry point, instead of an inner gate and a maze.
3. A keybank and eight keys. In CA or RA state, every person entering the PPS area will take a key with him/her.
4. A key switch and push button for door release.
5. An access and beam status display.
6. Intercom or telephone for communication.
7. TV camera for better visual control.
8. Search reset buttons (used in a search).

The above features allow the operators to maintain access control and allow people a safe entry. The emergency-off push button and the emergency exit are two features that allow people to be able to respond to dangerous beam situations if they are accidentally left inside a PPS area. The above-mentioned features are all required in the guidance ⁽³⁾ and most of them are standard features at SSRL with only a few exceptions. For example, the Linac and the x-ray hutch PPS areas do not have keybank because there are no CA and RA states. Features 2, 6, and 7 are not necessary in the hutch PPS areas either.

Beam Containment System (BCS)

Complementing the ACS, the BCS is designed to protect the people outside the PPS area from exposure to the radiation resulting from the normal and abnormal beam losses. Abnormal beam losses can be resulted from missteered beams and accidents, which will be defined later. Therefore, the BCS consists of four elements (see Figures 3 and 4): shielding (shielding housing and local metal shielding), beam stoppers, active current limiting devices (CLDs), and active radiation monitoring devices (ARMDs). These four elements for the BCS are described as follows.

Shielding

As mentioned in the previous ACS section, the shielding housing serves not only as a barrier for ACS, but also to shield the normal beam losses, together with localized metal shielding, so that the radiation levels outside the housing are below the 10 mSv y^{-1} limit. For abnormal beam loss situations, local metal shielding may also be used to intercept or collimate the beam so that the radiation levels outside a PPS area are within the accepted limits.

The Injector shielding design has been described in detail elsewhere (1,5). Therefore, only a few examples illustrating the Injector shielding design practices (see Figure 5) are reiterated to show the current policies and practices of shielding design at SSRL and SLAC.

There are three shielding design criteria used for the Injector in three different beam loss situations (normal, missteering, and accident):

1. For normal beam losses the annual dose equivalent outside the shield surface is less than 10 mSv . This is a DOE-mandated shielding design limit (4). A design example for this case is that the Linac beam can go to the Faraday cup in the Diagnostic room for 2000 hours per year (see FC in Figure 5). Therefore, the dose equivalent rate outside the

shielding from this normal beam operation is designed to be less than $5 \mu\text{Sv h}^{-1}$ (so the annual dose equivalent is $< 10 \text{ mSv}$). The Booster shielding was originally designed to have a maximum surface dose equivalent rate of $80 \mu\text{Sv h}^{-1}$, because it was planned to be operated for only 120 hours per year. However, due to the conservative models used in the shielding calculation, the measured dose equivalent rates outside the Booster walls in areas that people may occupy frequently were less than $5 \mu\text{Sv h}^{-1}$. Therefore, the limit of the operation period for the Booster has been removed.

2. Due to possible and extreme missteering, the beam can be totally lost at a point. Since no DOE or SLAC mandated limits are available, a guideline of 4 mSv h^{-1} maximum dose rate at the shield surface from such missteering was used by the Radiation Physics Department for the Booster design. For example (see Figure 5), the B2 bending magnet in the LTB line can be misadjusted to have zero or reversed polarity fields. The missteered beams would be intercepted by lead bricks inside the B2 coils so that the beams will not shower in the Booster ring outer wall (this is why it is called beam containment). The maximum dose equivalent rates from the containment of these missteered beams (zero and reversed polarity fields) were estimated to be 3750 and 1800 $\mu\text{Sv h}^{-1}$, respectively, which are below the guideline ($4000 \mu\text{Sv h}^{-1}$). Another similar example in the Booster is the maximum $1300 \mu\text{Sv h}^{-1}$ dose equivalent rate outside the outer wall from the containment of the missteered beam in the quadrupole QF4 in the LTB line (see Figure 5). Although the guideline was not used in all the Linac shielding designs, it turned out that the radiation levels resulting from the missteered beam losses in the Linac are all below the guideline, probably due to the Linac's lower beam energy. Two other Linac examples in Figure 5 show that the maximum dose equivalent rates outside the Diagnostic room from the containment of the missteered beams in the bending magnets M1 and B1 are estimated to be 580 and $530 \mu\text{Sv h}^{-1}$, respectively. Note that this missteered beam containment analysis has been performed for most

bending magnets and some quadruples, for which missteering is possible and the results could be significant. These beam loss scenarios were provided by the SSRL accelerator physicists.

3. The third criterion is a SLAC policy that, from an accident beam loss event, the integral dose equivalent per event shall be less than 0.03 Sv and the maximum dose equivalent rate shall be below 0.25 Sv h^{-1} . The accident beam loss situation is explained below. Figure 4 shows that, according to the SLAC policy, at least three interlocked beam stoppers are required to protect people in a neighboring PPS area (area B in this case), while the beam is in a PPS area (area A in this case). The beam stopper is either a mechanical device that can shield the radiation, or a deenergized magnet that prevents the beam from entering an occupied PPS area. For example (see the LTB line in Figure 5), the three beam stoppers between the Linac and Booster PPS areas are one bending magnet B1 and two mechanical devices ST1 and ST2. Figures 3 and 4 also show that at least three interlocked CLDs (e.g., SSRL uses the average current monitors, ACMs) are required to limit the beam intensity to its designed level. An accident beam loss situation is that, while the interlocks for two out of three beam stoppers or all three CLDs fail, the beam is still on. The worst case of an accident beam loss is then the Linac beam is hitting the beam stopper ST2 while people are inside the Booster ring (i.e., the bending magnet B1 is on while it should be off, the ST1 is out while it should be in and only ST2 is in). The maximum dose equivalent rate inside the ring resulting from this worst case was calculated to be 0.15 Sv h^{-1} , which is below the SLAC limit. The other two versions of this accident beam loss case (i.e., only ST1 works or only B1 works) would result in radiation levels lower than the worst version of 0.15 Sv h^{-1} , due to the extra distance and shielding factors. The above accident beam loss shielding analysis has also been performed for the beam stopper system between the PPS areas of the Booster and SPEAR and for the CLD system of the Linac.

The SPEAR shielding was originally designed for the SLAC beam injection. Some local lead shielding along the beamlines inside SPEAR were added based on the radiation measurement results. The shielding of the SPEAR has been reviewed for the beam from the new Injector. The radiation levels during current SPEAR injection outside the SPEAR walls in areas that may be occupied frequently have been measured to be less than $5 \mu\text{Sv h}^{-1}$. The radiation levels from several missteered beam loss situations were also measured and/or calculated to be within limits. The integral dose equivalent outside the walls from the SPEAR stored beam loss (only $4.9 \times 10^{11} \text{ e}^-$ at 3 GeV) is generally insignificant, compared to that from an injection loss.

