



FRCM CHAPTER 10

RADIATION SAFETY INTERLOCK SYSTEMS

Revision History

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PART 1 REQUIREMENTS

1001 Purpose, Scope, and Definitions

1. The purpose of a radiation safety interlock system (RSIS) is to prevent injury, death, or serious overexposure from high radiation levels. These systems are considered to be Credited Controls, as this terminology is used in [FRCM Chapter 2](#) and [FESHM Chapter 2010](#). The subject matter of this chapter does not apply to electrical safety interlocks.
2. For the purposes of this chapter personnel radiation safety interlocks include: radiation enclosure interlocks, radiation activated interlocks, and some beam controlling devices such as magnet current comparators, collimators, etc.
3. The provisions of this chapter apply to all Divisions/Sections having responsibility for providing and operating RSIS to prevent personnel exposure to high radiation levels.
4. The following definitions are pertinent to the application of the requirements of this chapter:
 - a. **Beam Enclosure.** Any area containing beamlines and surrounded by walls or fences with all access points interlocked to turn off the beam. Included are areas which do not contain beamlines but which represent potential radiation hazards equivalent to those of beam enclosures exemplified by spaces where muon radiation fields exist that can create radiological areas.
 - b. **Critical Devices.** Any power supply, beam stop, collimator, or device which prohibits the entry of a particle beam or otherwise prohibits the generation of ionizing radiation.
 - c. **Credited Controls.** Controls determined through safety analysis to be essential for safe operation directly related to the protection of personnel or the environment. See also Machine Controls (See <http://esh-docdb.fnal.gov/cgi-bin>ShowDocument?docid=348>).
 - d. **Failure Mode Critical Devices.** A secondary or back-up critical device which is actuated when a failure of the area critical device is detected.
 - e. **Major changes to the RSIS** include but are not limited to: fundamental changes to the design of the system, such as changes to the critical device designations, access controls, changes to the permit system that fundamentally change the design of the RSIS. All changes to critical devices, except magnet current windows, represent major changes. Major changes are approved by the SRSO via RP Form # 42.
 - f. **Minor changes to the RSIS** do not fundamentally change how the RSIS operates. Minor changes include but are not limited to: additions or removals of radiation detectors, changes to detector trip level settings, additions or removal of power supply

inputs, additions or removals of magnet current windows, additions or removals of beam line extensions to the permit system. Approval by the assigned RSO of minor modifications is sufficient.

5. The following reference materials may be used as guidance for designing radiation safety interlock systems:
 - a. Radiation Alarm and Access Control Systems, NCRP Report 88, National Council on Radiation Protection and Measurement, Washington, DC (1986).
 - b. Health Physics Manual of Good Practices for Accelerator Facilities, US DOE Report SLAC-327, April 1988.
 - c. "Application of Safety Instrumented Systems for the Process Industries", ANSI/ISA – 84.00.01 – 2004.
 - d. "Functional Safety of Electrical/Electronic/Programmable Electronic Safety-related Systems (E/E/PE, or E/E/PES)", IEC 61508.
 - e. "Functional safety - Safety instrumented systems for the process industry sector", IEC 61511.
 - f. "ANSI/HPS N43.1 "Radiation Safety for the Design and Operation of Particle Accelerators".
6. The RSIS should not normally be used for beam diagnostic studies or for the sole use of critical devices for equipment protection purposes. However, it is recognized that there are important parameters of proper equipment function exemplified by the presence of cooling water, operating temperatures within permissible values, etc. that should be controlled by the RSIS in order to prevent unexpected high radiation levels and contamination hazards to keep doses ALARA.

1002 Responsibilities for Radiation Safety Interlock Systems

1. **SRSO Responsibilities:** The SRSO, is ultimately responsible for, but may delegate one or more individuals in the ESH&Q Section Radiation Physics Engineering and Radiation Physics Science Departments the following assignments as Laboratory Interlock Coordinator:
 - a. Consult with and advise division/section heads on matters involving personnel radiation safety interlocks in their respective areas.
 - b. Review and approve the designs of RSIS for new or major modifications to existing accelerator radiation safety interlock systems.

