THE NBS LINAC MASTER CONTROL AND PERSONNEL PROTECTION SYSTEM

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Summary

The operation of the NBS linear accelerator and its beam handling equipment has been integrated with personnel and equipment protection safeguards and with the occupancy requirements of the linac complex. A mode switch is used to select beam direction and experimental area, and to program the requirements for personnel protection interlocks, beam handling system conditions, building mechanical services, experimental area services, and linac operation. The system includes visual and audible devices to indicate degree of readiness, hazards, faults, interlock information, zone of operation and emergency situations. A forced inspection of potentially dangerous zones, programmed cued taped warning announcements, key interlocks, and flexibility are built-in features. It offers the capability of providing maximum protection to personnel against environmental radiation hazards, and allows utilization of a maximum of laboratory space for varied beam conditions.

Introduction

As cost and complexity of accelerator facilities increase, it is important that beam transport equipment and experimental area arrangement have the flexibility to allow the most efficient use of the accelerator. The NBS linear accelerator facility was designed to have several separately shielded experimental areas to which the accelerator beam could be switched quickly, with due concern being given to the many and varied considerations which this rapid switch-over of the beam implies for experiments. The facility was planned to permit experimenters to occupy experimental areas which were not receiving the accelerator beam while the beam was in use in some other experimental area.

Facility and personnel safety and control is complex for any accelerator involving separate experimental areas due to the physical size and complexity of the installation. It becomes enormously more complicated for a very high power accelerator whose many special factors must be considered. Among these are such questions as radiation damage to system components, failure of experimental equipment due to beam heating, residual radioactivity in components, production of radioactive and noxious gases in air systems, and the need for special caution in proving the adequacy of protection of personnel against excessive radiation exposure under many and varied conditions.

The master control and personnel protection system at the NBS linac facility has been designed to provide the highest possible degree of protection to personnel and equipment consistent with the above goals, and to provide utmost flexibility and ease of operation.

The system has been in operation for nearly two years. With few exceptions it has proven to be reliable and to provide the ease and flexibility of operations which were originally desired.

The System

The linac complex includes an area which has 30 rooms, six stairways, numerous passageways, and a freight elevator, all distributed over three floor levels. There are also five 60 ton concrete plug doors and three demountable concrete barriers. Figure 1 illustrates the layout of the sub-basement level of the complex where the accelerator, beam handling system, and the measurement rooms and other experiment areas are located. The control room and three counting rooms are located on another level and are not shown. The counting rooms are associated with the experiment areas, and are provided with facilities to permit remote operation, monitoring, and control of an experiment in a safe radiation-free environment.

The safety and control system is designed around a master control center at which the desired mode of facility operation (beam destination) is selected. This master control center then either controls or interrogates (or both) various subsystems in the facility to set up and examine conditions of the subsystems, and to ensure proper and safe operating conditions. Information on three interlock chains is provided to the linac which controls the degree to which the accelerator can be operated. The three chain interlocks are rf power, injector power, and injector trigger. The first two of these are primary personnel protection interlocks, the third is an interlock for protection of equipment from beam damage and for experimental convenience.

The interlock chains are composed of a series of relay contacts, each representing the terminal point of a subsystem. All the contacts in the chains must be closed for beam capability. The injector and rf power lines are broken when it is essential to absolutely prevent beam production for personnel safety. Interruption of either power interlock line requires the linac operator to reset turn-on devices at the linac control desk in order to obtain beam after the interlock fault has been corrected. The injector trigger line is for system protection not involving personnel safety and permits the experiment to control beam production without requiring reset manipulations by the linac operator. Convenient facilities are provided at each experiment location for connecting experiments into the interlock chains.

