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SOME CONSIDERATIONS OF RADIATION PROTECTION IN THE MESON AREA

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Introduction

The Radiation Safety System in an experimental area has two primary functions: to control radiation, and to control and monitor radiation dosage received by personnel. The goal of the system is to reduce to the lowest feasible levels both the amount of radiation present and the dosage accumulated. It is presumed that these levels are always less than legal and Laboratory guidelines.

A fact that must be faced in any security system is that there is always associated with the system a probability of system failure - through component failure, human error, or malicious intent. Any intelligent system design must seek to analyze and minimize these probabilities. Along with the analyses of system failure probabilities, the consequences of such failures must be analyzed and the system modified to eliminate those that result in injury or damage to equipment.

The most straightforward understanding of the probabilities of system failures have to do with system hardware. A well-developed sequence of failure analysis has grown up under the necessity of providing reliable communication and life support systems for manned space flight, long-term reliability of interplanetary missions and the mundane requirements of the Bell Telephone System. Specifications of component and system hardware reliability are routinely available from manufacturers. It must be noted that, whether that probability is alluded to or not, each time a component is purchased or a system put together there is an implicit acceptance of some definite and finite probability of failure. Failure probabilities for any reasonable system component are of the order of one part in 10^6 for 1000 hours of operation. The failure probabilities of mechanical hardware, such as beam stops, is less well understood, but from experience, they are clearly much higher.

More difficult to analyze are probabilities of human error. In general, the more complicated the system the higher the probability of human error. Crude estimates can be derived from actual experience, e.g., the occurrence of three reported cases in the past year of jumpers being forgotten during check-out of the Meson interlock system can indicate a failure probability of about 1 in 3 for 1000 hours of operation. Similar estimates can be attempted for other elements of the system based on five years of experience.

It is essentially impossible to assign a probability to failure of the system due to malicious intent.

An analysis based on these considerations has been made for the overall radiation protection system for the Meson Area. Described in what follows are the steps taken to reduce the probability of the various types of system failure described above, and to eliminate, as far as possible, the harmful consequences of such failure.

I. Elimination of Radiation Sources

A. Cleanup

The first goal of the system is to reduce the amount of radiation. This is accomplished by identifying and cleaning up sources and shielding what remains. In the Meson Area a systematic program has been set in motion to remove vacuum windows from the beam lines where these are found to be a noteworthy source of radiation. (Examples are the M2 beam line in the 600-foot and 1000-foot areas, and the M1 line at 1300 feet where windows and air gaps were found to be sources of radiation on the mezzanine.) As part of the same program, the standard beam pipe has been increased from three inches to six inches to reduce radiation caused by misalignment of beam pipes or missteering of the beam. A further example is the replacement of the B1 dipole magnets of the M2 line by B2 dipoles to better match the system to the proton beam emittance. This will eliminate a radiation problem at the 1000-foot crossover caused by the tails of the high-intensity proton beam striking the face of the upstream magnet.

B. Shielding

The primary radiation shield is, of course, the shielding berm. In addition to this, portable shielding is used to absorb radiation from the beams being transported through the berm and used in experiments. Each beam is provided with a downstream beam dump sufficient to absorb the energy of the beam that appears in the hadronic cascade and electromagnetic showers. Residual muons not absorbed by the dumps are absorbed by Mt. Taijiyama. An extreme example of a local shield is the present M2 target cave which reduces the radiation on the experimental floor outside the cave to <10 mrem/hr with 3×10^{11} protons being targeted. Other examples are the local shield in M2 at the 1000 foot crossover, designed to reduce the radiation level in the M1 passage to <20 mrem/hr with M2 running high intensity, and the shield cave around the SAS beam dump in the Detector Building. Operations personnel have been instructed in methods of calculating shielding requirements by scaling from measured levels.

II. Delineation of Radiation Zones

After eliminating or reducing as many radiation sources as feasible, it is necessary for control of dosage to delineate zones of radiation corresponding to different levels of potential dose acquisition.

The primary zone is, of course, the beam itself, which is, by its nature a potential source of large dosage. This zone is best delineated by an evacuated beam pipe which serves to keep people out of the beam and to eliminate beam-gas collisions, a potential source of background for experiments and of radiation dose for personnel. As noted above, the Meson Area standard beam pipe has been increased from 3-inch ϕ to 6-inch ϕ. While reducing potential radiation sources, this change removes personnel to a point further from the beam proper. This enlarges the primary radiation zone, reducing accessible dose. Where the vacuum beam pipe is not practicable the primary beam zone may be defined by helium bags, Sono tube, or close fencing.