- c. Review and approve new radiation detectors, beam sensing devices, critical devices or major modifications to existing systems for compliance with the requirements found in this chapter.
 - d. Review and approve the effect of each major modification on the existing system. R.P. Form 19 is to be used for this purpose.
 - e. Approve of all personnel authorized to work on the radiation safety interlock system.
2. Responsibilities of ESH&Q Section Radiation Physics Engineering Department Interlocks Group:
- a. Obtain prior approval of the SRSO for any changes in the interlock system that reduces the level of safety.
 - b. Notification of instances of interlock jumpering with the exception of the following:
 - tests and repairs performed with the beam-off
 - by-passing of individual radiation monitors at the assigned Radiation Safety Officer's (RSO's) discretion
 - b. If the jumpered interlock will affect the level of safety in a primary or high intensity secondary beam area, prior approval from the SRSO is required.
 - c. Notification of instances of failures of interlock system or components that would have compromised the level of safety of the system.
 - d. Notification of completion of interlock tests and problems found which may have compromised the system. (Copies of the completed test procedures must be made available upon request.)
 - e. Drawings of new interlock systems submitted for review. Review and approval by the SRSO of all new installations are required prior to their initial use. Prudence suggests that the necessary drawings and functional descriptions be provided sufficiently early so that this review is completed prior to the construction and installation of the equipment. RP Form # 42 is to be used for this purpose. Failure to do so may result in delay of the interlock approval and thus in delay of operation of that beamline.

- f. Submission of drawings and functional descriptions of all major modifications¹ made to existing systems for review. RP Form # 42 is to be used for this purpose. (SRSO approval is required prior to use of modified systems.)
- h. Any changes to, or installation of radiation safety interlock systems requires the approval of the assigned RSO.

1003 Hardware Requirements for Interlocks

- 1. **General Requirements:** Devices for all interlocked areas should have a built-in redundancy either in hardware or methods. Their design should be as foolproof (highly resistant against human error and tampering) and fail-safe (failure leading to a safe status) as reasonably achievable. Systems which employ computer-based monitoring or subsystems shall have a demonstrated high resistance to external tampering (hacking). Where at all possible, reliance should be placed on passive items such as wall barriers, locks and shielding rather than on radiation detection devices or electrical surveillance systems. Well-stated written procedures and engineered hardware are essential.
- 2. **Material Quality Requirements:** Because of the potentially serious consequences of an interlock failure, the highest quality materials and workmanship feasible shall be utilized in the design and installation of the interlock systems. All devices and activation mechanisms should be as failure proof and tamper proof as possible.
- 3. **Fail-Safe and Redundant Systems:** Fail-Safe designs shall be used whenever possible. Redundancy of devices or methods is required for all interlocked areas.
 - a. A fail-safe system is one which continues to protect people in spite of all anticipated mechanisms of single component failure. Thus, loss of power, a cold solder joint, or a malfunctioning circuit element should result in a safe condition (e.g., beam not being permitted).
 - b. A redundant system is one which uses two or more independent (but not necessarily identical or parallel) methods of sensing and control to achieve the same goal (i.e., preventing or minimizing the severity of radiation accidents).
 - c. New and existing systems must conform to the requirements of this section. Exemption from any requirements will be granted by the SRSO on a case-by-case basis, the criterion being the incremental safety gained compared with the costs of modification.
- 4. **Requirements**

¹ If the work is just an extension of an older system or a minor modification, then reference to existing drawings or a memo stating the exact nature of the work on an interlock change request will be acceptable. Once drawings are available, copies may be requested by the SRSO or designated Laboratory Interlock Coordinator.

- a. Solid state devices can fail in either the “safe” or “unsafe” mode. When using these devices in an interlock system which must be fail-safe and redundant, parity checking of the redundant loops must be done at appropriate places to detect the loss of parity caused by an “unsafe” failure of one loop. If there is a discrepancy (each loop shows a different state) then the critical device must be latched off until the parity fault can be investigated. The use of computers in safety systems must conform to the Fermilab Policy on Computing which invokes the reference cited in Articles 1001.5.c, d, e of this chapter as part of its requirements.
 - b. All interlock safety system components shall be labeled and must be secured or supervised to prevent unauthorized access.
 - c. There must be two independent loops or methods monitoring each personnel access point and each key in a key tree that prohibit beam whenever a personnel access point is opened or key removed. Each key which allows access must be kept in a key tree. Key trees in unsupervised areas must be locked. Signals from both interlock loops shall be sent to the critical device(s).
 - d. There must be two independent switches or redundant methods (for example, one pulsed optical sensor set or one mechanical and one magnetic switch) on each door or personnel access for all new systems. These shall be placed on the side of the door opposite from the hinges except in the instance of pulsed optical sensors or switches designed to be used on the hinge side of the door. The switches must be inside the enclosure. In addition, the door must be locked, except in areas where gates and doors are used to separate interlocked beam enclosures and locking them would constitute a Life Safety Code violation
 - e. Enclosure interlock status indicators are required at each entrance. It is recommended that critical devices status indicators also be used at each entrance.
 - f. There shall be hardware to require a full search-and-secure at startup and after each gate/door interlock trip. The reset stations shall be connected in a sequence which ensures a systematic and thorough search.
 - g. An announcement or an audible warning must sound in the enclosures after the completion of the search-and-secure for a period of time sufficient to allow safe egress or interlock disablement, but for 30 seconds at a minimum.
5. Additional Hardware Requirements/Recommendations for Photon emitting Radiation Generating Devices or high activity sealed source gamma-ray calibrators or irradiators in Interlocked Controlled Access Areas: Table 10-1 gives graded approach for the levels of redundancy and control for areas where photon emitted or generated radiation is produced.