A mode selector switch is used to select desired beam direction and experimental area and the performance and protective requirements for this facility function. Satisfactory compliance with these requirements generates the subsystem relay contact closures in the interlock chains. The mode switch dictates conditions to be satisfied such as: potentially hazardous areas which must be inspected and locked, proper synchronization of beam handling operation with mode function selected, and operation of noxious gas removal systems. A 24 pole, 24 position rotary switch located in the interlock center of the linac control room serves as the mode switch. At present 13 of the possible 24 modes are in use. Some of the modes available at the present time are: beam into M.R. #1 (Measurement Room #1) with neutron slot open, beam into M.R. #1 with the slot closed, beam into M.R. #2, beam into 45° bay with 10° downward deflection, beam into Magnet Room straight to target area (See Figure 1). There is also an everything-off mode, and two test modes; rf-only, and injector-only. The neutron slot mentioned above is an opening in the wall between M.R. #1 and M.R. #3 which may or may not be filled with shielding material, and is one of several apertures provided in the complex for experiment convenience. The many possible combinations of utilization of the facilities added to the difficulty of establishing radiation safety criteria. It was found feasible to divide the areas possessing latent radiation hazards into ten zones of which any one or more could be related to a specific mode of operation. Each zone is equipped with a locking gate and is required to be inspected, evacuated, and locked when so programmed by the setting of the mode switch.

In the initial operation of the facility it was desired to operate in such a manner that essentially all zones were considered hazardous to personnel for all modes of operation. Then, as zones were proven safe by repeated and detailed health physics surveys for any particular mode of operation, occupancy of these zones could be permitted for this operation. To alter the status of a zone without rewiring the system, a limited-access patch panel is provided. As safe zones emerge for specific modes, the requirements for securing the zone may be removed electrically by inserting a plug into the proper hole in the matrix of the limited-access patch panel. Thus the inspection and locking requirement of a zone for each mode of operation is controlled by the presence or absence of a plug in the patch panel matrix. A high radiation level in an unlocked and uninspected zone as indicated by the radiation monitoring system described below overrides any noninspection requirement programmed by the panel. The sensitive nature of control provided by this panel mandates that it be locked and accessible only to authorized personnel. Flexibility is built-in to permit additional zones to be added to the system as future beam modes are developed.

Other features of the system include area-wide mode-in-use information, and a programmed tie-in to the interlock chains for experiment use. An extensive radiation monitoring system is incorporated to provide a high degree of accidental exposure protection to personnel. Visual displays, including signal lights, indicator panels, and a display board, as well as audible alarms and taped announcements, are used to indicate the degree of hazard and security throughout the linac complex. The fire detection system and chilled water monitoring equipment are also connected into the system.

Liberal use was made of relays, push button stations, electrical, mechanical, and key interlocks to obtain the protection and conveniences sought. To the greatest extent possible, the system has been designed to be fail-safe.

The Inspection System

The purpose of the inspection is to ensure that all personnel have been evacuated from a zone which is scheduled to permit beam operation. Each zone is equipped with a locking gate and a number of push button inspection stations. These stations are situated at points chosen to force the inspector to traverse the zone completely in operating sequentially all the inspection station push buttons. Upon completion of the inspection, the gate is locked and the key is returned to the key interlock panel located in the control room. A contact closure is then obtained in the interlock chain indicating that the zone is inspected and locked. Independent of accelerator operation the zone need not be reinspected unless personnel enter the zone.

Most zones are also provided with a non-locking inspection gate which is located within the area guarded by a locking gate. The function of the inspection gate is to minimize the inspection effort, particularly if the area between the locking gate and the inspection gate requires frequent access to adjust equipment during the course of an experiment. Inspection of the area beyond the inspection gate, an area usually containing hazardous residual radiation fields directly after interruption of the beam, is not required if the gate has not been opened. The inspection gates, concrete plug doors, and doors to rooms located within a zone are fitted with electrical interlocks. Once the inspection is made, opening any door within the zone will negate the inspection.

Concrete plug doors are also equipped with key interlocks. These doors are closed when required, and the key removed to the key interlock panel in the control room. The door cannot be opened without a key except in certain emergencies for which an emergency over-ride from within the dangerous area is provided.

The main feature of the locking gate system is the positiveness of the protection. The locking gate has both an electrical and mechanical lock. The requirement for bringing the key to the control room provides an additional interlock protection, and at the same time controls the location of the key. The key interlock on the locking gate is equipped with a defeasible keeper to permit anyone inadvertantly locked in a zone to exit.

