PROTECTION SYSTEMS

G. Babcock, K. E. Breymayer, D. D. Busick,
K. Crook, T. M. Jenkins, K. B. Mallory, Editor,
R. McCall, D. D. Reagan, and G. Warren

This chapter describes the equipment which is provided (a) for the protection of personnel from the hazards of radiation generated by the machine and (b) for the protection of the machine itself from damage caused by a missteered beam.

The procedural rules governing the use of this equipment are discussed in detail.

21-1 System interlocks for accelerator

Although many interlocks for personnel and equipment protection can be confined to the individual piece of equipment they control, e.g., interlocks on high-voltage safety doors and cooling-water circuits, there are some interlock circuits which provide system-wide interactions among injector, accelerator, switchyard, and end stations. The purpose of an interlock is to override operator control. These circuits are, therefore, quite independent of manual control systems. In general, their signals are carried on individual wire-pairs and make no use of the multiplexing systems.

There are six interlock circuits which serve to shut off the machine under irregular circumstances. They are

1. An access control system that prevents entry to a radiation area when the machine is on
2. A machine shut-off system that keeps the beam off and shuts off all RF power to the accelerator in circumstances where there is a possible radiation hazard to personnel
3. An "emergency stop" circuit that changes the geometry of the beam areas by inserting beam stoppers when excessive radiation is detected in the research yard

4. A machine protection system (1-msec network) that shuts off the injector in circumstances where there is a probable radiation hazard to equipment
5. A 50-μsec protection network that shuts off the injector when the switchyard is not ready to accept the programmed pulse
6. Pattern interlocks that shut off the program for a beam in circumstances where the beam is not desired by the experimenter or a beam channel is not ready to accept any beam.

The *access control system* contains a tone loop with a transmitter at Sector 2, interrupts at each variable-voltage substation, and a receiver in central control. If all substations are off, the loop is closed and permissive signals are sent to ventilation and access control relays in each area. When any substation is turned on, the loop is broken, interlock relays are released, and the central control operator has no power to release keys or initiate ventilation.

The major purpose of the access control system is to keep the number of people entering the housing, the number of people entering at one time, and the duration of each entry, to a minimum. The housing should not be cleared because the beam is coming on but because the need for occupancy is finished.

The purpose of the *machine shutoff system* is to limit the hazard of radiation exposure when personnel are in the housing by preventing turn-on of all variable-voltage substations which supply high voltage to the klystron modulators.

The machine shutoff system and the access control system form a complete interlock. If any substation is on, people may not be in the housing. If there are people in the housing, no substation may be turned on.

The machine shutoff system contains two parallel tone loops which indicate that each radiation area is secure. It has as inputs the doors to radiation areas, access keybanks, and "emergency off" pushbuttons.

In order to allow experiments to be carried out in one end station while equipment is being set up in the other, an alternative definition of security is required for the end stations. If appropriate beam stoppers are in position, the end station may be defined secure and access may be permitted without shutting off the variable-voltage substations.

If a person enters a beam area, the entry can be detected by limit switches which are wired into a fail-safe circuit. His entry is made unlikely by appropriate control of door-release circuits. There is, however, no automatic way to remove the person! If, despite all precautions, he is present in a beam area, it is necessary to shut down the machine.

The "*emergency stop*" *circuit* provides a means for removing the beam from the beam switchyard (BSY) and end stations when excessive radiation is observed in the research area outside the end stations, without resorting to the extreme measure of shutting down the entire machine. The primary function is to insert beam stoppers in the path of the beam, thus ensuring that the beam cannot leave the accelerator housing; the beam itself is also shut off through the machine protection system.

A distinction is maintained between "emergency off" buttons and "emergency stop" switches. The former are located within beam housings and shut off the machine completely through the machine shutoff system. The latter are located outside the end stations, in the research area, and stop only the beam through the "emergency stop" circuit.

The *machine protection system* has as its major component the 1-msec network, which consists of a tone transmitter in Central Control Room (CCR), tone interrupt units in CCR, Data Assembly Building (DAB), and each sector, and a tone receiver at Sector 0 (the injector area). The network shuts off the gun trigger if the circuit is interrupted at any of the tone interrupt units. The major inputs to the machine protection system at each sector are the signals indicating those conditions likely to damage equipment in the accelerator or BSY housing. A long ion chamber which detects excessive beam loss along the accelerator is connected to the system at CCR.

Any breach in the security of any of the radiation areas shuts off the gun through the machine protection system in addition to shutting off the variable-voltage substations through the machine shut-off system. The machine protection system shuts off the injector for a minimum of 1 sec and may be reset by the central control operator only after the trouble has been cleared.

The *50-μsec protection network* provides a pulse-by-pulse permissive signal to the gun which is withheld if any BSY interlock fails or if the pulsed magnets do not approach the proper field strength for the programmed beam. A pulse generator, located at the DAB, generates a 200-μsec pulse approximately 150 μsec in advance of each beam pulse. If the interlock determines that the switchyard is prepared for the beam, the pulse is transmitted to the injector trigger generator and drives a gate which allows trigger pulses to be transmitted to the gun. A beam thus cannot be accelerated unless the permissive pulse is received from the switchyard.

A similar network originates at the positron source. It transmits a permissive signal when the wand target is clear of the beam and also when it is in all respects prepared to produce positrons. A third circuit will be installed later at the take-off magnet for the storage ring.

Interlock signals that must operate on the next beam pulse are handled through the 50-μsec protection network. This network has no lockout feature. Interlock signals which are to be effective for a longer duration and are to affect only one beam shut off the *pattern interlock* for that beam at the pattern generator in central control. Examples of such signals are the experimenter's "on/off" switch for a particular experiment, interlock signals for the experimenter's equipment, and interlock signals for the beam transport system into a target area. Since the other systems generally turn off all beams, this is the simplest system which can handle signals which pertain to a single beam or experiment. The research area inputs to the 50-μsec network and to the pattern interlocks are discussed in more detail in Chapter 19.

21-2 Personnel protection system

Health physics requirements (TMJ)

The health physics requirements concerning personnel around or in the accelerator were formulated early in 1964 and are summarized here with appropriate updating:

1. All entrances to radiation areas, including housing, BSY, and experimental areas will be the responsibility and under direct control of either the CCR or DAB operators.
2. Operators in CCR and DAB will be trained and certified competent in radiation matters by the Health Physics Group so as to be able to make day-to-day decisions within the framework of the established radiation policy.
3. At least one member of the Health Physics Group will be available or on call to give advice or help in nonstandard situations.
4. All entrances to radiation areas will be controlled with a key that is in the interlock chain. For entrances not frequently used, the key may be kept in the CCR or DAB consoles. For other entrances, the key will be locally available within a few feet in a keybank. In both cases, CCR or DAB must give permission to allow removal of the key. Keys may not be removed unless the machine is off.
5. Every person entering a radiation area will carry a key with him while inside to guarantee that the machine cannot be turned on. The only exception to this occurs when the machine is open to unlimited access, in which case a search must be completed before the machine can be turned on.
6. Personnel entering a radiation area will be identified and logged in, and the integrity of the door maintained either by appropriate electronics signals or by posting a guard. If the security of an area is violated, a search must be made before it is locked again and considered secure.
7. Egress from all areas will be possible without a key. Emergency entrance will be possible by breaking a glass and taking a key, which automatically shuts off the beam.

In addition to the above, the following policies are observed:

1. The personnel protection system may operate within seconds, unlike the machine protection system, which must work in milliseconds. This is acceptable because human reaction times are involved, and these are very slow compared to the response times of electronic systems.
2. There must be audible alarms prior to turning on the beam, early enough to allow personnel caught inside to make their way to an "emergency off" button.

3. There must also be visible alarms preceding beam turn-on, such as blinking lights, with the lights being dimmed during actual beam operation.
4. These audible and visible alarms must exist within all radiation areas, but not outside the shielding. A visible indication at each point of entry is sufficient warning there.

It is required that every entrance into a radiation area be suitably identified. Thus, one should not be able to enter the klystron gallery without seeing an appropriate red or green light which identifies the radiation or potential radiation status. The lights installed to meet this requirement are convex so they are seen by someone entering from an adjacent sector. Above every entrance into the housing and BSY are magenta and yellow lights. The magenta signifies a beam or potential beam condition; the yellow signifies that the beam is off, but that the area should be entered with caution for there may remain residual radioactivity. Worded status lights are used at the entrances into the end stations.

In addition to status lights, radiation areas are further identified by placing a fence around them. These areas include the klystron gallery, BSY, and end station areas, but exclude the campus area and cryogenics building. Entrance inside this fence is limited to personnel wearing film badges. Within the radiation fence, areas with radiation levels $\geq$0.75 mrem/hour are roped off.

Design criteria (KBM)

A personnel radiation protection system consists of two major parts: a collection of equipment designed to safeguard personnel and a body of procedural rules for its use. The purpose of this section is to describe the equipment in the personnel radiation protection system. Only brief reference is made to the operational procedures developed by the Operations and Health Physics Groups. These procedures include: (a) the operational rules (e.g., "the operator will make verbal announcement over the public address system before turning on the beam") for use of the protection system, (b) an educational program about the rules and functions of the equipment itself, and (c) a supervisory or disciplinary procedure to assure that the rules are followed.

As at many accelerator installations, interlocks with acceleration power are the primary means used to protect personnel from direct machine-produced activity. These interlocks shut off the variable-voltage substation (VVS) supplies to all klystron modulators. Accessways to beam areas are also interlocked to make it difficult to enter while the accelerator is operating. However, the latter interlocks are regarded as secondary means of protecting personnel, because provisions for emergency entrance bypass the access interlocks.

Protection from residual activity is achieved by health physics procedures including radiation surveys and tagging or temporary blockading of "hot" areas. The system described below contains no provision for restricting circulation once a person has entered a radiation area. Such restrictions change from day to day or even hour to hour and are imposed and enforced by health physics personnel and the operations groups.

Although security system activities are generally performed locally at the scene by trained and responsible personnel, the geographical extent of the site, the large number of entrances, and the need to allow one area to be entered while another area is secure make it imperative that the chief operator be kept continuously aware of all such activities.

The hazardous areas to be considered are those areas directly exposed to the beam, and also the klystron gallery, the research yard, and certain enclosed spaces adjacent to the housing.

The system design had to take into consideration the fact that there are some ninety entrances to radiation areas spread out over the $2\frac{1}{2}$-mile long site. These include regular entrances to beam areas, any of which may be used during controlled access periods; other openings into beam areas, some of which are normal entrances for maintenance and construction during shutdowns; and entrances to additional areas which are insufficiently shielded from machine-produced activity and which, therefore, may not be occupied while the accelerator is operating. Since many areas remain hazardous when the accelerator is off, the operator must retain independent control of each entrance.

The interlock system is concerned with holding the machine off until the operations crew and the chief operator are assured that the areas are cleared and locked, preventing normal reentry as long as the machine is on, and shutting off the RF acceleration power and the gun if any of the above entrances are used in an emergency.

In the klystron gallery, red–green warning lights automatically inform personnel when the klystrons themselves are operating. Access to the klystron gallery is controlled at the gates of the peripheral fencing (see Chapter 27), rather than at the 150 doors of the gallery itself.

All accelerator entrances, including housing, BSY, and experimental areas are the responsibility and are under direct control of the chief operator.

When an access door is to be opened, it must be monitored by a qualified person, who will log, tag, or otherwise identify personnel entering and leaving. The alternative is to make a search of the accessible area before it is locked up again.

The primary control of access to radiation areas is achieved by a key-release system. For entrances frequently used, the key is stored locally in a keybank adjacent to the door; release of keys from the keybank is by signal from central control or DAB, as appropriate. For other entrances, the keys are kept at central control or DAB.

A person entering a controlled area keeps possession of the key while in that area and returns it to the keybank upon leaving. The keybank interlock thus cannot be closed until all personnel have left the radiation area.

In emergency, any access door may be opened without CCR permission by actuating a mechanical latch inside a "break the glass" enclosure. This latch either unlocks the door directly or releases a key from the keybank.

Except for emergency or forced entry, the interlock cannot be broken without permission from CCR. This insures that no accidental interruption of the machine occurs by thoughtless entry.

Interlocked beam stoppers allow personnel to enter one end station to set up experiments while an experiment is in progress in another target area. Once the chief operator has determined that entry is permissible, he will then delegate responsibility for key release and for search of end stations to an operator in the DAB. When major installation or rebuilding of experimental equipment is in progress, key control may be removed. All entrances will be unlocked and keys will not be released. The end station must be put back under key control and searched before experiments may be resumed.

The system is designed to maintain zero occupancy of the radiation area. Once the interlock system has been signalled that the radiation areas are empty, it can prevent normal entry of personnel and can permit the accelerator to be turned on. Once any person has entered a radiation area, it is the responsibility of the operations crew to restore zero occupancy.

Starting with a housing known to be empty, the operations crew can count all people entering and leaving and know when the housing is again empty. However, if at any time the number of occupants is in doubt, the entire area must be searched and cleared.

Because of the magnitude of the search procedure, the system is designed to minimize unauthorized entrance.

