Proceedings of the 9th International Conference on Cyclotrons and their Applications
September 1981, Caen, France

THE RADIATION AREA INTERLOCK SYSTEM AT IUCF*

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Abstract.-The high radiation areas at IUCF consist of three accelerator rooms and five target rooms.[1,2] A redundant-logic interlock system is used to prevent accidental entry into these rooms when beam is present. This system requires that an area must be both cleared and selected before beam can be admitted. Clearing is performed by pushing, in order, a series of switches placed strategically in the room to be cleared. This provides assurance that a thorough visual inspection has taken place. Flashing amber lights and a klaxon (interrupted tone) accompany this operation. If any door to the area is opened during or after clear, the operation must be repeated. Selection is done by pushbutton in the control room. After an area has been both cleared and selected, a steel shutter moves out of the beam path and operator-controlled beam stops are enabled. Beam can now be admitted. The system also takes account of bending magnet currents, radiation levels and vacuum valve status. A number of logic fault conditions are defined to detect loss of redundancy or mechanical/electrical failure. All of the active circuitry is located in the radiation-free control room; logic functions are implemented in industrial high-threshold logic, noted for its reliability and trouble-free operation.

1. Introduction.-In assuring that all personnel are excluded from an area which is to receive beam from an accelerator, one can adopt either a system which accounts rigorously for all persons entering and leaving the area or a system which will not permit the entrance of beam until a thorough visual inspection has been completed. The IUCF system emphasizes the latter approach. A second problem which occurs after a run has commenced is to provide the experimenter with safe and prompt access to a target area without turning off the accelerator. For this a high degree of redundancy in beam control is appropriate.

The design of the present system was guided by the following rules:

1. Minimize the number of decisions required of the operator by careful use of fail-safe hardware operating automatically.
2. Make display panels self-explanatory so that the operation of the system is apparent without extensive instruction.
3. Introduce redundancy at three levels: duplicate transducers for reporting a given event, duplicate circuitry for processing this information and multiple beam stopping devices to protect each area from unwanted beam.
4. Circuits and transducers must be used in such a way that their most common failure mode will cause the system to fail safely.
5. Each interlock trip must cause latching of the system so that correction of the fault does not restore the beam without a new command.
6. The loss of any degree of redundancy must be automatically announced as soon as it occurs.
7. Provision must be made for safe testing of each part of the system.

*Work supported by the U.S. National Science Foundation and by Indiana University.

The general arrangement of the laboratory is shown in Fig. 1. Beam originates in the Ion Source Room which houses High Voltage Terminals A and B and Beam Line I. The accelerator proper is housed in the Injector Cyclotron Vault, Main Stage Vault and Beam Corridor. From here the beam can be delivered to one of the following: (1) Gamma Facility, (2) 64 Inch Scattering Chamber, (3) Pion Spectrometer, (4) QDDM Spectrometer, (5) Beam Swinger Facility, (6) Isotope Area, or (7) Polarized Neutron Area (under construction). The only controls available to the operator at the console are a) the area selector (see Fig. 2) to determine final destination of the beam and b) beam stops for monitoring beam at selected locations. Major hardware items are as follows:

Neutron Shutter -A pneumatically driven steel block which closes the hole through which beam enters one of the above-mentioned areas. It opens automatically when

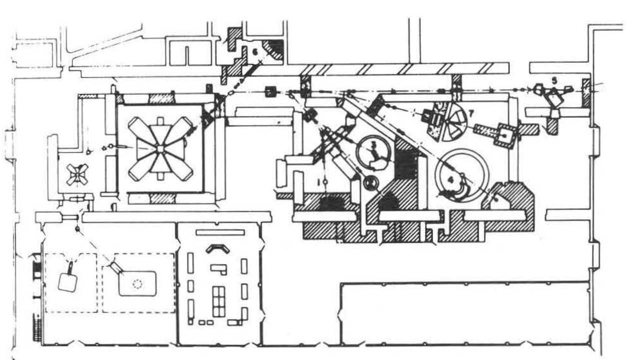

Fig. 1: Facility Layout

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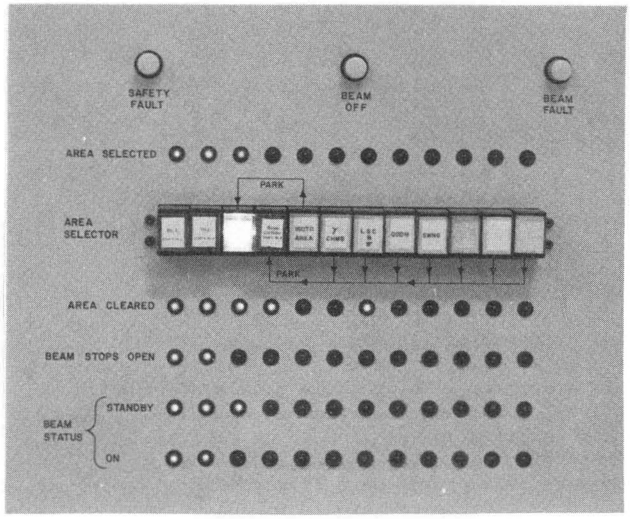

Fig. 2. Control Panel

its area is cleared and selected. It never intercepts beam in normal operation.