The inspection of a zone is accomplished in the following manner. The inspector enters the zone and pulls the gate closed behind him to power the zone inspection system. He procedes to the first station illuminated by an indicator light and depresses the "okay" button. This event closes a relay in the sub-chain and illuminates the light at the next scheduled station. The procedure is repeated for each station in turn. The last station provides a 15 second hold-over on the gate circuit to enable the inspector to exit through the gate without interrupting the power to the inspection system. The gate is immediately closed and locked and the key removed . A panel near the gate indicates if the area has been properly inspected and locked. The operation of the first inspection button in most zones will trigger a taped announcement over the loudspeakers in the zone indicating that the area is being inspected. Similarly, when the gate is locked, an announcement is made to that effect. Keys removed from the doors after locking are placed in matching key interlock cylinders in the control room in order to complete the inspection action. Coincident with locking the area after inspection, a revolving red beacon is actuated which sweeps its light around the zone.

It is not possible to remove a key from any gate unless the gate is closed and locked. If the zone is entered after it is inspected, it would require the inspection procedure again. Should anyone wander into the zone during inspection, the inspection power would be lost when the gate is opened, negating any inspection. If the zone contains an inspection gate, in addition to the locking gate, the inspector is required to close the nearest gate behind him before proceding with the inspection. Rooms with doors contain an inspection station to force the inspector to walk into the room, and also to make sure that no rooms are overlooked. After the room has been inspected, closing the door conveys the inspection power to the next station.

Emergency-Stop System

The emergency-stop system permits the beam from the linac to be stopped at any time from numerous locations within the linac complex. Large red push buttons are distributed throughout all zones, in the modulator room, and in each of the counting rooms. Depressing this push button will open the rf and injector power interlock lines. The area display panel in the control room indicates the zone in which the button was operated. If the emergency-stop system has been actuated it must be reset by operating a key operated switch located within the zone where the button was pushed. Reinspection of the effected zone is required.

Radiation Monitoring System

Most areas where high gamma radiation levels are expected are protected with three separate monitors. Two of these are small local ionization chambers located near the entrances to the area. The third monitor is a long pressurized coaxial cable used as an ionization chamber and distributed such as to have reasonably uniform sensitivity to the entire area. The monitoring equipment is adjustable to permit indication of above-tolerance conditions within the proximity of any chamber when radiation levels exceed safe limits. The radiation monitoring system is zoned in a manner compatible with the inspection zones, and above-tolerance signals are interlocked with the inspection circuitry. Such signals transmitted from inspected and locked areas merely indicate the radiation condition. Above-tolerance signals emanating from uninspected areas will switch off the accelerator, and require the zone to be inspected and locked before linac operation can be restored.

In addition to the two-aspect "okay" or "danger" signal provided outside of all gates, an opal signal light and a rotating red beacon light is energized in the affected zone in the case of high radiation levels. The area display panel also indicates zones with high radiation levels. An indicator at the control station of each plug door provides information pertaining to the radiation levels on the other side of the door. The radiation monitoring equipment panel in the control room contains a special key panel to be used when any monitoring unit is out of service. Operation of a key will program the zone for the inspection requirement for all operating modes.

Experimental Area Interlocks and Indicators

Adjacent to all areas where experiments may be performed or controlled, mode position information and accessibility to the master interlock chains is provided. A panel with 24 indicator lamps indicates by number the mode in use. From a terminal strip at the terminal corresponding to the mode in use 115 volts ac is available. Additional terminal strips provide access to the master interlock chains. Thus experimental apparatus may have functions programmed by the setting of the mode switch. The equipment may be tied into the interlock lines for protection purposes, and the capability exists to interrupt the beam at will. As the mode switch is changed, the service is transferred to other modes. Penetrations into the interlock chains are wired to be effective only for the experimenter's mode. A display panel near the linac control area indicates the status of these experimental interlock lines.