Beam Stoppers

Figure 6 shows the beam stopper systems at SSRL. As discussed before, the three beam stoppers required to block the beam from the Linac to the Booster are the bending magnet B1 and the mechanical devices ST1 and ST2 in the LTB line. The three beam stoppers that block the beam from the Booster to SPEAR are the ejection septum, the bending magnets BTS B2 to B6, and the mechanical device ST17 in the BTS line. The three beam stoppers inside the SPEAR ring to dump the stored beam are the mechanical devices 18ST1, 18ST2, and the VM1 valve.

There are nine main synchrotron radiation beamlines and 25 branch beamlines (13 x-ray and 12 vacuum ultra violet, VUV, lines). There are a total of 28 experimental end stations (also called hutches in the x-ray branch lines). Not all the beamlines have the same radiation safety features. Only the general features are described here to illustrate the protection requirements and principles for the beamlines.

Figure 6 also shows that the two injection stoppers in each main beamline used to stop the SPEAR injected beam from accidentally going into the beamline during injection. The water-cooled movable mask is to absorb the intense synchrotron radiation and to protect

the two injection stoppers. The movable mask and the two injection stoppers in every main beamline are interlocked to be in when the injection septum of SPEAR is on. The beam stoppers to stop the gas bremsstrahlung from going to the x-ray hutch are two mechanical devices called hutch shutters in the x-ray branch line. The two hutch shutters are interlocked to be in when the hutch is in PA state. There is also one fixed beam stop in the end of the x-ray hutch or in the median plane of the VUV line to stop the gas bremsstrahlung. There is one (or two) beam shutter followed by an isolation valve for each VUV branch line, similar to the function of hutch shutters for the x-ray line.

Active Current Limiting Devices: CLDs

The maximum beam intensity in the Linac (and thus the Booster and SPEAR) was limited to 3.1×10^{10} electrons per second (10 pulses per second) by a magnet chopper (which chops 99.9% of the beam from the RF gun) and, originally, two average current monitors (ACMs). The Linac has three accelerating sections, each with a 50 MeV maximum acceleration. The chopper, the first ACM, and the second ACM are located before the first section, after the first section, and after the third section of the Linac, respectively (see the schematic drawing in Figure 6). However, the operational experience has later demonstrated that, through misadjustment of the pre-chopper components, a transmission efficiency much higher than the design value of 0.1% through the chopper is possible, even though unlikely. This then violates the SLAC policy of a minimum of three interlocked CLDs needed for each primary beamline. Therefore, an additional ACM was added next to the first ACM and additional local shielding was also installed over the first Linac section, so that the shielding design limit for the missteering and accident beam loss cases are met.

Active Radiation Monitoring Devices (ARMDs)

The Beam Shut Off Ionization Chambers (BSOICs), designed and made at SLAC, are used as the active radiation monitoring devices at SSRL (see Figures 3 and 4). Figure 5 illustrates how the BSOICs are used at SSRL for monitoring the radiation levels from either the missteered or the accident beam loss situations. BSOIC S4 located outside the outer wall of the Booster is to monitor the radiation levels from the possible missteered beams from the bending magnet B2 and the quadrupole QF4. BSOIC S3 located inside the Booster ring is to detect the radiation levels from the unlikely accidental beam loss in ST2. There are two other BSOICs located on the roof of the Linac and Diagnostic rooms over the LTB and LTD lines (shown as S2 and S23 in Figure 7) to detect the possible beam missteering in the transport lines. The purposes of the other BSOICs in Figure 7 are explained as follows. BSOICs S6, S20, and S7 are used to monitor the missteered beam losses along the BTS line. BSOICs S1 and S22 are used to monitor the radiation from the chopper failure problem mentioned previously. BSOICs S8-S19 are used to monitor the SPEAR injection losses. The response times of the BSOICs around the SPEAR ring have been increased so that they will not respond to the short-period radiation spike resulting from a stored beam dump.

The BSOICs are interlocked to trip the beam off, if the preset trip level (generally at 0.5 mGy h^{-1}) is exceeded or the BSOIC power supply is lost. BSOICs also have a low alarm level generally set at 0.1 mGy h^{-1} for warning purpose. The BSOIC S3, whose trip level is set at 0.1 mGy h^{-1} , is bypassed automatically when the Booster is in No Access state. BSOIC has a nearly tissue-equivalent ionization chamber (a ten-liter aluminum cylinder of 24 cm diameter and 24 cm height filled with one-atm ethane, C_2H_6). A small $^{90}\text{Sr-Y}$ source is fixed inside the cylinder generating a signal of about $25 \mu\text{Gy h}^{-1}$ to act as a continuous internal check source to ensure that the BSOIC is working. With a high voltage

of 500 volts, the collection efficiency of a BSOIC is higher than 95% in a pulse field of 10 pulse per second and an average photon intensity less than 0.01 Gy h^{-1} .

Due to its near tissue-equivalence, BSOIC has equal dose response to photons and neutrons. On a dose equivalent basis, the neutron response is only 10% to 30% of photons, depending on the neutron spectrum (6). However, this is not a major problem for the mixed field monitoring at SSRL, because the radiation fields expected in the BSOIC locations from the missteering and accident beam losses are dominated by photon radiation.

Beam Interlock Network

The interlock network of the PPS for SSRL is shown in the dotted lines in Figure 3. If any ACM detects electron intensity higher than the design limit, the interlock system will remove the triggers to the modulators and the triggers to the RF amplifiers, and thus turn the beam off. Any BSOIC detecting radiation levels higher than its trip level will also remove the triggers. These problems can be regarded as violations of the BCS.

The access state of a PPS area is also interlocked to the status of the relevant beam stoppers. For example, the access to the Booster ring requires that the LTB stoppers (LTB B1 magnet, ST1, and ST2) be in/off and the Booster RF cavity be off (the electrical hazards are also off). If there is an ACS violation in a PPS area, e.g., a forced entry, the relevant stoppers will respond. Such responses are shown in Table 2. For example, if there is an ACS violation in any x-ray hutch, the two hutch shutters, the three SPEAR ring stoppers, and the three BTS stoppers will respond (i.e., the mechanical devices will be in and the magnets will be off). The LTB stoppers and the Booster RF will respond unless the BTS stoppers were already in. No response in the Linac is necessary in this case. If there is an ACS violation in the Booster ring, the first response is that the LTB stoppers will be in and the Booster RF will be off. The Linac will respond unless the LTB stoppers were already

in. The Linac response is that the high voltage power supply for the modulators and the triggers to the modulators will be off.