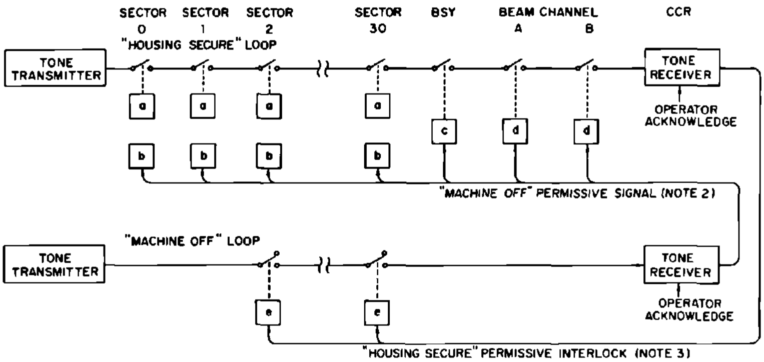
Since emergency shutdown of the accelerator can dump as much as 25 MVA of ac power supplying the klystron modulators, the system has been designed to minimize false alarms due to momentary ac power failures.

System description (KBM)

Each area—injector, sector, switchyard, or end station—is considered a unit for the system. Each area has its own radiation monitors, warning signals, and circuits for determining that its portion of the housing has been secured. The areas are tied together by the access control and machine shutoff circuits. The appropriate interconnections are made in the Central Control Building. The overall system interconnections are briefly described below; the circuits to be found in each area are described in more detail later.

The system consists of two major parts: the *machine shutoff* circuit, which insures that the machine cannot be turned on until the radiation areas are cleared and secured and which turns off the machine if the security of any area is broken, and the *access controls* which prevent entry into radiation areas while the machine is on.

In addition, the system contains warning devices and radiation monitors to help determine the state of the machine. Figures 21-1 and 21-2 are block



Note 1: Code letters in boxes refer to Figures 21-2 (a) thru 21-2 (e)

Note 2: Keys can be released and ventilation initiated by operator only if "MACHINE OFF" permissive signal is present

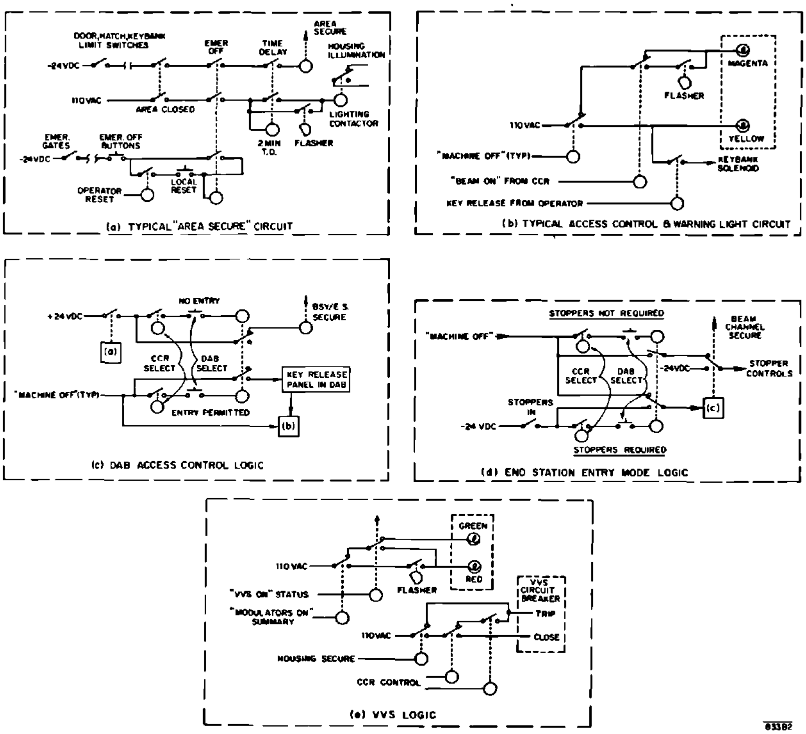
Note 3: All VVS's are automatically turned off if "HOUSING SECURE" tone loop is interupted.

Note 4: Transfer logic for BAS mode of operation is not illustrated.

833A1

Figure 21-1 Personnel protection system block diagram.

Figure 21-2 Personnel protection system logic details.



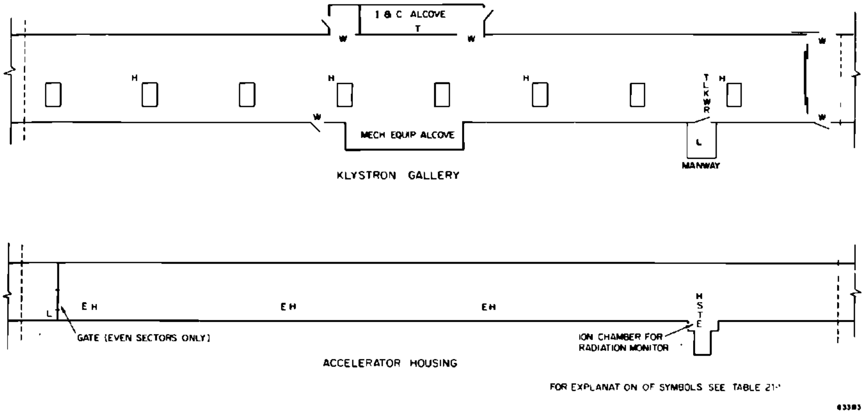
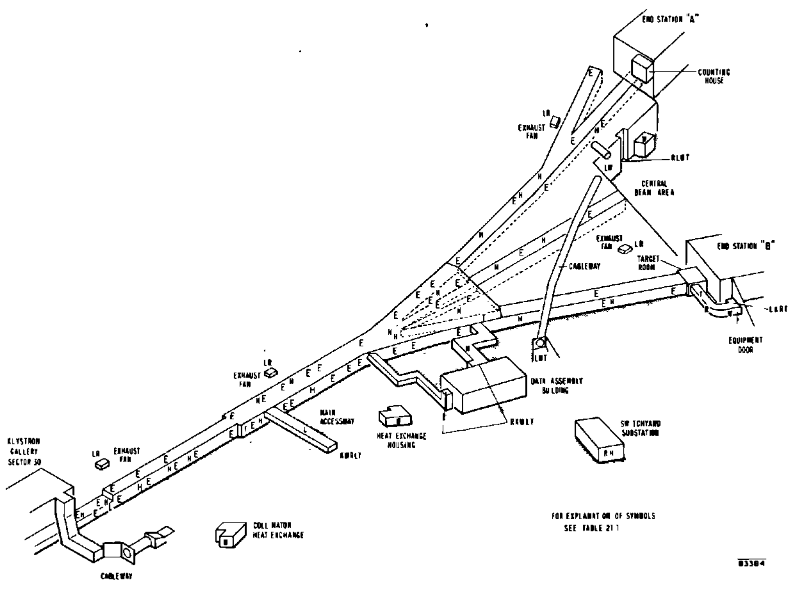


Figure 21-3 Location of personnel protection system components in a typical sector.

and schematic diagrams of the system logic. Figures 21-3 through 21-5 show the locations of system components.

MACHINE SHUTOFF SYSTEM. The machine shutoff system turns off all VVS which supply high voltage to the klystron modulators when the security of any radiation area is broken. As noted elsewhere, the gun is simultaneously shut off through an independent circuit.

Figure 21-4 Location of personnel protection system components in the beam switchyard.



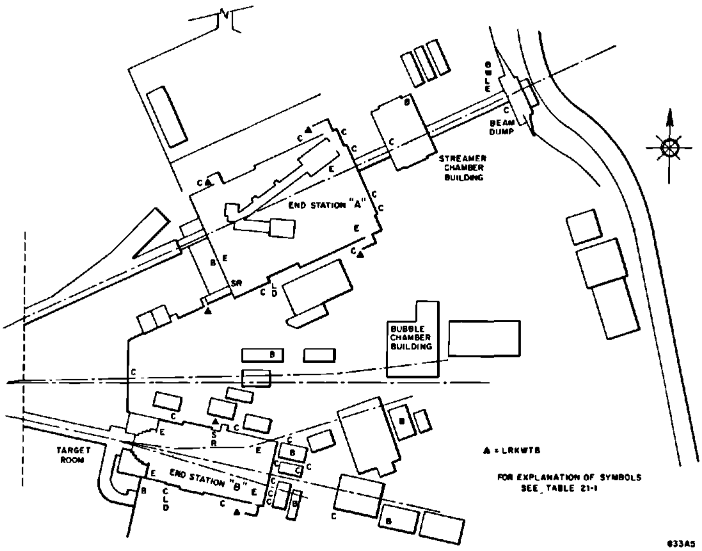


Figure 21-5 Location of personnel protection system components in the research area.

The system contains a "housing secure" tone loop which determines that each radiation area is secure. The tone equipment is identical to that used in the machine protection system. The system recognizes the following separate radiation areas: injector, Sectors 1, 2, ..., 30, BSY, beam channels A and B. If all of the areas have been secured, the tone loops are completed and a permissive interlock ("housing secure") allows the operator to turn on the VVS (Fig. 21-2e). If the tone loop is interrupted, all VVS are automatically turned off.

The machine shut-off system has the following inputs: all doors to radiation areas, certain gates within radiation areas, ventilation hatch covers, access keybanks, and "emergency-off" pushbuttons (Fig. 21-2a). Each time an "emergency-off" button is tripped, the area accessible from the vicinity of that button must be searched. Upon completion of this search a reset button within the area must be operated. Simultaneous acknowledgment by the central control operator is also required to complete the reset process.

In order to allow experiments to be carried out in one end station while equipment is being set up in the other, an alternative definition of security is required for the end stations. If the pulse magnet modulator for that area is interlocked off, a beam stopper is in position and the slits are closed, the beam channel may be defined secure and access to the end station itself may be permitted without shutting off the VVS (Fig. 21-2d).

A second alternative definition of security (the "BAS mode") allows operation of the accelerator to a beam-analyzing station (BAS) at Sector 20 for machine studies, warmup, or modulator adjustment. If the housing is

Table 21-1 Key to symbols used in Figs. 21-3, 21-4, and 21-5

Symbol	*Item*	*Remarks*
L	Limit switch	Two switches and two dc circuits per door.
K	Keybank	One dc status and one ac release circuit per keybank.
R	Radiation monitor	The symbol is used to designate the radiation monitors at accessways, air vents, and cooling-water heat exchangers. Details are given in the text.
W	Warning light boxes, magenta–yellow (radiation), red–green (klystrons)	One common three-wire circuit per area for each type of warning light.
H	Speaker	In public address systems operated from CCR and DAB.
T	Telephone	
V	Television camera	Video cables run to monitors in CCR and DAB. One control circuit and one status circuit per camera.
D	Door release	Electrical latch and local release button for utility tunnel gates and concrete doors. One common control ac circuit for all door releases.
E	Emergency off	One series dc actuating circuit and one parallel dc button illuminating circuit per area.
B	Emergency stop switch	One series dc actuating circuit around each end station.
C	Beam shutoff ion chamber	In series with emergency stop switches. Readout in DAB.
S	Search reset button	One dc circuit.

secure from the injector through Sector 29 and if beam stoppers at the ends of Sectors 20, 21, and 28 are in place, the VVS may be turned on through Sector 28 and access may simultaneously be permitted in Sector 30, the BSY, and the end station. The beam may be turned on if the BAS magnet is energized.

In general, the machine shut-off system has parallel redundancy as far as possible. Circuits arising in single-pole limit switches are being converted to dual circuits as early as practicable. Any normal entrance breaks at least two such circuits. The interlocks are operated from dc batteries so that momentary interruptions of ac power, whether general or local, need not destroy the housing security or unnecessarily turn all VVS off at once.

ACCESS CONTROLS. The access control system contains a tone loop which is completed only if all VVS are turned off. This is the definition of "machine off."

If all substations are off, the loop is closed and permissive signals are sent to relays in each area interlocked with ventilation and access controls. Release of keys and opening of ventilation hatches requires additional explicit signals from the central control operator (Fig. 21-2b). When any substation is turned on, the loop is broken; interlock relays are released and the central control operator has no power to release keys or initiate ventilation.

In the BAS mode of operation, Sector 30, the BSY, and the end stations are no longer beam areas.

When the beam stoppers are in, the chief operator and switchyard operator may, by agreement, set up the alternative state, "stoppers required," for either end station (Fig. 21-2d). This allows the accelerator to deliver a beam to one end station or to the tune-up dump while experimenters are working in the other end station.

When an end station is set for the alternative "stoppers required" mode of operation, the end station is no longer a beam area as long as the stoppers are in. If the end station has been secured, the stoppers may be removed for experiments, but must be replaced before the end station may be entered again. The stoppers cannot be removed unless the end station is secure. When entry to an end station is permitted, the keybank release is at the discretion of the switchyard operator (Fig. 21-2c).

The hatch covers or other air seals may be opened and the exhaust fans may be started by the operator in central control, or by local control in an instrumentation and control (I & C) alcove, or in DAB, only if all VVS are off or if the area is not a beam area.

The operator must assure himself that the housing and/or end stations have been adequately ventilated before releasing any keys.