Alarms and Signals

The staff in the linac complex is kept informed as to the operational condition of the linac by taped voice announcements, signal lights, and a continuously keyed tone. Linac injector, rf, or beam capability are all preceded by a cued taped announcement broadcast throughout the complex indicating the condition which will exist. Simultaneously, an appropriately colored signal light is energized in all areas, and for rf or beam capability a keyed tone begins. For example, when the rf could be turned on a taped announcement over the loudspeakers proclaims linac rf capability exists, the amber signal lights turn on, and the horns begin to beep at a slow tempo. The light and the horns remain activated until the rf capability no longer exists. Injector capability generates an announcement and the illumination of green signal lights. Beam capability (rf plus injector capability) triggers an announcement, red signal lights, and a fast tempo beep from the horns.

The signal lights are distributed throughout the complex at locations selected for effective visibility. Four fixtures with colored glass globes are used to signal the three linac functions and above-tolerance radiation. The signal is a continuous light. Flashing lights were not used in order to prevent electrical noise and short bulb life. The keyed tone is generated by small horns scattered throughout the complex. These are low current devices and are keyed by a motor-diven switch.

Cued Taped Warning Announcements

Warning announcements are generated by an automatic multichannel magnetic tape device and are transmitted over a public address system. These announcements are automatically selected and transmitted to the proper areas on cue from the protection and control system. The linac complex intercommunication system is connected to this public address system to utilize its paging capability. The public address system delivers a total of 125 watts to approximately 40 loudspeakers. Announcements to selected areas are routed through one of five individual 25 watt amplifiers. Ten tape decks are available for announcements. At present only five of these decks are used, one each for injector-on, rf-on, beam capability, inspection beginning, and zone locked. The messages range in duration to thirty seconds. Monitoring, recording, and erasing facilities are built into the system. A relay network permits the selection of announcements, establishes a priority rating for the announcements, and selects the proper routing for the message. Lower priority messages are interrupted if in progress and are held for transmittal at the proper time. Cue signals are developed from either switch or relay contacts.

Area Display Panel

An area display panel graphically illustrates the degree of hazard and security in the linac complex. Individual lights and illuminated panels are arranged to portray the floor plan of the complex. The status of important elements in the protection system is presented visually. The status of locking gates, concrete doors, removable shielding, radiation levels, accelerator operations, as well as indication of beam path, location of detected fires, location of emergency-off actuation, and the location of areas potentially dangerous due to the operational mode in use is continuously portrayed on the panel. A glance at the panel shows the zones which must be inspected and locked for the mode chosen, as well as the contemporary status of the zones and gates.

Primary Indicator Panel

This panel, located near the linac control position reveals the state of the various subsystems in the master interlock chains. It has proven valuable for rapid indication of the subsystem causing linac shutdown. An interruption holding circuit allows identification of subsystem at fault even for monentary interruption. Indicator lights for each subsystem signal its condition.

Removable Shielding Interlocks

The slot between Measurement Rooms #1 and #3, the demountable wall between Measurement Room #3 and the Magnet Room, and the port into Measurement Room #2 from the Magnet Room were provided for experimental flexibility. These openings can be filled with radiation shielding material, penetrated by slots for particle beams, or left open. The shielding aspect of these openings must be considered in setting the inspection requirements for the modes involving the use of these areas. Circuits are provided which integrate the status of the openings into the personnel protection system. These circuits consider the openings as open, or closed, as determined by visual inspection. Operating a key interlock at the opening location and transferring the key to a control room interlock programs a change in the status of the opening. When the key is in place at the opening, the system treats the opening as unshielded, and programs the adjacent zones to be inspected and locked. Needless to say the status of the openings will not change from day to day as many tons of shielding material is involved.

Air Flow Control

Radioactive air, ozone, and other contaminates are continually flushed out of areas in the complex through which the beam might pass. The magnet room and the three measurement rooms are each supplied with about 5000 ft^3/m of cooled conditioned fresh air from a common air system. During beam-on conditions the air flow to the magnet room and the measurement room in the beam path is increased to 10,000 ft^3/m by reducing the air flow to the other measurement rooms not in the beam path. A smaller separate system supplies air to the accelerator room and provides a 20% increase in air flow during beam-on operation.