DISCUSSION

This section will discuss the PPS of SSRL and compare it with some requirements in the draft Order of SAF. The shielding, beam stoppers, and current limiting system of the BCS are three most important engineering measures to control the radiation hazards. According to the draft Order of SAF, these system designs should be analyzed systematically using the concept of risk matrix (2,3).

The risk matrix method evaluates the risk level of a system failure event according to both the probability level and the consequence level of such event, and then determines the acceptability of the system. There are four levels proposed for the event probability, consequence level, and risk level: high, medium, low, and negligible (or extremely low). A system would be acceptable if the estimated risk level is low or negligible. If either the probability level or the consequence level of a system failure event is extremely low, the risk level will be low or negligible. If both the probability and consequence levels are low, or one is low while the other is medium, the system is also acceptable. The remaining situations are not acceptable and revisions of the system are necessary.

Shielding Design and Safety Analysis

As mentioned early, in the SSRL and SLAC shielding design, three criteria are used for three different beam loss situations. Table 3 summarizes the risk analysis for the shielding designs, using the risk matrix method. The design limit of 0.01 Sv y^{-1} for normal beam loss is the lowest and is the only one that is mandated by DOE. The normal beam loss events should have an event probability of high ($>10^{-1}$). However, the consequence from

the normal beam loss exposure should be negligible, compared with other industrial hazards. Therefore, the risk from normal beam loss scenario is low and, thus, acceptable.

The design limits of 0.03 Sv per accident event and a limit of 0.25 Sv h^{-1} from an accident beam loss are SLAC limits. The accident beam loss scenario, defined to be the failure of two out of three stoppers or all three CLDs, should have an event probability of extremely low, 10^{-6} to 10^{-4} , (for sure not higher than low, 10^{-4} to 10^{-2}). Even though the consequence level from the accident beam loss events could be medium due to the high dose level, the risk is still negligible and the system is acceptable.

The event of all three beam stoppers fail is incredible and its event probability is so small ($<10^{-6}$) that it is not considered in the shielding design. An accident scenario of failure of both the beam stoppers and the CLD systems at the same time was not considered either.

The shielding design for the missteered beam loss situations is perhaps the most complex, if not the most difficult, due to its wide range of situations that can be envisioned. Missteered beam loss scenarios at SSRL can have probability levels from medium, 10^{-2} to 10^{-1} (e.g., a beam loss from turning a single knob), to extremely low (e.g., a beam loss from a combination of misadjustments of several components). Such missteered beam, if not contained by shielding, could result in consequence levels from extremely low (e.g., missteered beam is self-shielded by components) to high (e.g., high power missteered beam showers on the shielding housing directly). To save the tedious and unproductive risk analysis effort, a dose equivalent limit of 4 mSv h^{-1} for all missteered beam loss scenarios was used in the Injector shielding design. This should correspond to a consequence level of extremely low or low at most. Therefore, the risk levels for all missteered beam losses would be acceptable, unless the probability of missteering is as high as that of the normal beam loss situation. At the expense of putting more effort estimating the event probability, the shielding design limit for the missteered beam loss situations can be chosen based on the

estimated probability level. This argument is, of course, valid for the shielding designs for other beam loss events.

There is one beam loss situation, i.e., the beam loss due to the failure of only one out of the three beam stoppers, that has not been discussed yet. There is no limit from DOE nor any internal guideline for this situation. The probability level for this type of beam loss event is most likely to be low. A dose equivalent level of 0.05 Sv h^{-1} should be appropriate, if a specific guideline is needed. Again, the risk method is a better approach, although may be more difficult and costly, than using a single dose equivalent limit for all cases in the shielding design for this beam loss situation.

In the risk matrix method, the consequence level should be determined by the dose equivalent, not the dose equivalent rate, that a person may receive. Therefore, two extra factors should be considered: occupancy factor (the frequency that an area may be occupied) and event period (how long the event persists). The occupancy factor can also be included in the estimation of the event probability. From the two SLAC accident limits, it is implied that the period of an accident producing a dose rate of 0.25 Sv h^{-1} should not persist longer than 7 minutes. Therefore, if an accident produces 1 Sv h^{-1} , it should not last longer than 2 minutes. Note that the 4 mSv h^{-1} limit was used by Radiation Physics Department in the case of missteered beam losses. This value was selected assuming that the event would be terminated within 15 minutes by a near-by BSOIC and/or the operator alertness, so that the integral dose equivalent is less than 1 mSv (annual limit for non-radiation worker). The BSOIC is a better choice to ensure the early termination of the abnormal beam loss event than the operators' attention and alertness. The maximum time period for a BSOIC trip to turn off the beam is less than 10 seconds (most likely within 0.1 seconds). Therefore, the exposure would be less than 0.7 mSv from an accident and less than $10 \mu\text{Sv}$ from a missteering. This would greatly reduce the consequence level from the abnormal beam loss event.

According to the redundancy principle of the beam interlock safety system in the draft Order of SAF, only a minimum of two interlocked devices (or a single device with two independent interlocked channels) is necessary. Therefore, the fact that there are only two beam stoppers or hutch shutters for each SPEAR synchrotron radiation beam lines does not violate the DOE requirement. Although DOE has specified a shielding design limit only for normal beam loss situations, it does require (2) that the adequacy of the shielding and beam stopper systems be demonstrated for all possible errant beams through measurements and/or calculations.

Operational Control

The draft Order of SAF requires that accelerators be operated in accordance with written procedures which are critically reviewed and approved. At SSRL and SLAC, the Beam Authorization Sheets (BAS) is the document that authorizes and governs the accelerator operation in a safe manner. The BAS for SSRL is prepared, approved, and issued by the responsible Radiation Physicists and the safety officer of SSRL, and is then concurred by the most senior Accelerator Department Operation Manager of SSRL. The BAS contains pre-running conditions that have to be met before operation (e.g., shielding verification, BSOIC calibration, and interlock system certification) and running conditions that have to be met during operation (e.g., administrative safety requirements). The BAS also specifies the operation envelope within which the accelerator can be operated.

Comparison With Other Accelerator Facilities

Synchrotron radiation accelerator facilities are low power facilities, compared with other types of accelerator facilities (e.g., the SLAC main facility). Because of the low power of the primary electron beam, the BCSs of the Injector and SPEAR are less complex in that there is no need to protect the shielding and beam stoppers from beam damage. For

example, for radiation safety purpose, there are no cooling water, burn-through monitor, or ion chamber attached to, and to protect, any local lead shielding or beam stopper that are used to contain the beam. However, due to the high power of the synchrotron radiation, the devices that contain or absorb the synchrotron radiation in the beamlines (e.g., masks, hutch shutters, and beamstop) may be water-cooled and/or equipped with burn-through monitors.