WARNING SIGNALS. There are several classes of radiation warnings to be considered. The simplest is in the klystron gallery, which has x radiation from the klystrons and from some of the penetrations to the housing.

Facing each outside door of the gallery are boxes with red and green warning lights. Green means VVS off; steady red means VVS on, klystrons potentially operable. Flashing red means one or more klystrons on within the sector (Fig. 21-2e).

In addition to these warnings of local modulator activity, there is a magenta–yellow light box adjacent to each entrance to the accelerator housing, BSY, and heat exchangers.

Yellow indicates machine off; steady magenta means high voltage is being applied to the modulators in one or more sectors—there is potential beam within; flashing magenta indicates that the beam is on. Note that yellow does not guarantee the absence of residual activity (Fig. 21-2b).

Adjacent to end station doors are illuminated warning signs: red "no access" and yellow "controlled access" (doors not locked; the area must be searched before returning to a secure condition).

Adjacent to each normal accessway to accelerator, switchyard, and heat-exchanger housings are meters indicating the output of a gamma monitor at the inner end of the accessway. The outputs are also displayed at CCR or DAB. These indicate whether it is safe to enter the housing as far as the monitor. Beyond this point portable survey meters must be used.

Audible warnings over the public address system are given by the operators according to operating procedures defined by health physics.

Control of the magenta and yellow lights outside the radiation areas is provided by the "machine off" interlock loop. A tone receiver in central control receives information that all VVS are off. This information is then fanned out to all sectors to turn on the yellow light outside all housing entrances (Fig. 21-2b). When any substation is turned on, the tone receiver output is removed and magenta lights appear outside each housing entrance.

When the injector is ready for pulsing, all beam-inhibit interlocks have been removed and a beam program has been turned "on" by the operator; a control signal is fanned out to all areas to make the magenta warning lamps flash.

WARNING SIGNALS WITHIN RADIATION AREAS (Fig. 21-2a). The general illumination within radiation areas is used as a warning when the area is being closed. The lights in the accelerator housing are interlocked with the manway hatch covers. In the BSY and end stations, they are interlocked with the large concrete doors and with an inner gate at other entrances. As soon as the area is closed, the lights are flashed off and on for 2 min and then left at a low level. This serves to warn any workers in the housing that it is time to proceed to the nearest "emergency-off" button. The "shutoff" buttons and a green exit light are illuminated and remain visible after the housing lights have been dimmed. Full illumination is restored immediately if the emergency-off circuit is tripped. In the end stations, a number of outlets are provided for connection of additional "emergency-off" buttons, as required.

RADIATION MONITORS. None of the radiation monitors is directly interlocked with the machine shutoff system or with the control of access. Some of them are interlocked with the beam through the machine protection system, others with the "emergency stop" circuit.

Five types of radiation monitors are used in the personnel protection system:

1. Portable gamma monitors in each sector and in the DAB.
2. Gamma monitor at all personnel accessways. These meters can be read out in central control as well as locally, so that the operator can determine whether residual radiation is sufficiently low to allow entry.
3. Gamma–beta air monitors at alternate air exhausts along the gallery and at every exhaust in BSY and beam dump east.
4. Gamma monitors in each nonradioactive secondary water loop of the switchyard heat exchangers. These monitors are interlocked with the

cooling tower pumps to shut off the primary water loop in case of leakage of radioactive water from the primary loop to the secondary loop.

5. Research area monitors to operate the "emergency stop" circuit. Readout of these meters is provided in DAB.

These monitors are described in more detail later.

NORMAL PERSONNEL ACCESSWAYS. Normal personnel accessways are characterized by having two interlocked doors and keys in a local keybank. In the accelerator and switchyard housings, one of the doors is airtight. A radiation monitor with readout at each entry is provided to indicate the existing radiation level inside the entry.

Each door uses a different key. A keybank stores only keys for the adjacent door. Release of the keys from the keybank is controlled from CCR or DAB, as appropriate. Interlocks prevent the operators from releasing keys unless the machine is off or appropriate beam stoppers have been inserted. A glass panel provides access to emergency manual release of keys.

In general, the locked door is self-closing so that a person requires a key *each* time he enters. Each person who enters is expected to take a key along with him. The absence of the key from the keybank is the worker's primary assurance that the accelerator cannot be turned on.

Each entrance has an inner gate or door which has no lock but which remains open any time a person is working inside. The inner gate is interlocked with the machine (just as is the keybank) and provides a second assurance that the machine cannot be turned on until the people inside have left the area and closed the inner gate behind them.

The airtight manway hatch covers along the accelerator serve the function of the inner gate for the accelerator housing. A wire screen door within the labyrinth serves the same function in other areas. The flashing light warning is also interlocked with the closing of this inner gate.

Since much of the shielding around the end stations is movable, the end-station entrances are not permanent installations. A portable entrance module furnishes a weather-tight vestibule bolted to the shielding blocks at each labyrinth entrance. The keybank, a TV monitor camera, and illuminated warning signs are located in the module. Its inner door is the locked control door for the end station; its outer door is for weatherproofing only. The inner gate at each entrance is separately bolted to the labyrinth-shielding blocks.

Each time the inner gates to an area are closed, the lights are flashed for about 2 min. After this period, the illumination is dimmed. The remaining illumination is sufficient to allow a person to find the nearest "emergency-off" button and the nearest exit.

SPECIAL ACCESSWAYS FOR EQUIPMENT INSTALLATION. In general, sliding concrete doors and gates in the end-station cable trenches are left open for the duration of the required access. There is no associated inner gate and a search of the entire accessible area is required after they are closed. Their limit switches are wired in series with the "emergency stop" buttons. Keys are required to open these doors, but the (exterior) local controls are inhibited unless it is safe to enter and the operator has decided to permit unrestricted access to the area.

It is possible to open the door from the inside without regard to interlocks and during temporary power failures. Local controls for emergency entrance are provided behind a glass panel by each door.

Entrances to cableways and some manholes which are not beam areas but which have substandard shielding from the accelerator housing or BSY are padlocked and the keys are kept at Sector 20 or in DAB in a keybank interlocked with the machine.

Special surveys must be made when the radioactive heat exchangers are entered since they will remain radioactive long after the accelerator is turned off. Keys used to control access to the heat exchangers are kept in an interlocked keybank in the DAB.

DAB DISPLAY PANEL. By perusing the display panel, the DAB operator can check the status of each door, ventilation hatch, gate, and keybank in the switchyard and end stations and can determine if the emergency stop circuit for any area has been tripped. He has controls that permit him to set each end station to either the "stoppers required" state or the "stoppers not required" state, and additionally to set each end station and the switchyard to the states "entry permitted" or "no entry." Changing any of these states requires concurrence of the chief operator. The DAB operator also has buttons to select states "controlled access" or "permitted access" for each end station, and a key release and a television monitor which may be switched to any controlled entrance to the switchyard and end stations. The key release is effective only during "controlled access."

A search reset button is provided for switchyard, B target room, and each end station. This reset button is effective only when the local reset button in the housing is pressed simultaneously.

A set of radiation meters allows the DAB operator to estimate the level of residual activity inside the switchyard or B target area before he releases a key.

The controls for the beam stopper and slit are located elsewhere but are interlocked with the state "stoppers required." The status signals: "pulsed-magnet off," "stoppers in," and "slit closed" are displayed.

Controls for the ventilation hatch covers in the switchyard are located elsewhere but are interlocked with the state "entry permitted" for the switchyard. A status signal "hatch closed" is displayed for each hatch cover.

CCR DISPLAY PANELS. The detailed display of the status of door hatch cover, exhaust fan, keybank, and emergency stop circuit for each sector is on the switched "sector display" panel. Controls for hatch, fan, keybank release, and search reset also appear on this panel.

The fan control is interlocked with the hatch cover; the hatch may be opened if the machine is off. Key release controls are ineffective until the operator has actively acknowledged that the machine is off. The search reset button is effective only when the local reset button in the housing is pressed simultaneously.

The backup console contains an array of meters to allow the operator to monitor the residual radiation at each manway entrance to the accelerator housing. The operator is expected to determine that the radiation is at a safe level before releasing a key. He also is expected to open hatch covers and start the fans to ventilate the housing for 10 min before releasing any keys.

The status signals "sector secure" and "door closed" are repeated on a summary panel in the maintenance console so that the operator may determine the security of the accelerator housing at a glance.

The summary panel contains indicators for the operational states of the switchyard and end stations ("entry permitted–no entry," "stoppers required–no stoppers," "controlled–unrestricted access"). Selector buttons are provided for the CCR operator to set these states by prearrangement with the DAB operator. Certain further indications of the state of closure of each area (keybank summary, door summary, "emergency off–search reset" status, etc.) are also provided.

Other summary panels also have status indications and reset key switches for the major tone loops "housing secure" and "machine off." The reset button for the "machine off" loop is the operator's acknowledgment that the machine is off and must be pressed before he can permit any entry to housing or end stations.

The reset switch for the housing secure loop must be operated before the operator can turn on any VVS. He thus acknowledges that the housing is secure to the best of his knowledge.

INTERLOCK WIRING. The interlocks are hard-wire circuits which prevent access to radiation areas when the accelerator is on and prevent turning on the accelerator before the housing is secured. The circuits have little direct connection with central control. They require, however, the fan-out of information to every sector. The Central Control Room is the place from which this fan-out can most easily be accomplished. Space in CCR has, therefore, been utilized for the equipment which detects interlock status and sends out permissive control information. For example, the tone receivers for the "housing secure" loop are located in central control. They, in turn, transmit signals which permit turning on the VVS. Similarly, a relay which is actuated when all substations are off ("machine off" loop) is located in central control. It transmits permissive signals allowing ventilation hatches to be opened, etc.

"EMERGENCY STOP" CIRCUIT. The "emergency stop" circuit for the research areas is designed to shut off the beam and to insert beam stoppers in Sectors

20, 21, and 29, and ST_{10} and ST_{30} in the switchyard when, through some fault of shielding or operational procedures, excessive radiation is observed in the research area outside the end stations.

The system is designed to protect personnel who must work in peripheral areas during an experimental run. Insertion of beam stoppers is less extreme than total shutdown and allows quicker return to normal operation once the fault is corrected. It is, nevertheless, quite absolute in its manner of removing the beam from the area.

A stopper consists of a 1-in. diameter stainless steel tube, 5 in. long, filled with lead. It is installed in a fail-safe condition such that air cylinders keep the stopper out of the beam path unless the air supply fails or the power is shut off. The means of inserting the stopper is primarily gravity with slight assistance from the atmospheric air pressure against the bellows seal at the stopper stem. Limit switches indicate the position of the stopper and are connected into the personnel protection interlock system. If the stopper is not in the retracted (out-of-beam) position, no beam can get into the switchyard.

The stopper was not designed to absorb any energy. It was designed to prevent stray pulses of the beam from reaching the switchyard and research areas. It is, in turn, protected through the machine protection system both by interlock switches and the long ion chamber.

The "emergency stop" switches are made of commercial parts. Each switch is actuated by two buttons. The "on" button is key-operated. With the key removed, the "on" button is nonfunctional, but the circuit may be tripped by the "stop" button. The key must be inserted and turned to allow resetting the circuit. The switches are located in research trailers and at each end-station entrance, as shown in Fig. 21-5.

The ion chambers are discussed in detail below. Three alarm levels are provided. One of the three alarm levels is a low set point alarm. A source added to the chamber gives a signal of about 2 mrads/hour, and the low set point is used as an indication of the correct operation of the circuit. The second alarm level is at about 25 mrads/hour. It lights an alarm in the DAB as an indication that the radiation level is becoming excessive. The third alarm level is set at about 100 mrads/hour and is used to turn off the gun and insert beam stoppers. Only the third alarm is part of the local unit; the other two alarms are part of the remote metering circuit in DAB.

No special reset circuit is provided. Each "stop" switch will remain open, after actuation, until reset by an operator's key. Each radiation monitor has a local reset, to be operated by health physics personnel. After the circumstances have been investigated to the satisfaction of the BSY operator, he may remove ST_{10} and/or ST_{30}. If CCR is satisfied, beam stoppers in the accelerator housing will be removed. The injector may, then, be turned on and operation may be resumed, with such extra surveys or restrictions as prove desirable.

Operation of system (KBM)

SEARCH PROCEDURE. One of the major functions of the personnel protection system is to make it possible for the chief operator to keep track of the number of people in the radiation areas. The operator in central control has immediate responsibility for the accelerator housing; the DAB operator has immediate responsibility for BSY and end stations.

If the operator knows the housing is empty, lets two people into an area and counts the same two people out, he may immediately secure the area and prepare to turn the accelerator on. After an extended shutdown, the number and the identity of the people in the housing may be unknown. A search is then required in order to clear the housing or at least to determine exactly how many people are left.

A search is also required any time an "emergency off" button has been operated or any time a person leaves an area through an unguarded door. The immediate and primary function of the "emergency off" buttons is to disable the accelerator. This interlock is reset by a "search" circuit linking the "search reset" buttons.