Beam Gate -A pneumatically driven water cooled copper block mounted immediately upstream from the neutron shutter. It opens (closes) when the access door to the area closes (opens) independently of the rest of the interlock circuitry. It never intercepts beam in normal operation, but would protect its area from beam if the entire interlock electronics failed.

Beam Stop -A pneumatically driven, water cooled copper block, insulated to monitor beam current and located at an appropriate point to facilitate beam tuning and to "park" the beam safely when an experimental area is entered.

Safety Key -The interlock circuitry includes a key for each radiation area which anyone entering the area can take with him. Beam cannot be delivered to an area unless the appropriate key is in place. If a master key is used to override this interlock, a flashing warning light will come on in the control room.

Door -Shielding doors are not required for access to radiation areas, since radiation attenuation is provided by labyrinths. Each door is a simple industrial type with latch. Several status switches on each door communicate with interlock systems. A door can be forced open from either direction should an emergency require this. Outside each access door is a panel on which lights indicate status of beam, area clear, neutron shutter position and radiation level.

2. Clearing Procedure:-The primary responsibility for safe operation of the cyclotron is a thorough visual inspection of all parts of the radiation area to be used. The clearing process (described above) is complete when the operator has inspected the entire area, depressing the switches in the correct order and closed the access door within the prescribed time interval. (An area may have from one to five check points, depending upon its complexity.) At this point the horn and amber lights stop and a red light starts flashing in the radiation area. This indicates that beam is permitted to enter. When beam actually enters an area, the radiation monitor will cause an audible radiation warning to sound. Cyclotron personnel are instructed that a flashing red light or an audible radiation warning indicates a serious emergency. Once an area is cleared, it remains cleared indefinitely until a door is opened. Latching annunciator lights indicate the need for reclearing an area.

3. Interlock Logic.-Initially, the system was conceived as two independent interlock systems A and B, each with its own transducers, electronics and beam stops. Either could operate if the other were disabled. In practice this approach leads to penalties in cost and complexity which are unacceptable. While it is straightforward to duplicate critical status switches, it is another matter to provide, for example, duplicate parking beam stops and neutron shutters or to employ fault commands in a simple way when either system A or B or both may be in use. Instead, the present system requires that duplicate status switches for doors and for neutron shutters always agree and that the detection of any logic fault (see next section) will generate independent outputs to close Stop A (controlled by System A) and Stop B (controlled by System B) in Beam Line I between Ion Source Terminal and Injector Cyclotron. A third Stop AB (controlled by either system) also drops in at the same time. In addition, critical circuits are paralleled in such a way that a single chip failure will shut down the system safely. As a final backup, each radiation area is guarded by a beam gate operated by its own door status switch and separate circuit which is independent of the main system.

System Faults. - These are divided into beam faults and safety faults.

Beam faults (listed below) do not represent personnel hazards but simply indicate that a) something remains to be done in order that beam be delivered to the selected area or b) an interlock has tripped after the beginning of a run: (1) Selected area not cleared, (2) Required vacuum valve not open, (3) Selected neutron shutter not open, (4) Bending magnets not on or off as required, (5) An outside door not closed, (6) Safety key for selected area missing.

Safety faults (listed below) only occur when some part of the system has failed and prompt action of some kind is required. In this case Stops A, B and AB will drop in and a flashing light on the fault panel indicates the nature of the problem: (1) Systems A and B not in same state, (2) Two switches on any door not in same state, (3) Any door not closed and corresponding beam gate open (4) Selected door not closed but area cleared, (5) Parking beam stop for unselected or uncleared area not closed, (6) Neutron shutter to unselected or uncleared area not closed and (7) Excessive radiation in a public access area.

Beam Status. For each radiation area the beam may be in one of four states defined below.

1. Beam Off = Stops A, B and AB closed. When any interlock is tripped, the system goes to this state. This is to be avoided during a run since thermal changes can cause cyclotron detuning.