CONCLUSIONS

Radiation safety problems at accelerators facilities are different from those of nuclear facilities, especially in the protection against the prompt radiation fields. This difference also results in the DOE action of applying a special safety Order for accelerator facilities. Using the Personnel Protection System of SSRL as an example, the radiation protection policies and practices at SLAC and SSRL are described. The Access Control System which consists of the shielding housing and standard entry modules and the Beam Containment System which consists of shielding, beam stoppers, current limiting devices, and active radiation monitoring devices are described. The comparison between the PPS at SSRL and the requirements in the DOE draft Order of SAF in some of the areas are also discussed. It is hoped that this overview would assist to narrow down the difference in the radiation protection policies and practices among accelerator facilities.

ACKNOWLEDGMENTS

The author is greatly indebted to those who all contribute to the establishment of the Personnel Protection System at SSRL, particularly to J. Cerino, R. Hettel, C. Troxel, R. Yotum of SSRL, K. Crook, G. Nelson, and H. Smith of SLAC, and E. Benson, N. Ipe, and W. Nelson of Radiation Physics Department of SLAC.

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LIST OF CAPTIONS OF FIGURES AND TABLES

Figure 1. A schematic layout of SSRL, which shows the Injector (Linac and Booster Synchrotron) and the storage ring SPEAR. The parameters (beam energy and intensity) shown are design limits, not physical limits. The six entry points to the Injector and SPEAR are also shown. Nine main synchrotron radiation beamlines are also shown (B: bending magnet, W: wiggler, U: undulator).

Figure 2. Possible radiation protection problems at SSRL. n: neutrons, γ : photons, X: x-rays, IA: induced activity, u: muons, SR: synchrotron radiation, GB: gas bremsstrahlung, PMS: peripheral monitoring station. Radioactive gas and ozone are also shown.

Figure 3 The Personnel Protection System (PPS) consists of the Access Control System (ACS) and the Beam Containment System (BCS), which have their own system elements. The ACS is to protect people from being exposed to very high radiation levels inside a PPS area. The BCS is to protect people from the radiation outside a PPS area. The beam interlock network is shown as the dotted lines (see text for detail description).

Figure 4. The features of the entry module for the ACS of a typical PPS area. The four elements of the BCS are also shown (see text for more detail).

Figure 5. A few examples illustrating the shielding design principles and practices for the SSRL Injector (see text for the explanation of the numbers and symbols).

Figure 6. The active current limiting devices (average current monitors at SSRL) and the beam stoppers for each PPS areas at SSRL.

Figure 7. The locations of the Beam Shut Off Ionization Chambers (BSOICs) at SSRL. The BSOICs are used to detect the radiation levels from possible missteering or accident beam losses, and to trip the beam off if the preset trip level is exceeded.

Table 1. The four access states for the PPS areas (Linac, Booster, and SPEAR) at SSRL.

The conditions of entry, radiation hazards, and electrical hazards are also shown.

Table 2. The beam stopper response of the beam interlock safety system in case of an ACS

violation.

Table 3. The risk matrix analysis for the SSRL shielding designs for different beam loss

situations.