A search of the entire accelerator housing and end stations requires several man-hours of work. The housing is, therefore, subdivided so that it is possible for the operator to keep a separate count on each area. In general, if unrestricted access is allowed to one area, only that area needs to be searched before securing the housing. An area which has not been entered need not be searched. The end stations, the B target room, the switchyard, and groups of sectors are separated by rigid barriers or gates; a separate accounting of occupants may be kept for each area. The gates between accelerator sectors and between the accelerator and switchyard housing are spaced so that there is seldom any need for personnel to pass through. They are not locked and may be opened easily if necessary, but they are interlocked so that a search is required in both adjacent areas if a gate has been opened.

A search is accomplished by a search team which starts at a dead end or a locked gate and sweeps through the area. As the team passes a gate, they either check that the gate is securely locked or they post a guard.

At specified accessways the team captain calls the operator and then actuates a reset button within the accessway. Simultaneous acknowledgment by the operator resets the search circuit. If the area is empty, the search team may lock the final accessway. If personnel have been left behind, they monitor the accessways until all personnel have been logged out.

When the final accessway is closed and the completion of search has been acknowledged, the illumination in the area flashes for 2 min and then dims to a level sufficient for a person to make his way to the nearest "emergency off" button. Should a person be left behind and press the "emergency off" button, the full illumination is immediately restored, the search circuit is upset, and the entire search must be repeated.

GALLERY AND ACCELERATOR HOUSING. The locations of the personnel protection system components in the gallery and housing of a typical sector are shown in Fig. 21-3. A key to the symbols of Fig. 21-3 and later figures is given in Table 21-1.

The basic lockup procedure for the accelerator housing starts with a search of the housing. At the end of the search, the display panel in CCR should show that all entrances to the accelerator housing have been closed and locked.

Once the chief operator has assured himself that the housing has been cleared and that all entrances are secure, the accelerator housing is ready for the beam. After the BSY and the end stations have also been secured, the accelerator may be turned on.

When entry to the accelerator housing is desired, it is first necessary for the chief operator to acknowledge that the accelerator has been turned off (all VVS off). The chief operator may then release keys to individual doors. The housing ventilation may be started as soon as all VVS are off.

BEAM SWITCHYARD. The location of the personnel protection system components in the switchyard are shown in Fig. 21-4.

Once the DAB operator has assured himself that the housing has been cleared and that all entrances are secure, he may signal to the chief operator in central control that the switchyard is ready for beam. *Simultaneous* acknowledgment by the chief operator sets up the state "no entry" for the BSY and operates interlocks to prevent release of keys for doors and to prevent opening of exhaust fan hatch covers.

When it is desired to enter the BSY, it is first necessary to set the state "entry permitted." This cannot be done until the accelerator has been turned off (all VVS off) or the BAS mode of operation has been established. The chief operator may then press his button "entry permitted" for the switchyard. Simultaneous acknowledgment by the DAB operator denotes his acceptance of the responsibility for control of entry to the switchyard housing.

The DAB operator may then initiate ventilation and release keys to individual doors.

B TARGET ROOM. At time of writing, the B Target Room is a part of the switchyard. It has a separate "emergency off" and reset circuit. Keys may be released from the keybank only when entry to the switchyard is permitted. The B Target Room must be secure before the state "no entry" may be set for the switchyard.

Late in 1967, a shielding wall will be installed between the B Target Room and the BSY. The B Target Room will then be interlocked as part of end station B.

END STATIONS. The location of the personnel protection system components in the end stations A and B are shown in Fig. 21-5.

The end stations have two entry modes, "controlled access" and "access permitted." Under "controlled access" personnel may enter the end station only at designed doors with keybanks. Under "access permitted" personnel may operate local release controls for any door to the end station. Before a search may commence, the DAB operator must set the "controlled access" state, thus immobilizing the release mechanisms for the concrete door and for the gates and utility trenches.

When it is desired to enter an end station, it is first necessary to set the state "entry permitted." (This state includes both the "controlled access" and the "access permitted" states described above.) This cannot be done until (1) the accelerator has been turned off (all VVS off), (2) the BAS mode of operation is established, or (3) the stoppers for that end station are in.

The DAB operator may then release keys to individual doors or may choose "access permitted." This activates local release circuits for operating doors; keys will not be required for entrance until "controlled access" is restored. If "access permitted" has been elected, a full search of the end station is required before it can again be secured.

21-3 Radiation monitoring

Introduction (RM)

Radiation monitoring is accomplished by using a combination of fixed detectors and movable detectors, and within that framework, by continuous monitoring and spot-checking or batch sampling. Examples of the different monitoring concepts are as follows:

1. *Batch sampling.* The cooling water for the klystrons and accelerator waveguides passes under the klystron gallery floor to a heat exchanger in the mechanical equipment alcove. There are thirty such alcoves along the klystron gallery. Radiation levels from these return water lines and heat exchangers are monitored only periodically. The heat exchanger itself is a doubly isolated unit; should a leak develop in the radioactive-water side, the chances of this water reaching the cooling tower are sufficiently remote (because there would have to be a corresponding leak in the cooling tower loop) as not to require a continuous monitor in the cooling tower loop. Water in this line is checked on a periodic basis, taking batch samples back to the laboratory for analysis.

2. *Continuous monitoring.* The heat exchangers for the slits, collimators, and dumps are singly isolated; therefore, a leak in one side contaminates the water in the other. The cooling water loop for these units runs from the tower to the individual units in series. After the final heat exchanger, a continuous water radiation monitor is provided, which not only records the levels, but will shut off the water pumps and indirectly the beam if levels rise above a predetermined value. The air exhaust points of the BSY are other examples of continuous monitoring, with the air being monitored

continuously during the period of probable radioactivity (the first 15 min of venting).

3. *Combination of continuous and batch monitoring.* The air monitors in the klystron gallery are examples of this type of monitoring. There are fixed air monitors at every other exhaust point. Those points not continuously checked will be sampled on a spot-checking basis until a pattern has emerged or "hot spots" identified. The ultimate location of the fixed air monitors and their number will await the results of these checks.

Each of the continuous monitors may employ the following readouts: (1) local only, (2) local and remote, (3) a combination of the above plus beam interrupt. Examples of the first type are the air monitors which have a local ratemeter plus chart recorder. These charts are checked periodically by health physics. The manway monitors are examples of the second type, with a local ratemeter and a remote ratemeter located either in CCR or DAB. The water monitor, which stops the water pumps under alarm conditions, is an example of the third type.

The end station areas require special attention. Although the personnel protection system ensures that no one can enter an area without turning the beam off, the end station walls are not thick enough to attenuate the radiation should a significant fraction of the beam be stopped within the end station itself. In cases where a significant power is to be absorbed within an end station, local shielding must be employed. However, even though the local shielding may be adequate for normal running conditions, there are cases where radiation levels outside the end station walls may rise significantly due to beam missteering, magnet failure, and so on. Levels as high as hundreds of rem per hour may result. Two systems have been installed to minimize this hazard to personnel.

The first system is concerned with high radiation levels at the outside walls of the end stations themselves. Discrete, tissue-equivalent ion chambers are installed around the walls which will (a) read locally, (b) alarm locally and in the DAB if a level of 25 mrads/hour is reached, (c) shut off the beam through the "emergency stop" circuit if a level of 100 mrads/hour is reached. These units respond within 1 sec.

The second system is concerned with radiation levels in the vicinity of an experiment and serves to protect the experimenter. Tissue-equivalent ion chambers, positioned according to the particular experiment, will read and alarm locally and in the DAB if the dose rate rises above 1 mrad/hour. In addition, these units will integrate the dose received over a period of 1 hour. If this integrated dose is greater than 0.75 mrad, an alarm lights in the DAB. Both alarms require that the operator take some action, which may be simply sending one of the available health physics technicians to monitor the area.

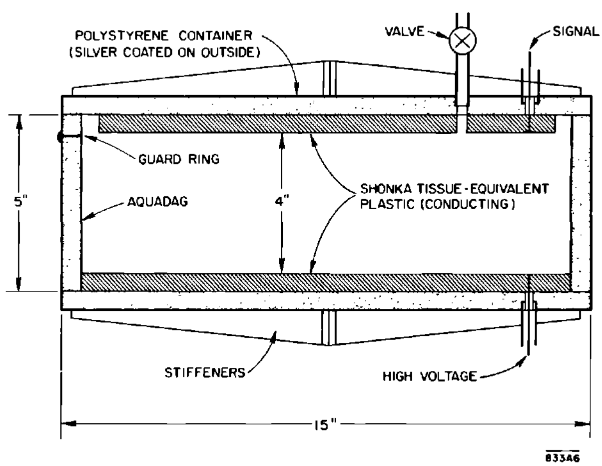
In addition to fixed monitoring along the machine, health physics maintains eight peripheral monitoring stations, consisting of moderated BF_3 and Geiger counters, which print out once each hour. Information from these stations is used to assess the radiation levels at the SLAC boundary lines.

Research area monitoring system (GB, GW)

The research area monitoring system consists of ten stations and a central readout unit located in the DAB. The monitoring stations are located at strategic points in the research area depending upon the experiments in progress. Each station consists of two four-decade log ratemeters and two ionization chambers. Dose rate information (0.1–1000 mrads/hour) is displayed locally and transmitted to the DAB. If a preset dose rate is exceeded, an alarm light is turned on locally and also in the DAB. Pulses from the tissue equivalent plastic chamber are transmitted to the DAB and integrated for 1 hour. If the dose for 1 hour exceeds a preset level, an alarm is energized.

One chamber at each station is designed to give the total absorbed dose. This ion chamber is a polystyrene container lined with Shonka tissue-equivalent plastic and filled with Shonka tissue-equivalent gas. See Fig. 21-6 for construction details. The outside is coated with silver conducting paint. The chamber has essentially parallel plate geometry with 4-in. plate separation. The collection efficiency has been checked in a constant field of 400 rads/hour and is essentially saturated (90%) at 550 V. Boag[1] gives equations for the collection efficiency for steady radiation fields and also for pulsed radiation fields where the time between pulses is long compared to the transit time of the ions formed and the pulse width is short compared to the transit time. At 1 pulse/sec, this condition is approached. The theoretical collection efficiency for a 1.5-μsec pulse at 1 pulse/sec is 90% at 10^6 R/hour. At higher repetition rates and the same pulse width, this condition is not fulfilled. Theoretical collection efficiencies for repetition rates up to 360 pulses/sec are, nevertheless, greater than 90% at 550-V collection potential, for average dose rates

Figure 21-6 Construction details of tissue-equivalent ionization chambers.



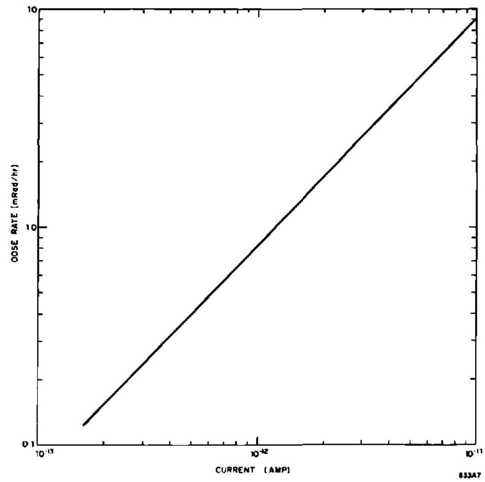


Figure 21-7 Current response of tissue-equivalent chamber to neutrons and gammas.

up to 5 R/hour or more. Figure 21-7 shows a calibration curve of dose rate for Pu–Be neutrons and ^{226}Ra gammas versus current. The dose rate from this chamber is compared with a known tissue-equivalent chamber (Rossi P chamber).

The second ionization chamber is a commercial design, described under manway monitor below.

In order to save on development time, it was decided to modify a commercial instrument for processing the ionization chamber signals. With the exception of two electrometer tubes, the instrument is all solid-state.

Its design concept is as follows: The front end uses one of the electrometer tubes in a common cathode configuration as the input stage of an amplifier the sole function of which is to monitor the charge voltage on a holding capacitor at the input and to maintain a clamp on an otherwise free-running multivibrator. When unclamped, the multivibrator injects a subtractive charge into the holding capacitor through the second electrometer tube connected as a diode. The sense of this subtractive charge is such that the electrometer amplifier reclamps the otherwise free-running multivibrator. Thus, equilibrium is established when the time integral of the subtractive charges exactly equals the time integral of the incoming charges (the signal from the ionization chamber). The digitization is of the order of 1 pulse per picocoulomb. These pulses are used to trigger a circuit which has an analog output proportional to the logarithm of the rate of the input pulses.

This instrument was modified by installing a buffering amplifier in order to bring out the pulses, which are linearly related to the current from the ionization chamber.

These two output signals (a linear signal in digital (pulse) form and a logarithmic signal in analog form ranging from 0 to 5 V) are sent from the remotely located monitoring station via 50-ohm coaxial cable and shielded twisted pairs to the common readout chassis located in the DAB. Analog data from the ten tissue-equivalent chambers are read out on individual meters identical to the ones located in the local instruments. A station selector switch permits analog data from the ten aluminum ionization chambers to be read out on a single meter.

Digital data (from the tissue-equivalent chambers only) are read out on two types of registers. One is a predetermining counter with four significant figure resolutions which can be set to produce an alarm signal at any selected integrated dose level. Each of the ten tissue-equivalent chambers has its own individual predetermining counter.