2. Beam Ready = Stops A, B and AB open. These stops can be opened only when there are no beam fault and no safety fault.

3. Beam Standby = Beam Ready plus area cleared and area selected. In this state the beam is ready to be delivered to the area except that one or more beam stops are closed. The Beam Standby and Beam On states refer to a particular area since at any given time some areas but not others can safety receive beam.

When an area has been cleared and selected, the neutron shutter will open without further command. When the neutron shutter has opened fully (its travel time is 45 seconds), the appropriate Beam Standby light will appear on the control panel (see Fig. 2).

4. Beam On = Beam Standby plus all required beam stops open. The beam may be delivered by opening all upstream beam stops. At this point the appropriate Beam On light will appear on the control panel.

4. Operating Procedure.-To enter a target area during a run, the experimenter selects the prescribed parking beam stop (see Fig. 2) which "unselects" the target area and causes the neutron shutter to close. When the neutron shutter is fully closed, he then opens the door and enters. This closes the beam gate and the beam line vacuum gate valve. The cyclotron will continue to deliver beam to the parking beam stop. When the experimenter is ready to continue the run, he opens the beam line vacuum gate valve and follows the standard clearing procedure to provide visual inspection of the area. When the door closes, the beam gate opens. He then returns to the control room and selects the target area. After the neutron shutter has opened fully, the operator can open the parking beam stop and deliver the beam on target.

5. Radiation Monitors.-When radiation shielding is infinitely thick, the complete protective logic may be based on status of interlock switches only. For the highest energy beams at IUCF, radiation monitors must be included. Each monitor has low and high level trips (with latch and manual reset) which are set to an appropriate value for each area. When a set point is exceeded, a flashing light on the fault panel warns the operator that corrective action is required. A radiation monitor trip in a public access area shuts off the beam.

6. Hardware Realization.-Several possibilities were considered for hardware realization. Microprocessors were rejected because of n-mos static susceptibility, length of development time and difficulty of repair. TTL would have required extensive input isolation and our isolators (at that time) were not considered sufficiently reliable. Motorola's 15 volt high threshold logic (MHTL), which is used extensively by Allen-Bradley for industrial controls, was the final choice because of its high noise margin (five times that of TTL), low speed (glitch-free operation), and high reliability.

Six printed circuit cards were developed for our standard wirewrap bin; one for sequential push-button room clear (see Fig. 3), one for shutter and shutter latch operation and so on. All requirements are realized with straight combinatorial logic plus reliable 355 timers. This logic is in five wire-wrap bins in the control room; from this point cables radiate out to remote solid-state relays, sirens, switches, lights, stops and shutters. A redundant 15 volt power supply with automatic switchover in event of failure powers the bins.

This straightforward design has paid dividends. Diagnosis of problems can be made with a VOM instead of a logic analyzer. Repairs are quickly achieved with card replacement. In its three years of operation, the system has experienced almost negligible downtime. [Note: Since the vendor plans to discontinue the MHTL logic family, its use is no longer recommended. TTL logic with all inputs photo-isolated is now a better choice.]

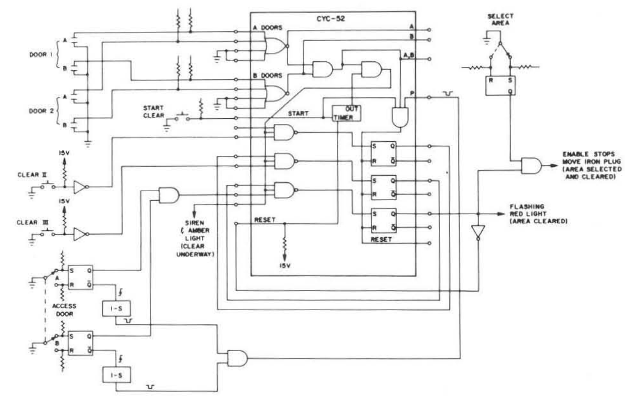

Fig. 3. Room Clear Logic

7. Testing.-The entire system is checked every four months. This is done at night during a shutdown to minimize interference with other work. All areas are cleared, beam is simulated on target and then various faults, such as opening doors to a cleared area, are generated. The system response is noted on a checklist and failures are repaired the next day. Failures to date have been of a mundane variety: burned-out lights, sticking beam stops. This check-out takes three people about two hours.

8. Summary.-During three years of daily use, the IUCF radiation area interlock system has proved to be both safe and reliable. Down time after initial debugging has been negligible, operators have found it easy to use and experimenters are afforded fast and safe access to target areas.

References

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2. "IUCF Status Report," R.E. Pollock, IEEE Trans. Nucl. Sci. 26, No. 2, 1965 (1978).