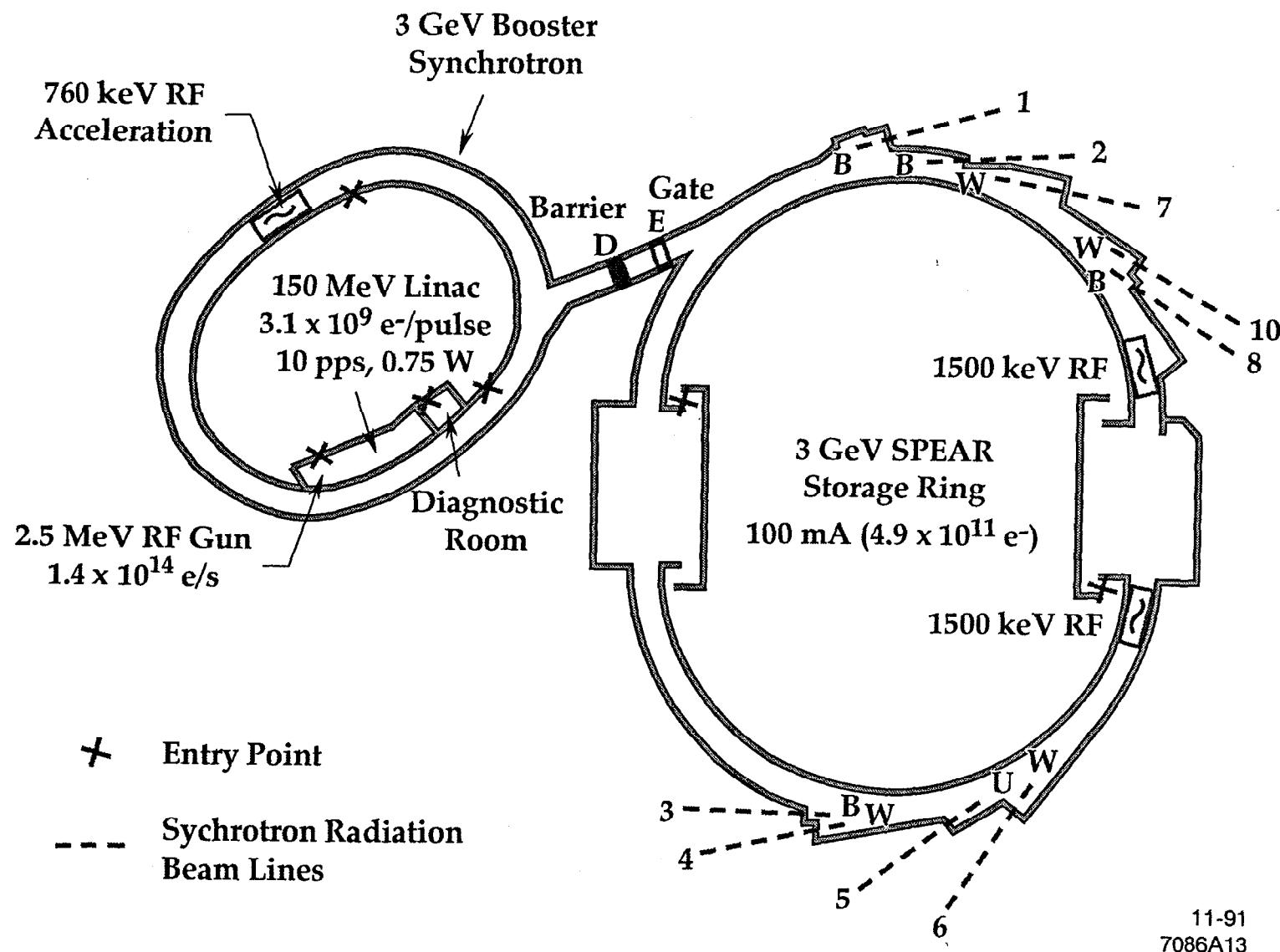


FIGURE 1

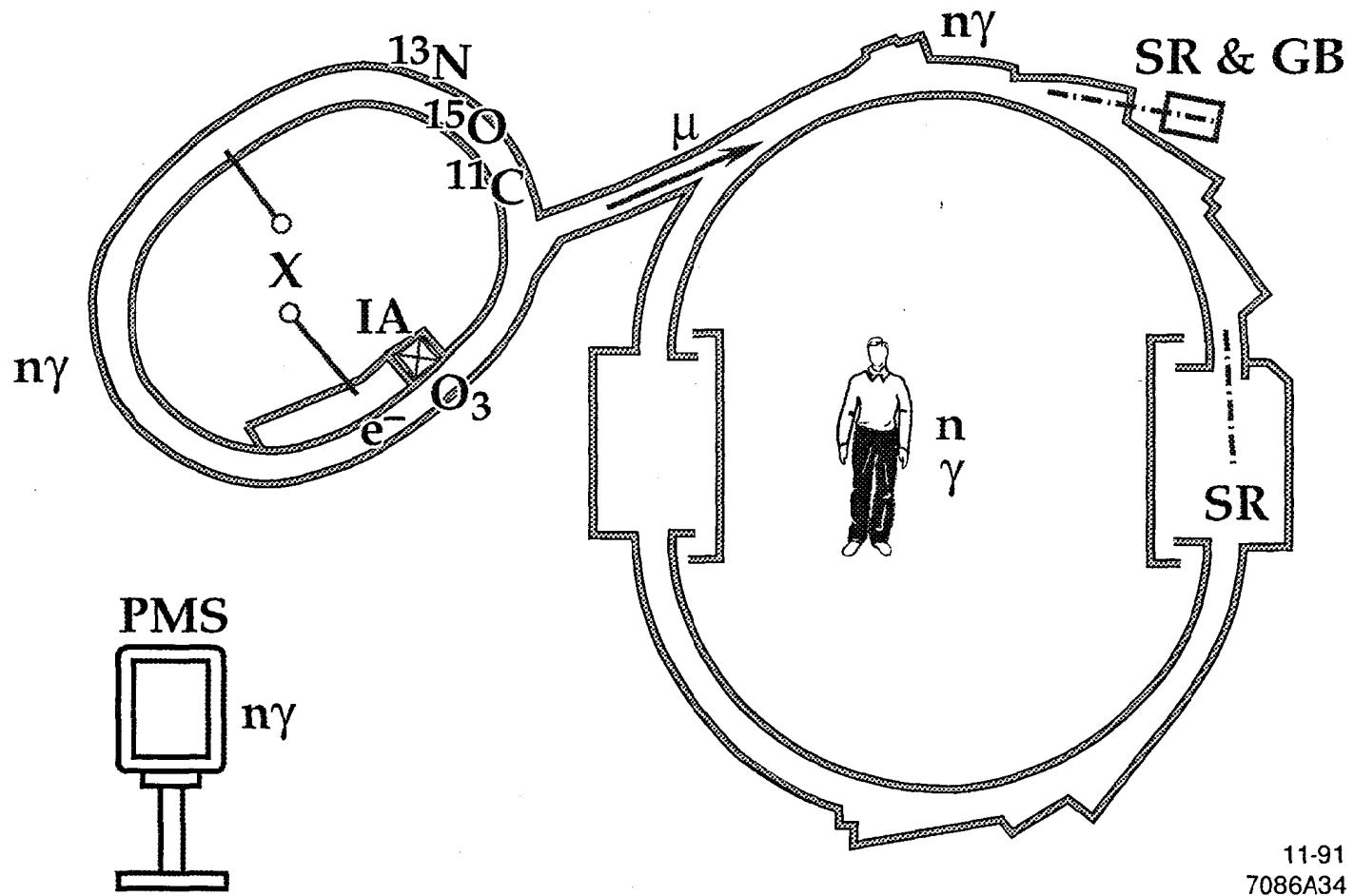
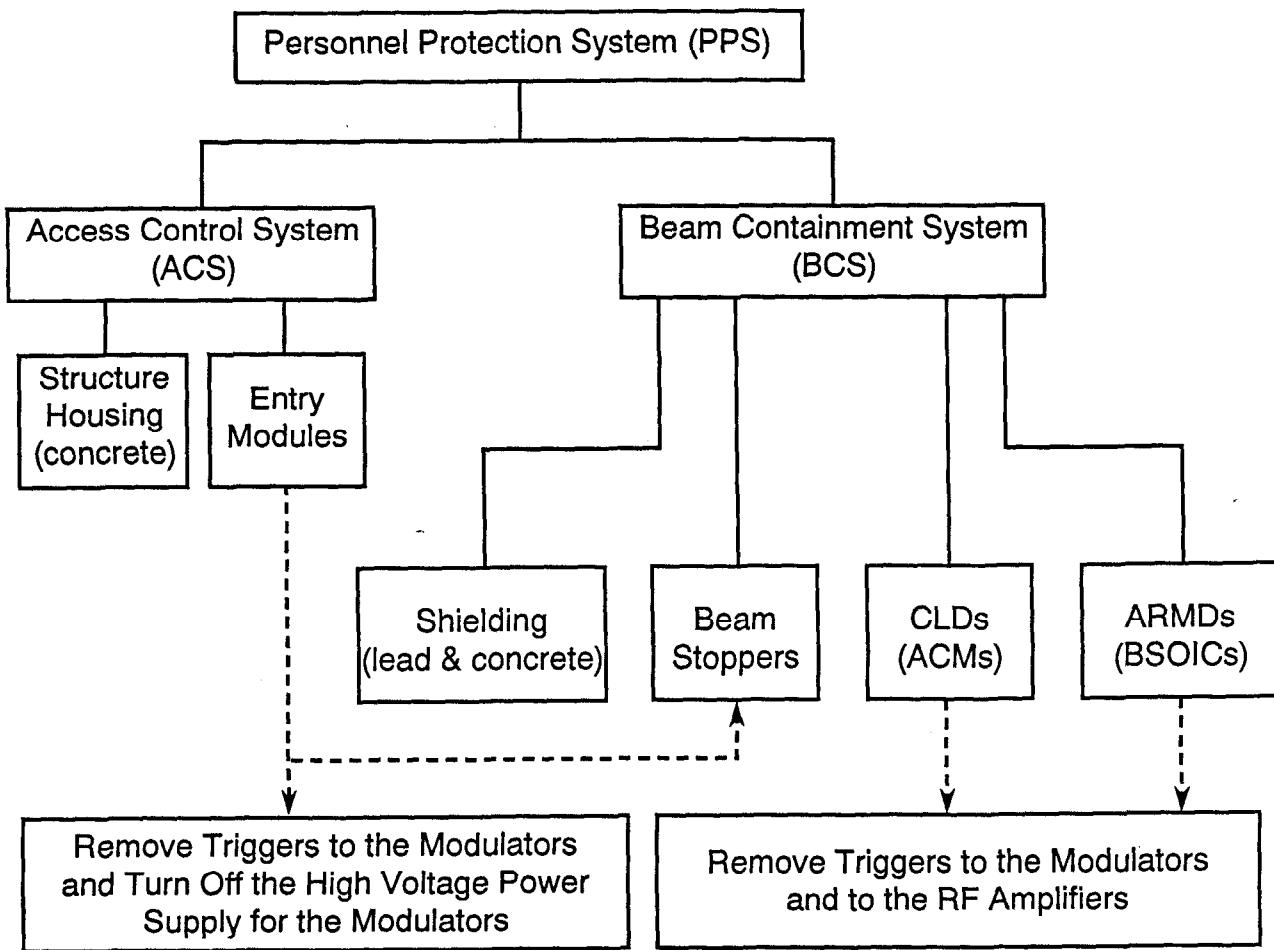