The second type of register displays the integrated dose and automatically prints a record of the integrated dose every hour. A programmer generates the necessary commands to stop accumulating data, print, and reset the registers hourly. Dead time as a consequence of this program is less than 20 sec each hour. The analog readouts are not affected by this program.

Because of the limited pulse pair resolution of the registers (40 msec minimum), each of the ten channels of digital information is prescaled by a factor of 32. The derandomizing effect of the prescalers and the short-term averaging response of the ionization chambers in conjunction with the use of a "nonparalyzable" pulser to drive the registers enables the digital portion of the system to keep up within the saturation limitations of the ionization chambers for any type of doses (including pulsed) the average rate of which is less than 600 mrads/hour. Due to the nonparalyzable feature just mentioned, higher average fluxes than this maximum will be read out as approximately 650 mrads/hour.

The calibration of the digital channels of information is such that 1 mrad of absorbed dose will be indicated as 100 digits on the digital registers. All channels of information can be individually adjusted so as to exhibit mutual agreement within the limits of reproducibility of this type of instrumentation. A toggle switch permits the operator, at his discretion, either to reset the predetermining registers simultaneously with the automatic hourly resetting of the printing registers or to reset any combination of the predetermining registers at any time with individual pushbuttons. Beyond this one option, the system is entirely automatic. It is completely contained on a single chassis occupying about 15 in. of standard relay rack space.

Peripheral monitoring (TMJ, GB)

The presence of radioactive ground water is monitored through the use of wells. For this purpose there exists a network of eighteen peripheral wells (Fig. 21-8). Samples have been taken from these during the last 18 months to establish background conditions. These wells could also be used to lower the local water table if necessary. The wells are sampled once every 2 months.

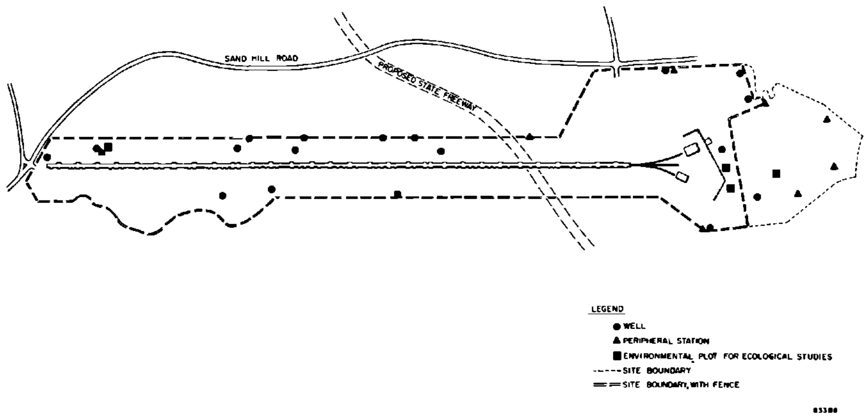


Figure 21-8 Locations of peripheral monitoring stations, water sampling wells, and bio-environmental plots.

In addition, samples are taken from San Francisquito Creek upstream and downstream of the project on a monthly basis. Operating wells in the San Francisquito basin downstream of SLAC are also sampled, including those used by Stanford University. Samples are sent to a commercial laboratory for gross beta and tritium measurements; γ-ray spectra are measured at SLAC.

Finally, there are four environmental plots for ecological studies. Vegetation samples are taken from these on a semiannual basis and compared with similar samples from a distant location. Gamma-ray spectra are measured in-house and gross beta are measured in the ashed samples at a commercial laboratory.

The peripheral monitoring stations serve to provide automatically recorded data concerning radiation levels near the boundaries of the accelerator site. A prototype system was constructed and put in use for approximately 1 year prior to the first turn-on of the accelerator beam, thus giving data on the prior radiation history of the site. Subsequently, three "penultimate" and four "final" versions of this instrument were built, giving a total of eight stations around the site. Seven of these stations are situated relatively near the BSY end of the site, the eighth station is near the injector (see Fig. 21-8).

Convenience, reliability, and cost dictated use of ac power for these stations, supplied from the main facilities through weatherproof cable.

Radiation information is obtained with a Geiger tube and an enriched paraffin-moderated BF_3 tube. Except for sharing a common power supply and a common readout device, the two sources of radiation information are completely independent. The readout device prints and displays ten columns of numbers. The associated circuits assign five of them to the Geiger tube, and five to the BF_3 tube. The resultant display is the equivalent of two independent scalers capable of storing 10^5–1 counts each.

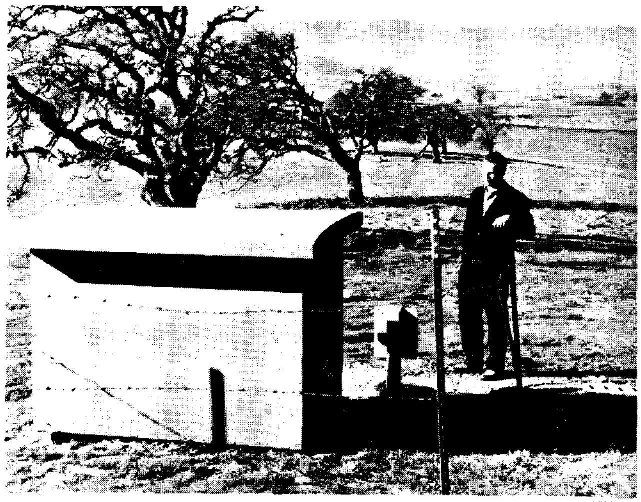
Due to the pulse pair resolution limitation of the register (40 msec minimum), prescaling of the input pulses was again considered necessary. Accordingly, bistable multivibrators were connected serially to provide prescaling coefficients of 8 for the BF_3 tube, and 32 for the Geiger tube. Resultant sensitivity is such that a flux having an average value for 1 hour of 1 mR/hour will be read out as 4800 counts on the Geiger tube channel, and a neutron flux having an average value for 1 hour of 1 mrem/hour will be read out as 48,000 counts on the BF_3 channel. The printout cycle is the same as that for the research area monitors. Although the printed data are usually gathered by health physics personnel once a week, attendance on these stations could be limited to semiannual replacement of roll paper and/or printing ribbon.

An important feature of this system involves the pulser that drives the register. It is of the nonparalyzable type. This means that if the instantaneous rate (20 pulses/sec) is ever exceeded, the register will merely not count the pulses in excess of its maximum rate. It can count at this maximum rate continuously. This rate corresponds to approximately 15 mR/hour for the Geiger channel and about 1.5 mrem/hour for the BF_3 channel. This saturation limit is rarely likely to occur under normal circumstances, since normal readouts are less than one-thousandth of the maximum (7×10^4 counts) that could be acquired in 1 hour.

The Geiger tube can be biased on its plateau with a front panel control switch providing 900–1000 V in 25-V steps. A corresponding front panel control switch provides a bias voltage for the BF_3 tube ranging from 2000 to 2400 V in 100-V steps.

The pulses from the Geiger tube trigger a one-shot multivibrator which, in turn, drives the prescaler (scale of 32) which triggers the nonparalyzable pulser which drives the Geiger portion of the register. Since the pulses from the BF_3 tube are much smaller than those from the Geiger tube and since amplitude discrimination is needed, the BF_3 channel is slightly more complex. A cylindrical extension attached to the BF_3 tube serves as a housing for a bootstrapped field effect source follower amplifier having a gain of approximately 0.95 and an output impedance of about 50 ohms. The output of this amplifier drives a 93-ohm coaxial cable which transmits the signal to a linear amplifier (gain = 100) located within the main chassis. The output of the linear amplifier is presented to a tunnel diode discriminator of which the output drives the BF_3 prescaler (scale of 8). Thereafter the circuitry is identical to the corresponding circuitry in the Geiger channel. Although these stations do not have the sophistication of more elaborate laboratory-type equipment, they appear to accomplish their intended function reliably. They are protected from the weather by being housed in hinged plywood boxes resembling large steamer trunks (see Fig. 21-9).

Tapes are collected monthly from the eight peripheral stations, and the data are fed to a computer which plots the levels in mR/hour for gammas, and mrem/hour for neutrons using a conversion factor of 8 neutrons/cm^2/sec = 1 mrem/hour. This is probably a conservative value and will be revised by



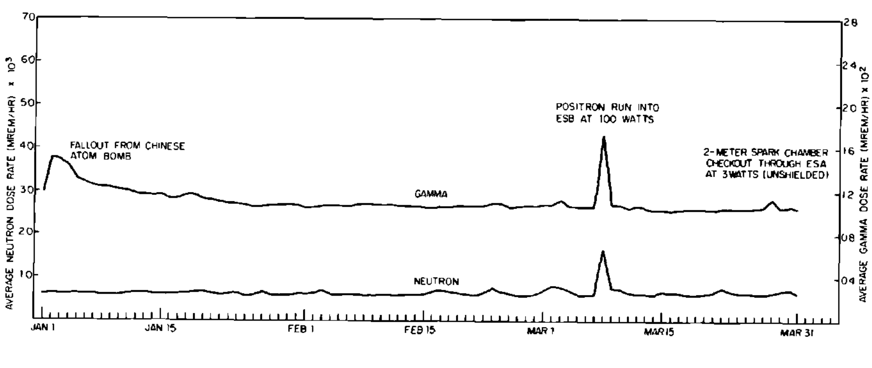
835A9

Figure 21-9 Typical weatherproof peripheral monitoring station.

placing a proton-recoil proportional counter at the peripheral monitoring sites to measure an effective average neutron energy. Once this is established, a new conversion factor will be used in the computer to plot dose levels.

The plots are normally made by using values obtained by averaging the readings for a 24-hour period. If a more detailed analysis is desired, the computer will plot out an hourly level. Figure 21-10 is a plot made from one of the monitoring stations during the first quarter of 1967. Peaks corresponding to high radiation level runs in both end station A (ESA) and end station B (ESB) appear clearly on these plots.

Figure 21-10 Radiation levels at peripheral monitoring station No. 1, first quarter of 1967.



835C10

Manway monitors (TMJ)

The primary purpose of the manway monitor is to measure the level of residual radioactivity at the base of a manway penetration to check radiation hazard to which entering personnel will be exposed. A secondary purpose is to determine radiation levels in the tunnel for purposes of shielding evaluation, etc., while the machine is in operation. A manway monitor is located at each manway along the accelerator, each entrance to the BSY, and at the entrances to the heat exchanger pads for slits, collimator, and dumps. Readout is both local (beside the keybank next to the entranceway) and remote (either in CCR or the DAB) to inform both the person entering and the operator of the levels in the vicinity of the detector.

Because the distances involved (up to 2 miles) make frequent checking of these instruments impracticable, the utmost in stability is required. Conventional electrometer circuits have too much drift. The electronics of this system uses a pulse charging technique of which the drift is less than 1 mR/hour over periods of months. (See section on Research Area Monitoring System for details.)

The detector is a 2.5-liter sensitive volume, 4-atm air-filled ionization chamber with an energy response flat to $\pm 10\%$ within the energy range of 80 keV to 3 MeV. An aluminum wall was specified to minimize induced activity in the chamber walls, and the location of the chamber was chosen to give the closest approach to the accelerator possible while maintaining adequate shielding against forward-directed high-energy particles when the beam is on. In the accelerator housing, the detectors are positioned within 8 ft of the waveguide, while they are within 10 ft of the upper housing in the BSY. Their locations are shown in Figs. 21-3 and 21-4.

The range of the meter, located 50 ft from the chamber, is from 1 mR/hour to 10 R/hour with logarithmic readout. The instrument will handle peak intensities greater than 10^3 times full scale, allowing it to be used during machine operation. Typically, when the machine is tuned properly, and with a beam power of about 10 kW, the manway monitors read less than 100 mR/hour, and often less than 10 mR/hour. These units proved extremely helpful during initial beam trials in aiding the operators to locate sectors of maximum beam loss before the long ion chamber was operational. They still serve as a backup to that system.

Water monitor (TMJ)

This section is concerned only with those sources of radioactive water at SLAC that could get into the public water supply. The radioactive cooling-water loops are designed so that a leak to the outside will drain into sumps. A leak into the return water loop of the heat exchanger would be detected by an in-line water monitor and the pumps would be turned off before the contaminated water could reach the cooling tower.

The water monitor consists of ten Geiger tubes with a sensitive volume of 2085 cm^3, immersed in a single stainless steel well through which bypass water flows at a rate of about 1.5 gal/min. The Geiger tubes form two separate detectors, five Geiger tubes per detector. Each detector has its own preamplifier, high-voltage supply, and ratemeter electronics.

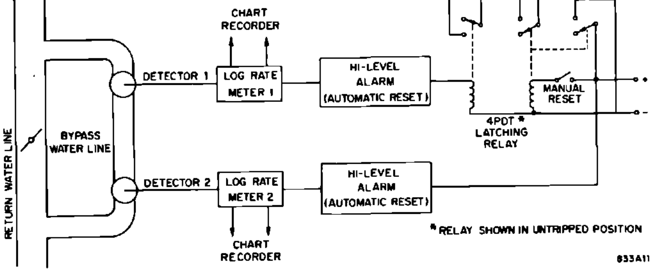
Detectors and preamplifiers are located inside the BSY substation building near the return water lines. Readouts of 500 to 2500-V variable supplies and log ratemeters are located in the DAB. When the meter pointer reaches the alarm setting, a relay contact within the ratemeter closes. This is an automatically resetting relay, opening within about 1 sec after closure. If the condition which caused the high level persists, the needle will "chatter" about the alarm point. Also, when this relay closes, a local red light on the ratemeter lights, and then turns off when the relay resets itself.