Directivity and volume of air flow for different modes of operation is controlled by commands from the mode switch to the damper equipment. Compliance with the command is indicated by the operation of pneumatic-electric switches actuated by velocity sensors in the supply and exhaust air ducts. Indicator lights and the closing of the air flow interlocks indicate satisfactory system compliance.

System Components

All components are industrial type items which are rated for continuous 24 hour duty. The majority of the relays are those made for the machine tool trade and are rated at 300 volts ac. They offer a compact arrangement with a high degree of reliability. The same base size is used for the entire family of relays, a convenient feature when circuit modifications are called for. The operating reliability of these relays is such that only one relay out of over 400 in use has failed in two years of continuous operation.

Wiring for the system is installed in conduits and ducts specifically reserved for this application. All relay boxes throughout the complex are fitted with locks to prevent tampering with the system. In areas with expected high radiation levels glass-asbestos insulated wire is used. Inspection station components have some parts which may be vulnerable to radiation damage. Not enough experience has been obtained to ascertain the degree of vulnerability.

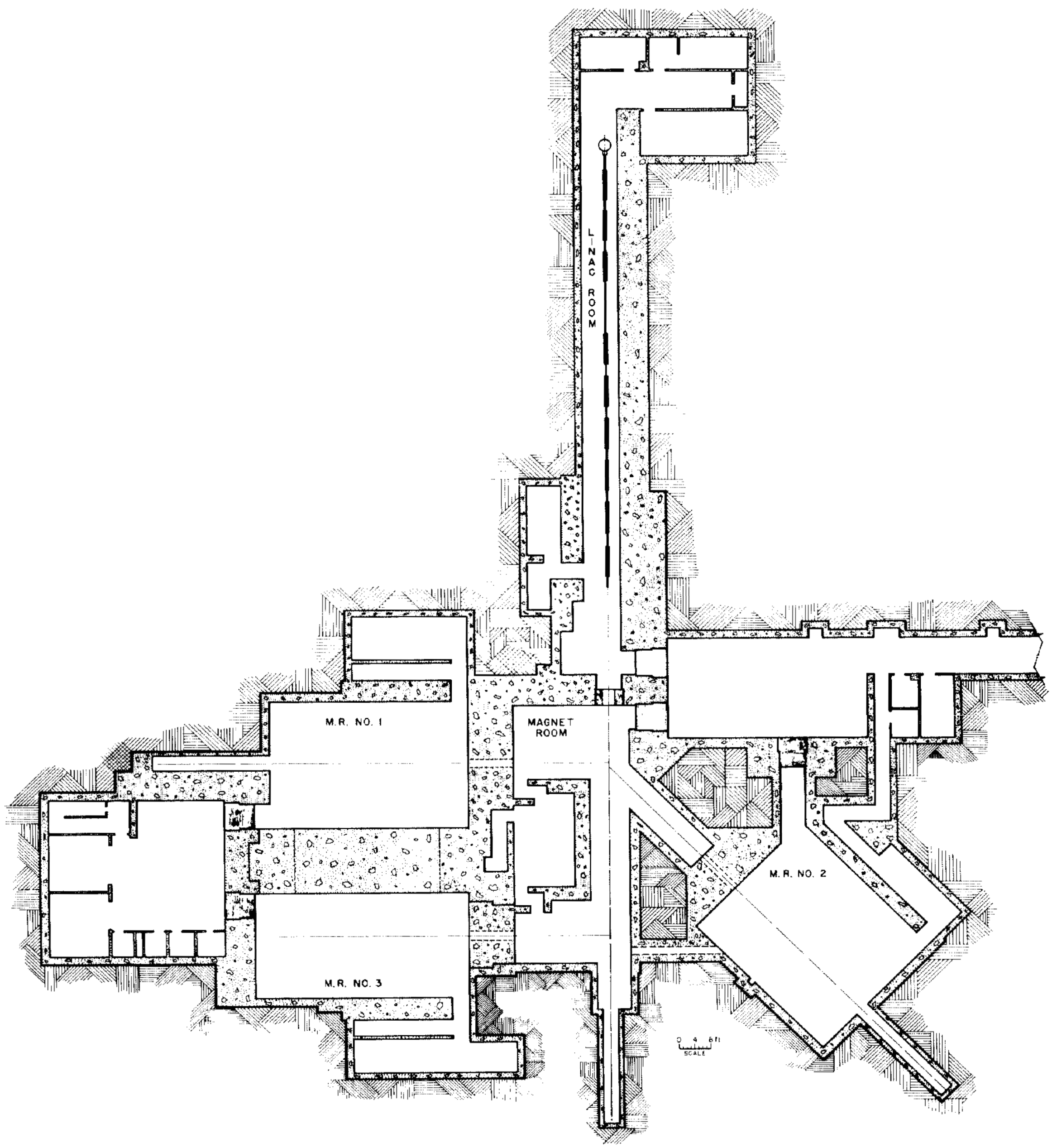

Fig. 1. Sub-basement floor plan of linac complex.

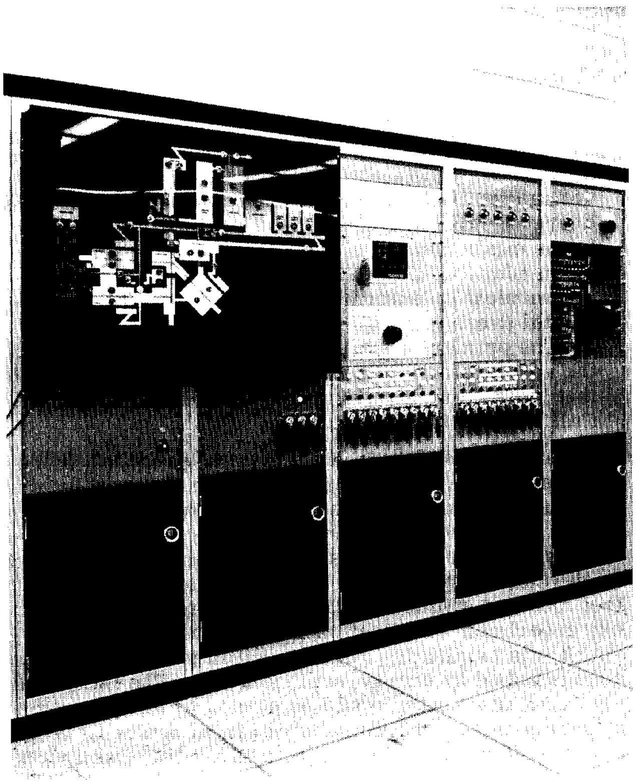

Fig. 2. Linac master interlock and control center showing area display board, patch panel, mode switch and key interlock cylinders with keys.

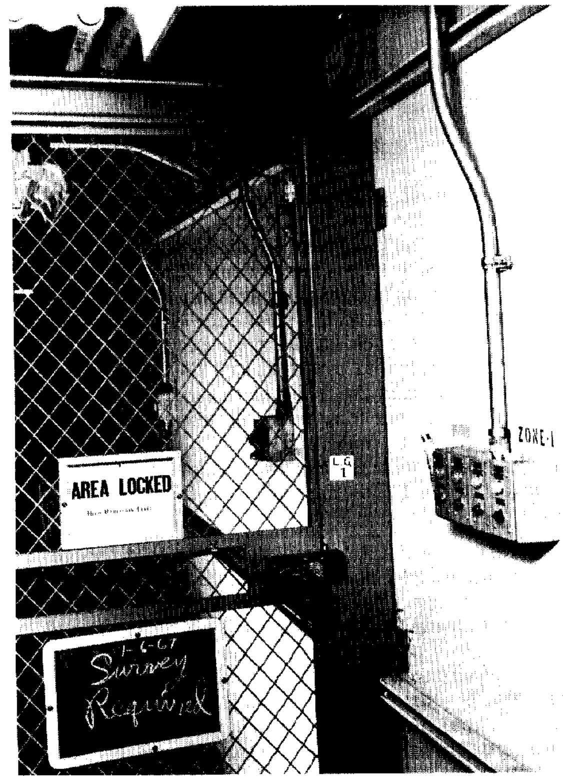

Fig. 3. Typical locking gate arrangement.