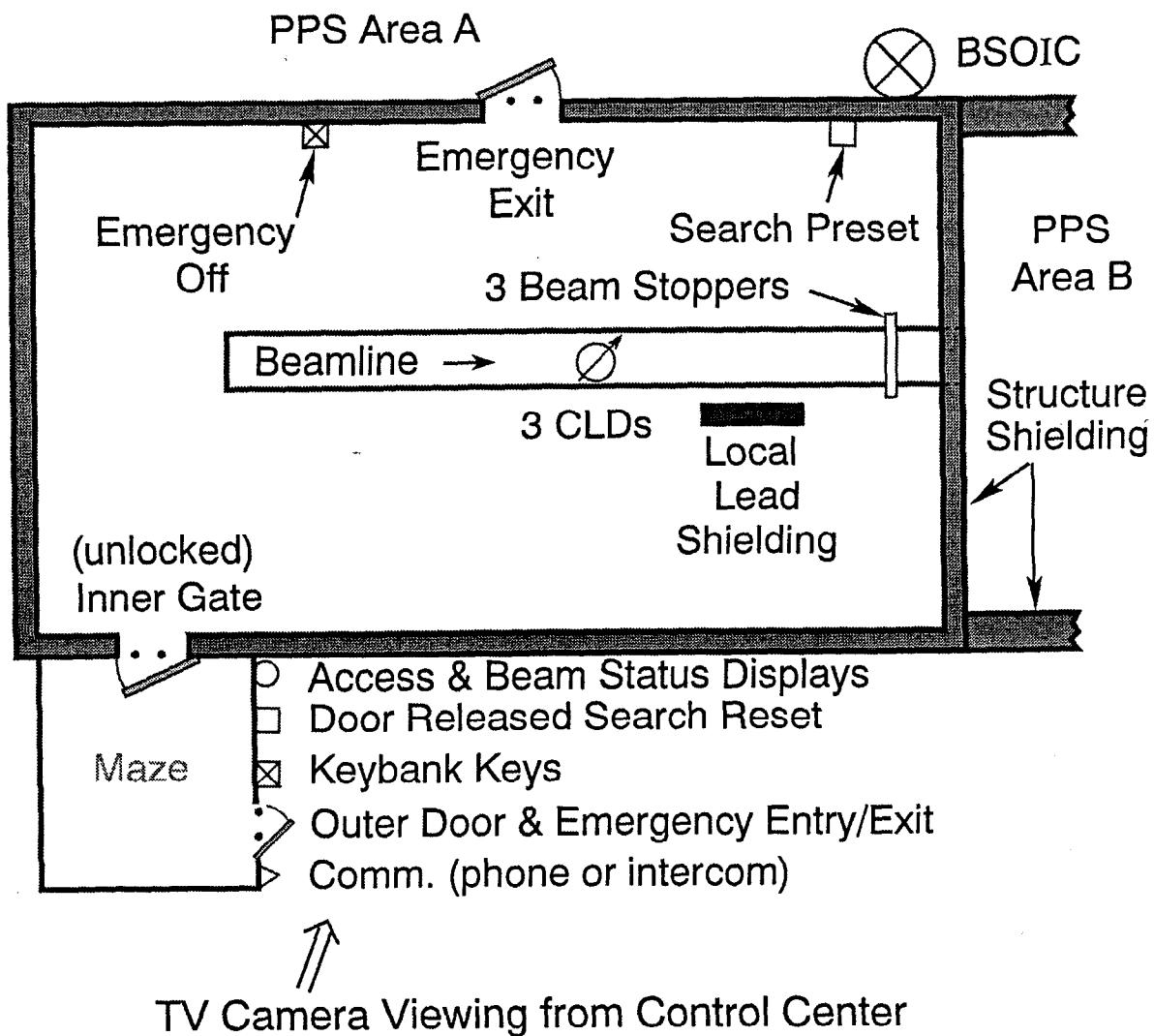
FIGURE 2



CLDs: Current Limiting Devices
 ACMs: Average Current Monitors
 ARMDs: Active Radiation Monitoring Devices
 BSOICs: Beam Shut Off Ionization Chambers