When both ratemeters alarm in coincidence, a latching relay closes. This lights a local red light as well as a light on the DAB console, and also interrupts a repeater relay of which the normally closed contacts are connected across the cooling tower pump motor "trip" circuit. The pumps cannot be turned on again until the latching relay is reset by pushing the reset button. When reset is accomplished, the red lights are extinguished.

These units were not designed to be fail-safe, so that if one or both units should lose power, the pumps will not shut off. The units are checked daily, and the probability of a leak occurring during the period of a unit failure is sufficiently remote to preclude the failure of the accelerator to shut off in such an event (see Fig. 21-11).

In cooling towers, where water is lost by evaporation, normal radiation levels rise due to the presence in the atmosphere of fallout products which dissolve in the water and are concentrated by the evaporation process. The State of California has estimated that an impurity level of 50 to 3750 pCi/liter will normally occur after a year or so of operation with a waste flow of 5000 gal/day. Thus the alarm level must be set taking into account the normal rise in radioactivity in the cooling water. Normal background from each detector

Figure 21-11 Coincidence and latching relay circuit of water monitor.



(consisting of five Geiger tubes) immersed in the cooling tower water is about 70 to 100 counts/min. The unit is surrounded by 2 in. of lead so that radiation levels from the accelerator itself will not actuate the pump shut-off system

Radioactive gas monitor (GW)

Radioactive air produced inside the accelerator housing will present a significant hazard to personnel. Using a 3% beam power loss uniformly distributed along the accelerator, DeStaebler[2] has calculated concentrations of various isotopes produced in air. For air the following reactions are of concern: $^{14}N(\gamma, n)^{13}N$; $^{14}N(n, 2n)^{13}N$; $^{16}O(\gamma, n)^{15}O$; $^{40}A(\gamma, p)^{39}Cl$; $^{14}N(\gamma, 2np)^{11}C$. The calculated equilibrium concentrations are shown in Table 21-2. To reduce the hazard, the tunnel which is normally sealed during operation is first vented before entry is permitted. During venting, one complete air change occurs approximately every 10 min.

A radioactive gas monitor is located at alternate exhausts from the accelerator and at every exhaust from the BSY. Monitors are also available to measure the concentration of radioactivity in the tunnel or BSY before venting.

The radioactive gas monitor is a modified commercial design and essentially measures the activity in an 11-liter volume through which air is being pulled at a rate of 3 ft^3/min. The monitor is divided into two sections. One section consists of the GM tube, triggered pulser, pump, and shield and is located in the manway access housing; the remaining section consisting of the ratemeter, recorder, and timer is located in a rack near the manway housing.

The ratemeter and recorder meter movements operate continuously. The air pump starts when the exhaust fan is started and remains on as long as the exhaust fan is on. The recorder drive starts when the fan is turned on and runs for a preset time. The chart drive speed is 2 in./min. The highest concentration occurs in the first few minutes of venting, and then declines. The preset recording time is variable so that the decline in concentration can be followed for a desired length of time (nominally 15 min). The time can be set from 1 to 60 min.

Table 21-2 Calculated equilibrium concentrations of radioactive nuclides

Final nuclide	*Equilibrium concentrations in tunnel* (pCi/cm^3)
^{11}C	3.1
^{13}N	190
^{15}O	220
^{39}Cl	5.5

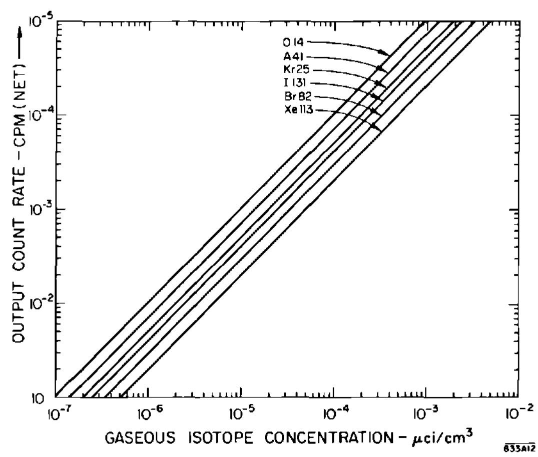


Figure 21-12 Air monitor calibrations.

The unit is calibrated with ^{85}Kr and gives 200 counts/min above background for a concentration of 5×10^{-6} μCi/cm^3. Typical calibration curves are shown in Fig. 21-12. The detector is a 50-mg/cm^2 stainless steel Geiger tube filled with a mixture of neon and halogen. The tube is connected to a triggered pulser that provides a 4-V negative pulse, 2 μsec wide, into a 93-ohm load.

The ratemeter is a combination ratemeter and high-voltage supply. The ratemeter is four-decade logarithmic and indicates counts per minute. The high-voltage supply is variable from 500 to 2500 V and provides 100 μamp.

Personnel beam shutoff ionization chambers (GB, GW)

The monitoring station in the research area personnel beam shut-off system ("emergency stop" circuit) consists of an ionization chamber and a four-decade logarithmic ratemeter indicating from 1 to 1000 mrad/hr full scale. The analog information is displayed locally and transmitted to the DAB. There are three alarm conditions: one system failure alarm and two radiation level alarms which are set at 25 mrads/hour (warning) and 100 mrads/hour (beam shutoff). The "system failure" turns on an alarm light in the DAB and requires a manual reset at the DAB alarm panel. The "warning" turns on an alarm light in the DAB and is reset automatically when the radiation level is reduced. The "beam shutoff" turns on an alarm light at the DAB, turns off the injector, and inserts a beam stopper. The "beam shutoff" requires manual reset at the chamber location. A block diagram of one channel is given in Fig. 21-13.

The "system failure" and "warning" level alarms are controlled by a dual optical meter relay used as the analog readout in the DAB. The "beam shutoff" level alarm is controlled by a latching-type contact meter relay in the unit.

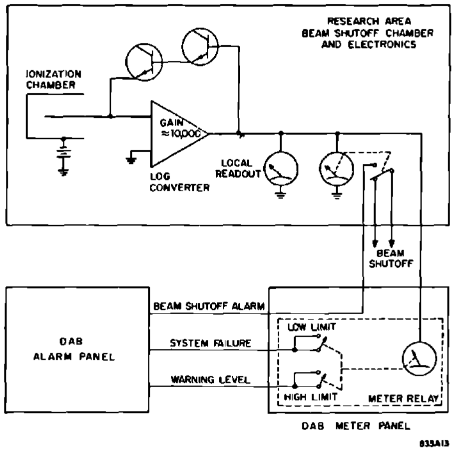


Figure 21-13 Beam shutoff ion chamber and electronics.

The ionization chamber is constructed from aluminum and filled with a tissue-equivalent gas. It is cylindrical, with the collecting electrode supported by a Teflon insulator and the high-voltage electrode supported by a Lucite insulator. Incorporated within the chamber is a 0.4-μCi ^{90}Sr source which produces a current corresponding to 2 mrads/hour for the system failure check. The chamber is designed to produce 1 pA/mrad/hour (10 liter-atm with a collecting potential of 1000 V). It has been checked for saturation in fields up to 100 rads/hour.

Except for two 500-V batteries in series which provide the collecting potential for the ionization chamber, this system is ac-powered and the electronics are all solid-state. The log converter consists simply 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 exhibits an open loop gain of the order of 10,000. Primarily because of the temperature dependence of the log converter, this entire circuit is enclosed in an oven operating at approximately 50°C. The proportional controller for this oven uses a thermistor for temperature sensing. Within $\frac{1}{2}$ hour from a cold start, this device has the oven stabilized to within ± 0.1°C. The entire oven temperature control circuit is also located within the oven housing. The oven housing measures approximately $3\frac{1}{2} \times 3\frac{1}{4} \times 2\frac{1}{4}$ in.

A moderate survey of readily available devices quickly led to the discovery that the 2N2484 transistor made by the Texas Instrument Company exhibited a practically ideal logarithmic characteristic (i.e., base-to-emitter voltage versus base-to-emitter current) over the range of 10^{-5} to 10^{-12} A. Surprising uniformity was observed among thirty devices randomly selected, all of them having a conversion slope closely approximating 60 mV per decade of current at room temperature.

The entire monitor unit is enclosed in a weather-tight aluminum housing, 28 in. long and 10 in. in diameter. This housing and the 50°C oven insure that the unit operates with no loss of stability or reliability over the full range of local temperatures (approximately −5° to +45°C). The mechanical and electronic layout is such that the unit may be operated in any position and mounted anywhere space allows. This gives a wide choice of location so that the units may be placed to optimize personnel protection for a given set of beam conditions.

Meteorological measurements (DDB)

Early in the design phase, it was recognized that significant amounts of radioactive gas, and possibly radioactive dust particles as well, would be formed by machine irradiation of the air in the accelerator and BSY housings. It was also anticipated that radioactive gas would be evolved from the water used to dissipate beam energy in the switchyard and end station beam dumps. The latter source has since been eliminated by the use of closed-loop catalytic recombiners; however, ^{15}O and ^{11}C isotopes released from dump water prior to the installation of recombiners were used as tracers to measure the atmospheric dilution which occurs between the vent point and the site boundaries.

Atmospheric dilution factors were calculated, using a simplified form of the equation given by Sutton and Pasquill[3]:

$$\frac{\chi_p}{Q} = \frac{8}{\mu}\left(\frac{X}{2}\right) \exp\left[-1.75 + \frac{b(1-C)}{\mu}\right]$$

where

χ_p = the center-line concentration (curies per cubic meter)
Q = the source strength (curies per second)
X = the distance from the source (meters)
C = the fraction of the sky covered by low clouds
b = +0.5 at night and −1.2 during the day
μ = the wind speed (meters per second)

The equation holds for $X \leq 2$ km and $\mu > 2$ meters/sec. The night and day values of χ_p were calculated for various values of C and μ with a beam power of 1 MW, and assuming the source to be 400 meters from the site boundary. The relation between beam power and source strength was taken to be $Q \approx 1$ Ci/sec/MW. This was confirmed by measurement (see Fig. 21-14). The results are given in Fig. 21-15. The calculated dilution factor, χ_p/Q is plotted in Fig. 21-16 as a function of X, for constant μ and various values of C.

The maximum permissible concentration (MPC) for ^{15}O and ^{11}C is based on a submersion dose; therefore, total dose for whole-body radiation is used as the limiting criterion. Further, because the MPC is based on the

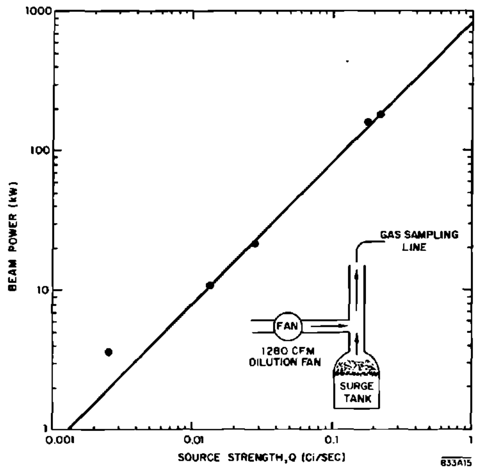
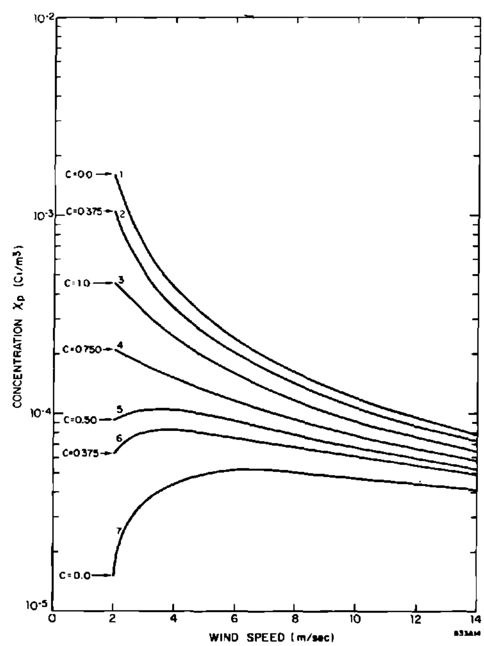


Figure 21-14 Source strength measured at the exhaust stack of a surge tank as a function of power absorbed in a large water dump.

Figure 21-15 Calculated concentration at 400 meters for 1-MW beam absorbed in a large water dump. Curves 1 and 2 for nights; curve 3, overcast day or night; and curves 4, 5, 6, and 7 for days.