Table 10-1 Levels of Redundancy and Control for Photo-Emitting Radiation Generating Devices

DOSE RATES AT 1 FOOT (mrem/hr)	REQUIREMENTS
Dose Rate \leq 100	No interlock hardware controls required to inhibit x-rays
$100 < \text{Dose Rate} \leq 1000$	One method of turning off each RGD
Dose Rate > 1000	Two independent methods of turning off the RGD. Opening the access door must shut off the RGD independent of the action of the key tree.

6. Additional Hardware Requirements/Recommendations for Beam-Off Interlocked Controlled Access Areas
- a. One critical device protecting a given area is required, but two are recommended. If only one is used, a failure mode critical device is required.
 - b. In those areas where a single critical device is used to ensure safety, status monitoring is required to detect a device failure and inhibit a failure mode device. Where two or more critical devices are used, status monitoring is recommended. In addition, in order to preserve redundancy and independent control, the control permit to the failure mode critical device must be different from the control signal to the primary critical device(s). Lastly, the failure mode critical device must be different from the primary critical device or inhibit the primary critical device in a completely different manner.
 - c. Opening the access door must shut off the critical device independent of the action of the key tree.
7. Additional Hardware Requirements/Recommendations for Beam-On Interlocked Controlled Access Areas (See Article 236)
- a. “Squawks” or similar devices which operate independently from the interlock system are recommended to indicate the presence of beam.
 - b. There must be an indication of beamline critical device status at each access point.
 - c. Where appropriate, there shall be two redundant methods to prevent or detect beam going down the wrong beam channel(s).
 - a. There must be a mechanism to lock-out the beamline critical device for experimental areas where beam-on access is possible so that personnel may safely work in the path of the beam. There shall be hardware to prevent re-enabling of the locked-out device by personnel other than the initiating person.

- e. There shall be a system to remove beam from a beam-on access area whenever a controlled access door is left open for a period greater than approximately 45 seconds. The line may be reset only by authority of the designated Division/Section personnel.

1004 Interlock System Program Elements

The following programs are maintained by the ESH&Q Section RPE/RPS Departments and or the Accelerator Division Operations Department and apply to all operating accelerators and beamlines. Each operating (accelerator/beamline) area shall have written procedures for the categories given below.

1. Interlock Key Accountability

- a. Radiation safety interlock keys must be inventoried at least annually.
- b. Lock systems compromised by the loss of any key which operates them must be replaced.
- c. Extra keys² must never be used to replace lost or missing keys. If any extra keys are to be maintained, then the Division/Section Head must approve the use of an extra key except to replace a broken key. Extra keys are to be stored in locked cabinets and only accessible to members of the ESH&Q Section Radiation Physics Science and Engineering staff members. Extra keys must be inventoried at least annually.
- d. The Chief Safety Officer or designee is responsible for assuring that interlock keys are procured only by personnel designated in writing.

2. Search-and-Secure

- a. The purpose of search-and-secure is to ensure that exclusion areas have been cleared of all personnel before beam is permitted.
- b. ESH&Q Section in collaboration with Accelerator Division Operations Department shall have an established and auditable program for verifying the adequacy of its search-and-secure procedures for exclusion areas.

An ingredient of this programs includes the practice of hiding “dummies” in any accessible portion of an enclosure whenever practicable to test the adequacy of actual search and secure operations at the discretion of the assigned RSO.

² Extra keys are those not interlocked. This includes control and master keys. It does not include extra key-core sets.