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FIGURE 3



CLDs = Current Limiting Devices

BSOIC = Beam Shut Off Ionization Chamber

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FIGURE 4

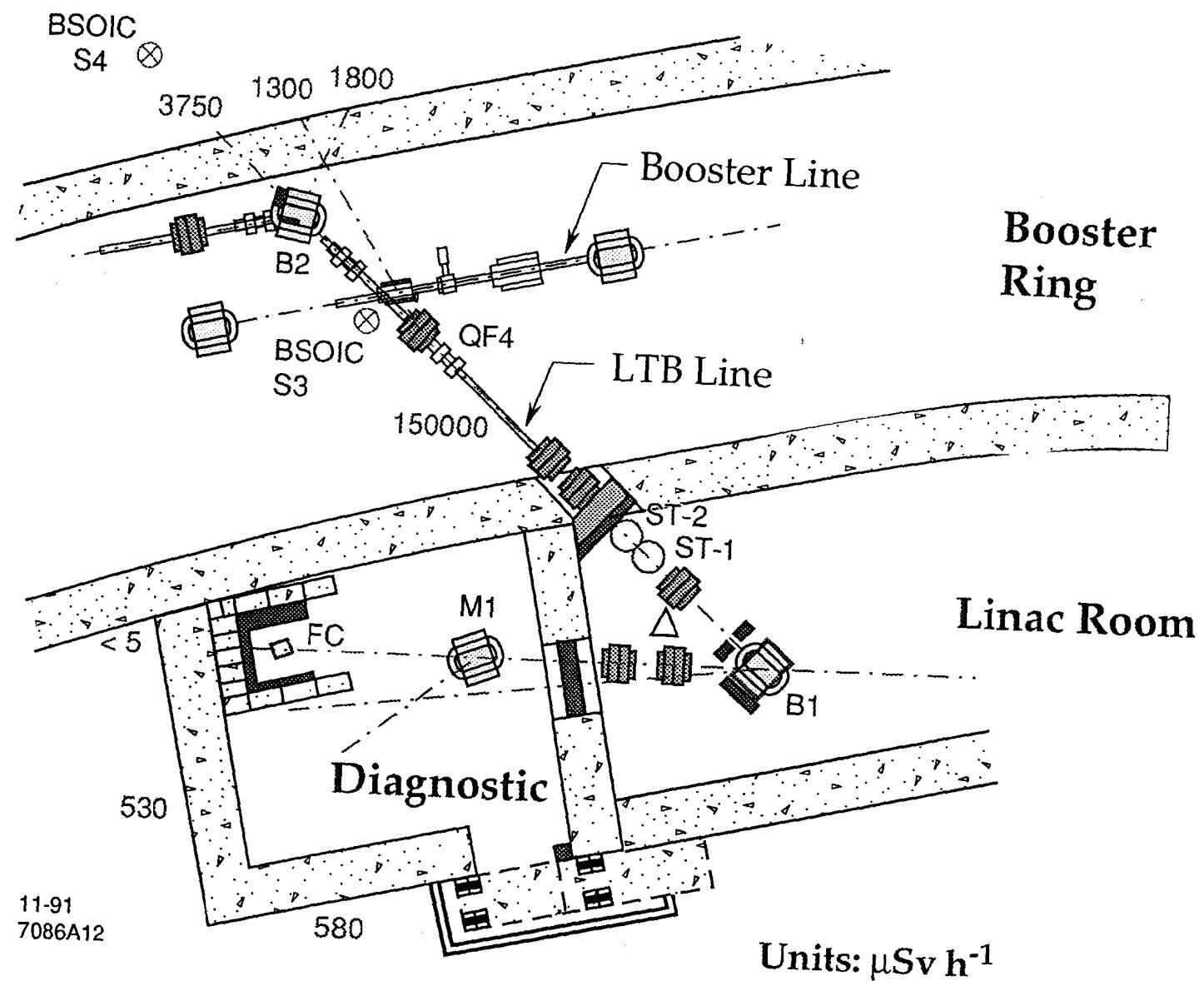


FIGURE 5

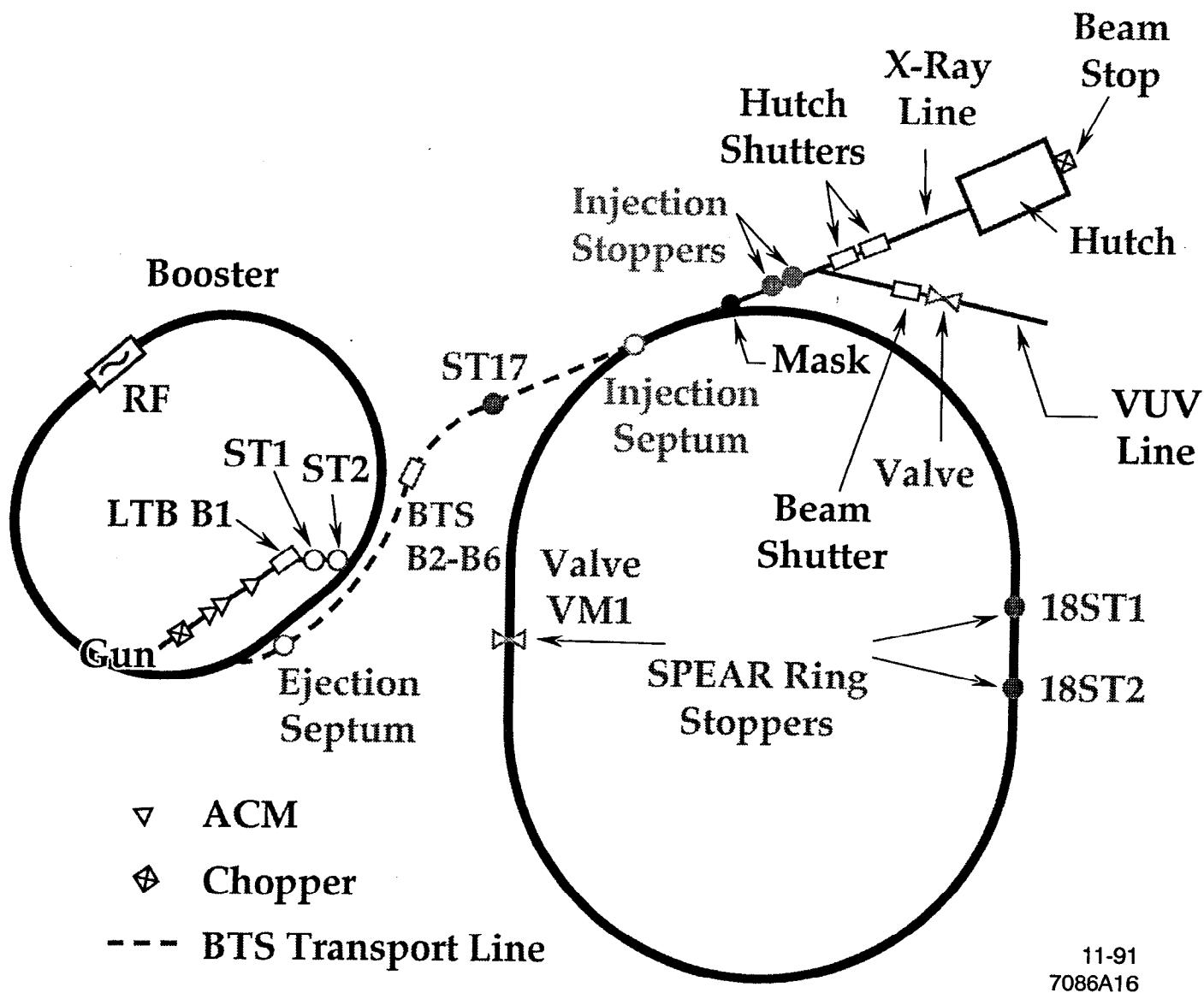


FIGURE 6

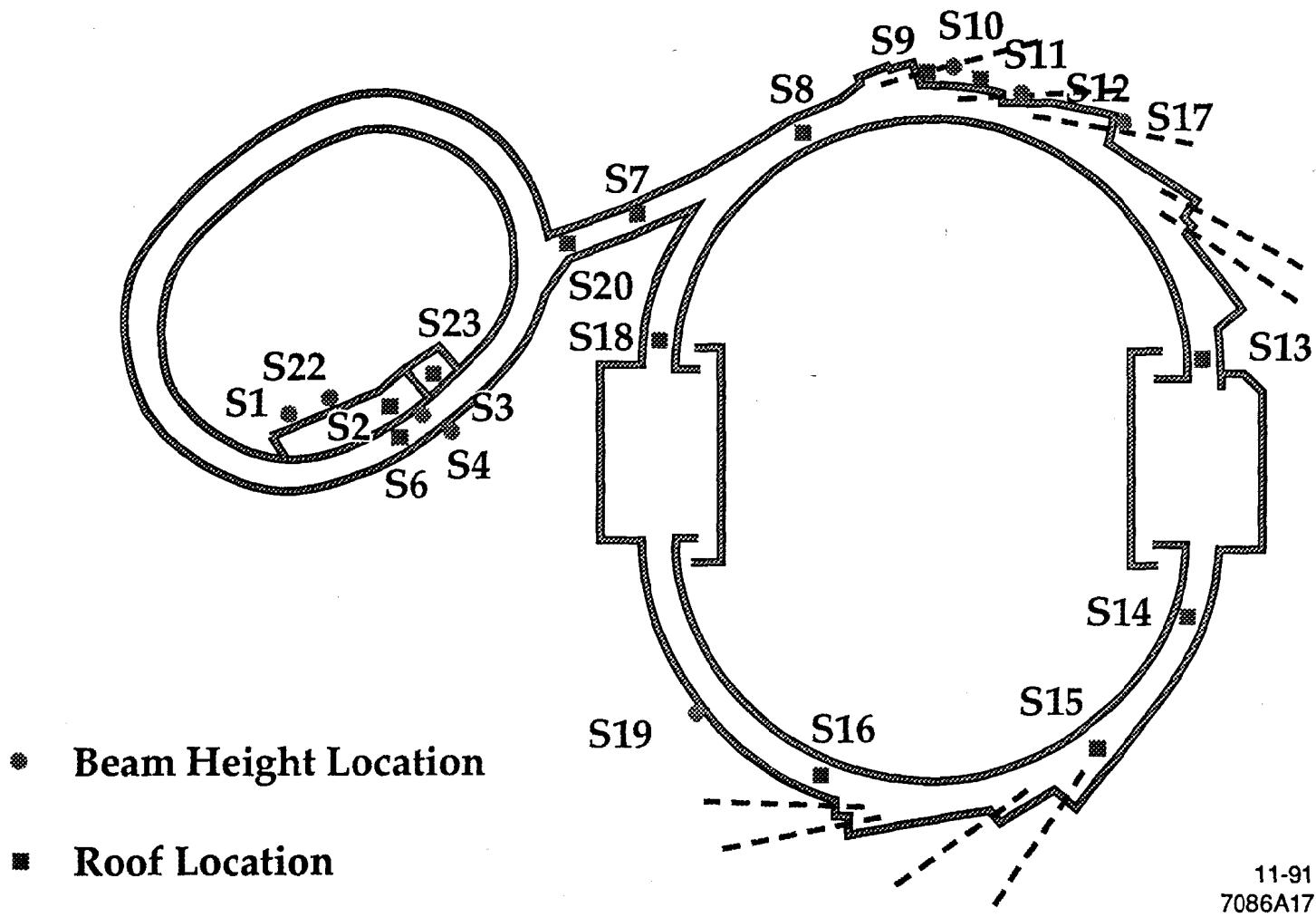


FIGURE 7

TABLE 1

Access State	Condition			PPS Area		
	Entry	Radiation Hazard	Electrical Hazard	Linac	Booster	SPEAR
Permitted Access (PA)	Unlimited	No	No	✓	✓	✓
Controlled Access (CA)	Limited	No	No	—	✓	✓
Restricted Access (RA)	RASK	No	Yes	—	✓	✓
No Access (NA)	No	Yes	Yes	✓	✓	✓

Note: The change of the access state of a PPS area is always in the sequence of PA → CA → RA → NA or the reverse.

RASK: Restricted Access Safety Key

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TABLE 2

Response ACS Violation	Hutch Shutters	SPEAR Ring Stoppers ^a	BTS Stoppers ^b	LTB Stoppers ^c and Booster RF	Linac ^d	Additional
Hutch	In	In	In/Off	In/Off if BTS Stoppers are not In	N/A	—
SPEAR Ring	N/A	In	In/Off	In/Off if BTS Stoppers are not In	Off if LTB or BTS Stoppers are not In/Off	SPEAR Electrical and RF Hazards Off