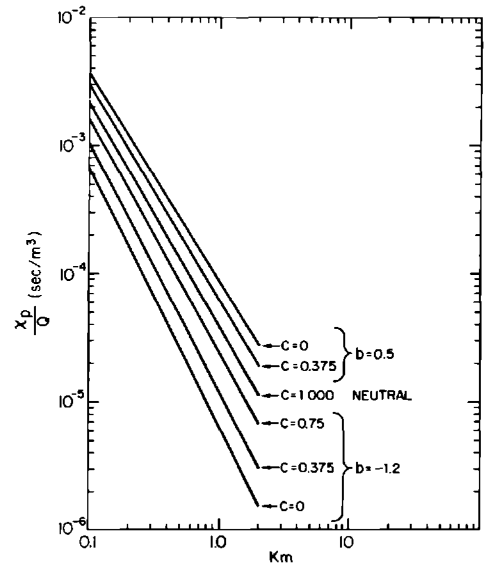


Figure 21-16 Dilution factor vs distance for various atmospheric stability conditions for a 4-meters/sec wind speed. (C, fraction of sky covered by low clouds.)

exposure of a receptor in a semi-infinite cloud, the observed ratio between the maximum dose rate from such a cloud and the measured concentration is used to predict the dose from calculated concentration values at a given distance. This ratio was measured at SLAC and was found to be 0.03 at a distance of 100 meters from the release point. The ratio is not constant because it is dependent upon the vertical and horizontal expansion of the cloud and is also affected by atmospheric turbulence close to large structures. The center-line concentration overestimates by large factors (2–100) the actual ground concentration any receptor might be exposed to at the site boundary. These predictions are, therefore, conservative.

In addition to continuous source strength monitoring, the experimental area is ringed by thermoluminescent γ dosimeters at the site boundary. These dosimeters are collected and evaluated quarterly. As described earlier, there are seven peripheral radiation monitors with BF_3 and Geiger tubes about 700 meters from the point of discharge. These monitors accumulate counts for 1 hour and then print out, giving a measure of integrated n and γ dose on an hourly basis. Only the Geiger measurements are affected by the radioactive gas cloud. These two peripheral monitoring systems will permit a more precise evaluation to be made of the radiation exposure at the SLAC site boundaries. The data will be correlated with wind speed and direction records collected at two on-site weather stations.

Each pair of sectors contains a ventilation fan which removes air from the accelerator housing at the rate of 9000 ft^3/min, making a total of 135,000 ft^3/min from all 30 sectors. This amounts to a complete change of air every 10 min. Each discharge point is slightly above the roof line of the klystron gallery.

The switchyard is vented by five fans having a total capacity of 83,000 ft^3/min, sufficient to change the air every 6 min.

As previously mentioned, radioactive gas monitors are located at alternate vents in the accelerator and at every vent in the switchyard. Exhaust air is continuously monitored while the fans are on.

It has been found that air activation products do not offer serious problems. Under most conditions, atmospheric dilution factors are sufficient to maintain the site boundary dose well below 500 mR/yr.

21-4 Equipment protection systems

General (KEB)

One of the major problems in the development of protective circuits was the evaluation and understanding of all the system interactions. For the purpose of this analysis, it was convenient to define two major systems: (1) the RF system which is used to generate and to distribute the RF energy, and (2) the beam guidance system which injects and guides the beam to the user. The analysis of the relations existing in each system and between the systems defined the protection requirements that had to be implemented.

In the RF system proper, protection is normally confined to a particular piece of equipment with appropriate self-protective features. The requirements for the system transporting the beam were more complex, because both RF power and beam were involved and some interactions extended over the whole length of the machine.

Protection requirements arising from the presence of RF power in the waveguide and accelerator sections and its interactions with the modulator-klystron, vacuum, and cooling-water systems were covered by the modulator–klystron protection system, as detailed in Chapter 15. Protection is provided by turning off individual modulators in case of abnormal operating conditions.

The extended interactions led to the development of the machine protection system, which consists of three major parts: the 1-msec network, the 50-μsec network, and the Panofsky long ion chamber (PLIC). The system is designed to turn off the injector before the start of the beam pulse following detection of trouble. (By the time, say, that beam loss or spill is detected during a pulse, it is too late to do anything about it—indeed, the injector and first few sectors will have already finished their work before any signal could possibly be transmitted back from the point of detection.)

The 1-msec network shuts off the beam in case of failure of components the normal operating state of which is steady during beam operation. The beam is kept off until normal operation for the component has been restored. The beam can then be turned on by a manual reset and may continue to exist as long as all protected components operate normally. Three types of components are protected. Some are partially or fully exposed to the beam and require water cooling for proper functioning. Such items include protection collimators along the accelerator and the positron targets. Other components, such as vacuum valves, are normally completely out of the beam path, but must be protected against the beam if they close in response to a vacuum fault. Some failures in the RF distribution system can produce beam energy changes that exceed the momentum acceptance of the BSY. Certain of these failures are used to turn off the beam through the 1-msec network and serve as backup to the after-the-fact protection provided through the 50-μsec network.

The 50-μsec network was designed primarily to provide protection for switchyard components. The state of switchyard interlocks is edited between each pair of beam pulses according to the trigger pattern signal specifying where the next beam pulse is to be delivered. (For example, if the beam is to go to end station A, B-beam interlocks are to be ignored.) As late as possible before each beam pulse, a permissive signal is transmitted to the injector if the interlocks are satisfied. The network can also be used to inhibit the beam if the positron wand target is not centered at the correct time during its transit across the accelerator aperture.

The PLIC protects the disk-loaded waveguide from damage by the beam itself. The beam is shut off when radiation due to beam interception by the waveguide exceeds a preset level.

One-millisecond network (KC)

The 1-msec network provides a means of automatically turning off the beam if certain interlocks open. The name derives from the speed of operation of the system. Components of the machine protected are the automatic and manual vacuum valves, the protection collimators, and the accelerator disk-loaded waveguide. Inputs to the system are listed in Table 21-3.

SYSTEM DESCRIPTION. A block diagram of the system is shown in Fig. 21-17. The major assemblies are the tone transmitter at the CCR, a tone interrupt unit (TIU) in CCR, the DAB, all sectors and the injector, and a tone receiver at Sector 0 (injector). Two tones (40 and 50 kHz) are generated by the transmitter. When all interlocks are in the normal state, the TIU's provide a through path, and the tones appear at the receiver input. The receiver output (-20 V dc) is applied as an enable input to the injector trigger generator. When any input to a TIU changes to the alarm condition, the signal path is broken and the receiver output changes from -20 to 0 V. This removes the gun trigger and turns off the beam.

Table 21-3 Machine protection system inputs

A. For Sectors 1–30		
	RF drive OK	
	Sector secure	
	Fast valve open	
	Manual valve open	
	Vertical degaussing power supply[a]	
	Horizontal degaussing power supply[a]	
	Beam scraper (except Sector 1)	
	Sector vacuum (main manifold gauge controller)[a]	
	Fast valve control panel	
B. For Even Sectors (2, 4, etc.)		
	Conventional substation output[a]	
	VVS 600-V circuit breaker status[a]	
C. Special		
	Sector 0:	Sector secure
		Vacuum (main manifold gauge controller)
	Sector 1:	BAS-1 vacuum gauge controller
		Temporary positron source, water flow
	Sector 2:	VVS-V1A 600-V circuit breaker status
	Sector 11:	Flood control, automatic–manual switch status (For other interlocks, see TIU 2)
	Sector 20:	BAS-2 vacuum controller
		BAS-2 electronics
		Beam stopper
	Sector 21:	Beam stopper
	Sector 28:	Beam stopper
	Sector 30:	Drift section vacuum controller G1-0
		Fast valve control panel (30-9)
	DAB:	Radiation emergency stop
	CCR:	Beam off
		PLIC
		BAS magnet current
D. TIU 2 Interlock		
	Sector 11:	Main manifold 2, gauge controller
		Source gauge controller
		Fast valve control panel 2
		Fast valve control panel 3
		Fast valves 2, 3, 4, open status
		Fast valve control panel 4
		Positron water cooling
		Wheel–wand–profile monitor status
		Source gauge, fail status

[a] Will become "resettable" interlocks. They will shut off the beam, but the operator may resume operation if they represent a fault in a sector not in use.

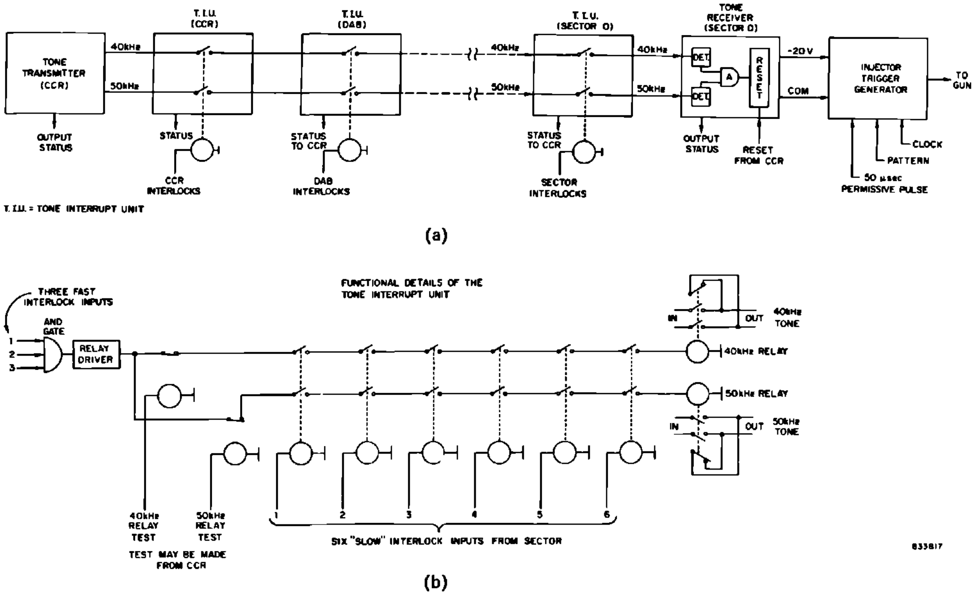


Figure 21-17 One-millisecond network beam shutoff system. (a) Block diagram of 1-msec system. (b) Functional details of the tone interrupt unit.

EQUIPMENT DESCRIPTION. The tone transmitter consists of two independent generators, one at 40 kHz and the other at 50 kHz. The outputs are stable sine waves of 5-V rms amplitude. Each output is transformer-coupled to a 125-ohm balanced wire pair. If either output drops below a preset level, a detector generates an audible and visual alarm.

The tone receiver comprises two independent level detectors, a two-input AND gate, and a reset module. When both tone levels are above the preset value at the receiver input terminals and when a −24-V dc reset signal transmitted from CCR is applied to the reset circuit input, the receiver generates a −20-V dc enabling voltage for the injector trigger generator. The reset signal operates a latching circuit and can be removed once the receiver has been reset. When either or both tones drop below the preset value, the receiver output changes to 0 V, thereby gating off the trigger generator pulses to the injector gun. When the tone inputs have been restored, the receiver has to be reset before the −20-V output can be produced. The delay time between the change of an input tone level and a change in the receiver output voltage is less than 500 μsec. The receiver channel bandwith is ±1.5 kHz. The input threshold is adjustable from 0.25 to 2.5 V rms, and is set 6 dB down from the normal received input. Line attenuation at 50 kHz is 5 dB/mile.

Provision has been made for operating the receiver with one tone only, thus allowing protection of the machine while the other tone circuit is being tested.

The TIU provides a through path for each tone if all interlock inputs are in the normal state. When any one input goes to the abnormal state, the TIU opens both tone paths. The input-to-output connection is made or broken by sealed dry reed relay contacts. The contacts open both conductors of each pair and also short each conductor of a pair on the receiver side of the break. Two types of interlock inputs are accommodated: fast inputs (dc levels) operate logic gates in the TIU and open the paths within 500 μsec; slow inputs are applied to relays which release on removal of the input and open the paths within 1 msec. For test purposes, each tone path can be opened independently by remote control from CCR. Whenever the TIU goes to the alarm state, a status change signal is transmitted to CCR.

BAS-2 OPERATION. When the machine is operating in the BAS-2 mode, the tone path bypasses the BSY and Sector 30, and feeds directly from CCR to Sectors 29, 28, etc., and the injector.

Panofsky long ion chamber (DDR)

If missteered at high power, the SLAC electron beam can cause local melting of accelerator components in a fraction of a second. Even relatively low-level irradiation of the accelerator waveguide might ultimately cause harm, gradually changing critical dimensions by altering the crystalline structure of the copper. To protect the accelerator, a system has been installed which is based upon a single long ion chamber[4,5] which runs the whole 2-mile length of the accelerator housing. The signal from the ion chamber operates equipment that turns off the beam when any local radiation level becomes too high. The same signal, observed on an oscilloscope, is sometimes helpful in steering and focusing the beam.

The ion chamber is assembled from some twenty lengths of 4.1-cm diameter RG 319/U coaxial cable, and pressurized to 1 atm gauge with a mixture of argon and 5% carbon dioxide. The facing surfaces of the cable conductors are bare copper spaced by a narrow spiral of polyethylene. The cable is supported by straps near the ceiling of the accelerator housing, 2 meters away from the accelerator disk-loaded waveguide.