3. Controlled Access

- a. **Beam-Off Controlled Access:** Beam-off controlled access (beam-off entry without breaking interlocks) is the practice in the vast majority of interlocked accelerator/beamline areas. Controlled access is accomplished by removing keys from their interlocked positions in a key tree. During the access the interlocks are not broken; therefore, these keys provide assurance that beam cannot be turned on. It is therefore required that every person making an entry have a key in his/her possession at all times. The keys used to open the entry door shall not be left in the “enter” box or door. In general, all personnel entering must have had appropriate training and be current with their controlled access training. Specific exceptions to these training requirements may be permitted for short-term accesses involving, for example, visiting dignitaries, provided appropriately trained escorts accompany the visitors and the assigned RSO or designee has granted approval. More detailed provisions related to controlled access are provide in FRCM Article 337.
- b. **Beam-On Controlled Access:** Beam-on controlled access is essentially the same as the above. This sort of controlled access is discouraged and is very rare at Fermilab. Care must be taken by all entering personnel to keep out of the path of the beam and specific requirements must be clearly stated in a written procedure approved by the SRSO. All personnel entering should be approved by the RSO or designee and must have been trained by the RSO or designee and be current with their controlled access training. More detailed provisions related to controlled access are provide in FRCM Article 337.
- c. **Training for Controlled Access:** All unescorted personnel making controlled access shall be trained. Specifications for training are given in [FRCM Chapter 6](#).

4. Interlock Work

a. **Maintenance, Repair and Testing**

- (1) All work of this type is coordinated with the Accelerator Division Operations Department.
- (2) No beam is permitted during tests and/or maintenance.
- (3) Any maintenance or repair work may only be made by personnel authorized in writing by the SRSO.
- (4) All work must be documented in a permanent logbook, either hardbound or electronic. The integrity of the interlocks must be verified by appropriate tests prior to their next use to protect personnel.

- (5) The entire interlock system in each area (including each key in each key tree, each door switch, each critical device each radiation activated or current/voltage activated interlock) must be thoroughly tested at intervals not greater than 6 months (plus up to a 4 month grace period) when the system is in use. If a system has not been in use for 6 months or longer, then it must be tested before it is used. All interlock tests must be documented. These test records shall be forwarded to the designated Laboratory Interlock Coordinator (see Article 1002) for records retention.

b. **Documentation of Systems and their Modifications**

Interlock systems must be documented by a complete set of drawings, a written functional description and a written test procedure, and approved for operation by the SRSO or his/her designee prior to use. For major changes, an approval for fabrication should be obtained at an early stage to facilitate efficient operations. When the additions and changes to a system are minor or do not affect the procedures, then reference to existing documentation will be acceptable.

Documentation recording the decommissioning of interlock systems shall be forwarded to the SRSO.

c. **Jumpering**

- (1) By-passing of any interlock component must be approved in advance by either the assigned RSO or Division/Section Head and may require approval of the SRSO (see 1002.2).
- (2) If the jumpered interlock will affect the level of safety in a primary or high intensity secondary area, prior approval is also required from the SRSO.
- (3) Once a jumper has been placed and before beam is to be delivered to the area, a test must be performed to make certain that only the desired component was jumpered.
- (4) When a jumper is removed, the system must be tested to verify proper functioning of the circuit/component.
- (5) All jumpering, unjumpering and testing of the interlocks must be documented in a permanent record. All jumpers must be inventoried annually.
- (6) Removal of jumpers installed as part of a documented interlock test procedure (i.e., jumpers necessary to facilitate interlock system testing) shall be inventoried as part of the interlock system test record.

5. Special Shielding and Barrier Components

There are numerous areas where shielding blocks and other barriers are employed to exclude access and provide shielding between beamlines and accessible areas. These include equipment hatches, rollup doors (in some cases with shielding behind them), strategically placed shielding blocks, and enclosure “cave” structures. It is impractical to protect against the removal of these components with the normal interlocked switches. However, the removal and restoration of this shielding must be controlled to prevent inadvertent removal or beamline startup before restoration. These installations shall be documented as part of the relevant shielding assessment (see article 812). The following procedures are the minimum required to provide the necessary control.

- a. **Locks:** These components must be secured in a manner such that a lock (and a chain if possible) can be placed in a conspicuous spot (lifting eyes of shielding block, hatch cover, etc.) that would prevent inadvertent removal of the components. The key for this lock shall be part of the interlock chain for the enclosure, or under the control of the assigned RSO.
- b. **Signs:** Signs shall be conspicuously posted on the shielding blocks, hatch cover, or lock to indicate whom to contact for removal.
- c. **Procedures:** Procedures shall be written to specify the control measures allowing unlocking and removal of these shielding blocks and controls taken (such as removal and locking up an interlocked key for the enclosure, or otherwise maintaining the key under the control of the assigned RSO) to prevent beamline startup before shielding is restored. A highly recommended procedure to monitor shielding removal and restoration is the use of a second lock under the control of the assigned RSO. The key of this lock needs not to be part of the interlock chain.