Booster Ring	N/A	N/A	N/R	In/Off	Off if LTB Stoppers are not In/Off	Booster Electrical and RF Hazards Off
Linac	N/A	N/A	N/R	LTB Stoppers In/Off	Off	—

N/A = Not Applicable

N/R = Not Required

a) 18ST1, 18ST2 and VM1

b) Ejection Septum, BTS B2-B6 Magnets, and ST17

c) LTB B1 Magnet, LTB ST1 and LTB ST2

d) High Voltage Power Supply for Modulators
and Triggers to the Modulators

TABLE 3

Beam Loss ¹ Scenario	Probability Level	Dose Equivalent Limit	Consequence Level	Risk Level ²
Normal	High ($>10^{-1}$)	0.01 Sv y ⁻¹ DOE	Extremely Low	Low
Missteered ³	Medium to Extremely low	4 mSv h ⁻¹	Extremely Low	Negligible
One Device Fail ^{3,4}	Low (10^{-4} – 10^{-2})	0.05 Sv h ⁻¹	Low	Negligible
Accident	Extremely Low (10^{-6} – 10^{-4})	0.25 Sv h ⁻¹ (or 0.03 Sv)	Medium	Negligible
All Fail	Incredible ($<10^{-6}$)		Not Considered	

¹ BSOIC can be used to trip the beam off if any beam loss scenario is detected, except the normal cases.

² System with a negligible or low risk level is acceptable.

³ Flexible limit should be used based on the true probability level.

⁴ The failure of one or all interlocked protection devices is not considered in SSRL shielding design.