When high-energy electrons strike the inner wall of the accelerator structure, a cascade shower is produced in the copper waveguide. The shower density is proportional to the intercepted beam current and to the primary electron energy. The flux of ionizing radiation and the charge collected in the ion chamber are thus proportional to the local electron beam power loss. An ionizing event gives rise to a negative pulse in the cable, which splits with one-half the energy being propagated in the forward direction while the other half is propagated backward toward the injector. The backward pulse travels to the injector end of the cable, which is extended some 500 meters to form a delay line. It is there inverted and reflected by a capacitor, and returns along the cable, which is extended into the CCR and terminated. Each backward pulse arrives in CCR with a relative time delay which is proportional to the distance of its origin from the injector. In CCR, the pulse train from the cable

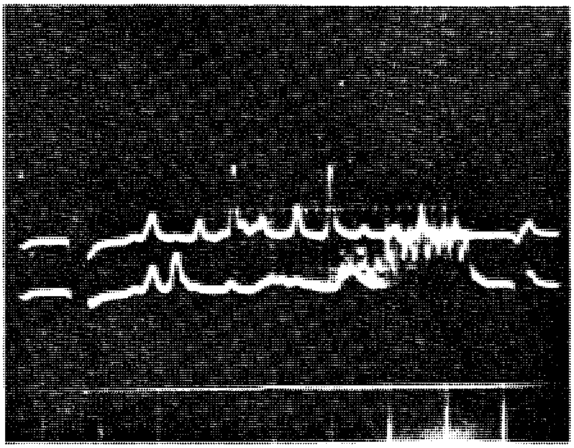
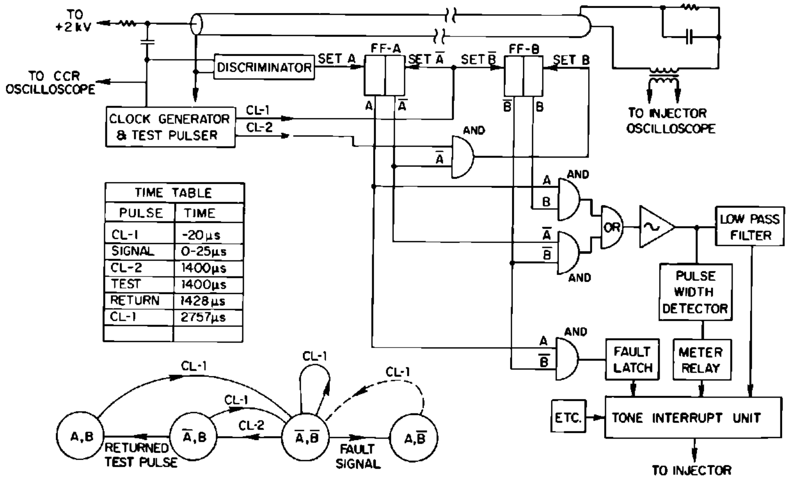


Figure 21-18 Long ion chamber pulse trains as observed in Central Control Room.

is displayed on an oscilloscope (Fig. 21-18) and fed into a discriminator circuit.

Observation of the backward pulse train at CCR enables one to estimate the magnitude of beam power loss in various regions along the machine and to establish the location of a beam-scraping event to within a few decameters. The closely spaced spikes shown in Fig. 21-18 represent signals from beam scrapers, spaced 100 meters apart. The parameters governing the space resolution are the electron collection time,[6] ~0.27 μsec, the electron velocity in the accelerator, *c*, and the propagation velocity of the cable, 0.92 *c*. The 0–50% and 10–90% rise times have been measured for pulses making a two-way transit of the whole cable. They have been found to be approximately 0.1 and 2.5 μsec, respectively, in agreement with results cited by Kerns *et al.*[7] The effect of the presence of free electrons and ions upon the propagation of signals in the cable has been estimated[8] and found to be small for the ionization densities usually encountered in practice.

An important advantage of a single long ion chamber is its uniform sensitivity. This uniformity is somewhat impaired in this application by the presence of extra material, such as quadrupoles, dipoles, and beam scrapers between the beam and the ion chamber and by geometrical asymmetry. Multiple scattering of the beam and of secondary electrons tends to reduce the effect of axial asymmetry. When a 10-MW (peak) beam is steered so that it all strikes the inner wall of the accelerator waveguide in a distance of 20 or 30 meters, a pulse amplitude of about 1 V is observed in CCR. By manipulating the location and orientation of missteering, it has been found possible to vary the pulse height through a range of about 30%. A crude calculation indicates that system sensitivity will be about 40% less for an event in which the beam strikes a beam scraper rather than the accelerator waveguide.



TIME TABLE	
PULSE	TIME
CL-1	-20μs
SIGNAL	0-25μs
CL-2	1400μs
TEST	1400μs
RETURN	1428μs
CL-1	2757μs

Figure 21-19 Block diagram, time table, and state transition diagram for the long ion chamber logic circuits.

THE DISCRIMINATOR AND PULSE TESTER. Whenever any local beam power loss causes a signal which exceeds a preset value, typically 2 V for 360-pulses/sec operation, the discriminator system turns off the electron beam by operating the 1-msec tone loop system described in the previous section. The tone loop system responds to the loss of one or more input signals by interrupting tone signals in two channels. Absence of tone signal in either channel causes the injector to be turned off within 1 msec. A pulse generator and a system of logical gating circuits, illustrated in Fig. 21-19, test several properties of the ion chamber system during each interpulse interval. In the test, a pulse is transmitted along the cable, its transit time to the injector end and back is measured, and it is verified that the reflected pulse indeed operates the discriminator.

The test circuit consists of a pair of bistable multivibrators, a clock and test pulse generator, and logical gating circuits. The operation of the logic circuits can be understood with the aid of the state transition diagram shown in Fig. 21-19. Flip-flop A is set to state A whenever the signal exceeds the discriminator threshold. Flip-flops A and B are reset to states ($\bar{A}$, $\bar{B}$) by clock pulse CL-1. Flip-flop B is set to state B whenever CL-2 is coincident with state $\bar{A}$. During normal operation, as the system cycles through states ($\bar{A}$, $\bar{B}$), ($\bar{A}$, B), (A, B), ($\bar{A}$, $\bar{B}$), etc., a "fast" enable signal is generated by passing a signal corresponding to ($\bar{A} \cdot \bar{B} + A \cdot B$) through a low-pass filter. Thus during the brief 28-μsec cable transit time interval during which state ($\bar{A}$, B) persists for normal operation, the low-pass filter maintains the fast enable voltage. However, if the transition from ($\bar{A}$, B) to (A, B) fails to occur, state ($\bar{A}$, B) will persist for 1.4 msec. In this event, the enabling signal will decay below an acceptable value in approximately 100 μsec, thereby signaling a system fault and shutting off the tone signal to the injector. A simple pulse width detector measures the duration of state ($\bar{A}$, B) and produces an analog signal which is applied to a meter relay. Repeated failure to arrive at state ($\bar{A}$, B) will result in a meter relay current of zero. If state ($\bar{A}$, B) persists for approximately 28 μsec during each 2.78-msec interpulse interval, the meter relay will read within its high-low limits. Finally, if ($\bar{A}$, B) repeatedly persists for a half-cycle, the meter-relay reading will exceed its high limit setting. The meter relay is interlocked with other meter relays measuring ion chamber high-voltage and dc current and with a pressure switch actuated by the gas pressure in the ion chamber. These relay circuits interrupt a "slow" enabling signal applied to the TIU.

When a signal fault occurs, the system is set to state (A, $\bar{B}$) and the fast enable signal is removed within 100 μsec. A fault-latching circuit and redundant relay circuit continue to withold the slow enabling signal even though the system again proceeds through its normal cycle after CL-1. The fault-latching circuits must then be manually reset to resume operation.

THE POSITRON GATE. When positrons are being generated, a large signal is produced in the long ion chamber. The discriminator is accordingly provided with a gating circuit which acts to prevent the signal from the positron source from shutting off the injector. The positron gate is normally triggered only when the positron beam is in operation. Its time delay and duration are adjustable, so that the system can retain full sensitivity during those periods when no large burst of radiation is expected from the positron source.

DISABLING THE CIRCUIT. A key-operated switch is provided for disconnecting the system and supplying dummy inputs to the CCR TIU, without disturbing the circuits that produce the oscilloscope signals.

Fifty-microsecond network (permissive pulse system) (KC)

The 50-μsec network establishes the beam permissive condition on a pulse-to-pulse basis. A beam pulse can be released only if the field of the BSY pulse deflection magnet has reached 70% of the final desired value. To allow for rise time and transmission delay associated with the twisted pair cable, the permissive pulse starts at least 50 μsec before the next beam time (hence the system name).

Figure 21-20 shows the system block diagram. In the BSY mode, the permissive pulse is generated in the DAB and transmitted at a 50-V level on a wire pair to CCR. The pulse width is approximately 150–250 μsec and the rise time is 50 μsec. When a positron source pulse (1.5 msec) is present at CCR, the AND gate connects the DAB pulse through to the injector. In the BAS 2 mode, the 150 μsec pulse is generated in CCR and transmitted to the injector on a wire pair.

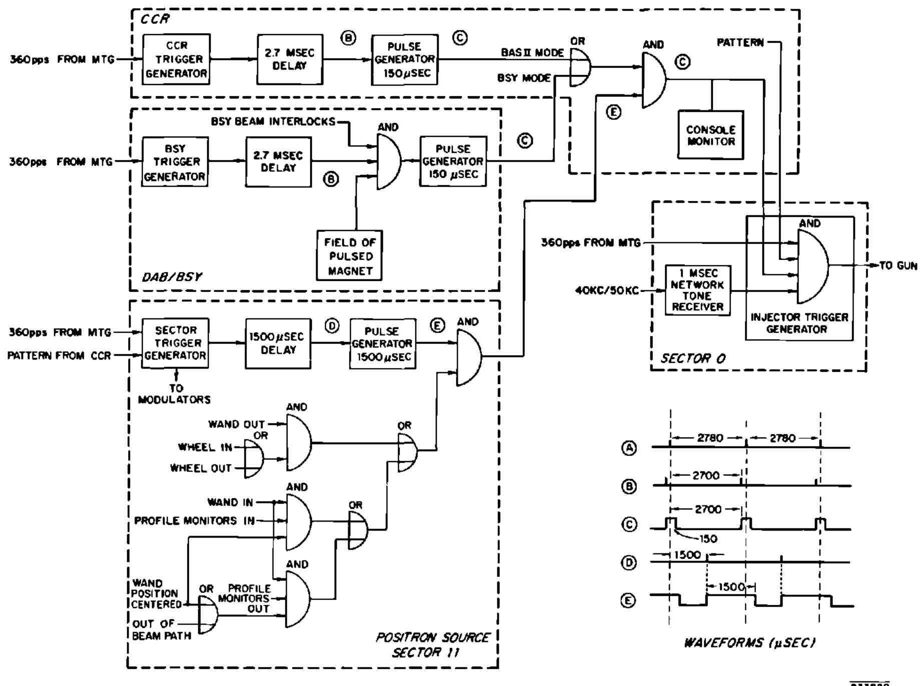


Figure 21-20 Block diagram of 50-μsec network.

The injector trigger generator produces a pulse to the gun when the 1-msec tone receiver output is normal and when the clock, pattern, and permissive pulses are present.

Acknowledgments

We would like to acknowledge the contributions of M. Fishman, who designed the electronics circuits for the long ion chamber protection system. Also, we would like to thank J. Jasberg and V. Waithman for their critical reviews and suggestions for improvement of the personnel protection system.

References

1 J. Boag, in *Radiation Dosimetry, Vol. 2: Instrumentation* (F. Attix, W. Roesch and E. Tochilin, eds.), p. 24, 3rd Ed., Academic, New York, 1966.

2 H. DeStaebler, "Radioactive Gas in the Tunnel," Rept. No. SLAC-TN-62-9, Stanford Linear Accelerator Center, Stanford University, Stanford, California (March 1962).

3 F. Pasquill, *Atmospheric Diffusion*, Van Nostrand, Princeton, New Jersey, 1961.

4 W. K. H. Panofsky, "The Use of a Long Coaxial Ion Chamber along the Accelerator," Rept. No. SLAC-TN-63-57, Stanford Linear Accelerator Center, Stanford University, Stanford, California (July 1963).

5 H. DeStaebler, "Note on Panofsky's Long Ion Chamber," Rept. No. SLAC-TN-63-63, Stanford Linear Accelerator Center, Stanford University, Stanford, California (July 1963).

6 B. Rossi and H. Staub, *Ionization Chambers and Counters*, p. 14, McGraw-Hill, New York, 1949.

7 Q. Kerns, F. Kirsten, and C. Winningstad, in "Radiation Laboratory Counting Handbook," Rept. No. UCRL 3308 (Rev.), Counting Note, File No. CC2-1, Lawrence Radiation Laboratory, University of California, Berkeley, California (1959).

8 D. Reagan, "Plasma Effects in Panofsky's Long Ion Chamber," Rept. No. SLAC-TN-63-91, Stanford Linear Accelerator Center, Stanford University, Stanford, California (November 1963).