The second radiation zone is that contiguous to the beam and experimental apparatus. This is as much an electrical as radiation safety zone, since the radiation levels from beams of modest intensity are usually not significantly different from Zone 3, the general access area. The barriers which delineate Zone 2 from Zone 3 serve to keep personnel away from "hot" magnet buss and connections, and from experimental high voltage. A barrier fence usually suffices here. The fence should be designed to be consistent with fire as well as radiation safety. A modular barrier fence, consistent with these safety requirements, has been designed and is being procured for this purpose.

The third zone is that which is more or less generally accessible to experimenters and personnel under the restriction of having personal radiation monitors. It is desirable to maintain this zone at an ambient level of $\leq$2.5 mrem/hr, with local "hot" spots $\leq$10 mrem/hr. A program is in progress of more effectively posting this zone.

The fourth zone is that accessible to the general public. The shielding berm and external building walls serve to delineate much of this zone. In other areas the delineation of the zone by fences and posting is necessary.

III. Control of Radiation Levels Within Zones

It is of primary importance, once zones have been delineated, to maintain the radiation levels in those zones consistent with their definition. This requires that the zones, particularly Zones 4 and 3 must be continuously monitored. Provision must be made in case of an excursion, to shut down the offending system and/or sound an alarm when the zone limit is exceeded. In consultation with Radiation Physics we have updated the radiation monitor circuitry to increase the trip setting accuracy and the reliability and also provide direct readout into the Control system for monitoring and alarms.

One of these detectors is placed behind each beam dump to prevent excess levels in the area behind the dump. (The area behind the dump is, in general, not available to the public.) In addition, other detectors are strategically placed along the beam lines to monitor excursions. All of these devices are coupled to one or more "critical devices" capable of shutting off the offending beam in one pulse.

IV. Beam Containment: Zone I

The most intense radiation region in any beam line is the beam itself. A prime function of the Radiation Safety System should be to keep the beam in its proper channel (i.e., inside Zone I). The standard beam pipe has been increased to 6-inch diameter to facilitate this containment. As far as possible, continuous vacuum is provided to reduce radiation and also keep people out of the beam. In addition, we have embarked on a development program in collaboration with the BEST group to develop the hardware and software necessary for single-knob tuning of the beam line dipoles. In the M6 line, all the dipoles are in series. This not only simplifies beam tuning, but also makes it nearly impossible to deflect the beam out of the beam pipe, since all the fields track. By analogy with this, a system is developed to establish an algorithm for each beam line which effectively does the same thing. In the event of equipment malfunction, causing the beam to leave the beam pipe, preset radiation monitors turn off the beam by actuating the critical devices.

V. Access Control: Zone 2

Zone 2 is the area immediately contiguous to the beam line and experimental apparatus. It may contain both electrical and radiation hazards. Access to the zone is required upstream for examining or working on magnets and beam apparatus, and downstream for examining and working on experimental equipment. The discussion will be limited here to those areas which are accessible to experimenters while the proton beam is on the primary target. Access to this zone is controlled by fences and interlocked gates. Control of the radiation levels is accomplished by collimators which may be used to increase and decrease the beam intensity and by "critical devices" which are capable of stopping the beam.

The radiation incidents which have occurred in Meson Area have to do chiefly with Zone 2. An analytical review of these incidents pinpoints the problem areas as fences, jumpers left in security systems during checkout, mechanical operation of critical devices, maintenance procedures, and discipline (rule violations).

A. As noted above, a new safety fence module has been developed and is being procured. The module is in safety yellow so a violation of the fence is clearly visible. The fence may also be scaled in case of fire, a serious problem with the present chain-link fence. The modules are fastened with metal fasteners, rather than tie-wraps, to inhibit casual violations. (Being reusable they are also more economical than chain-link fence.)

B. To alleviate the problem of errors in maintenance/checkout procedures, a new solid-state logic system is being implemented. The enhanced capability of more modern electronics allows for better built-in diagnostics. By use of modern reliability analysis and techniques the system will be specified and maintained at a level of <1 "gate" failure in 10^6 per/1000 hours of operation.

C. It is a straightforward exercise to specify and achieve the reliability of the gate hardware and logic circuitry. The weak point in the system is the critical device specification and hardware. The one serious radiation incident in Meson Area was failure of a beam stop "critical device". To improve reliability, "Max-Palmer"-type collimators are being procured for all beam lines. Experience in Neutrino, Proton, and Accelerator is that these are much faster acting and close more reliably than the complicated Meson Area collimators, <10 sec closure vs 4 minutes. These new collimators may then be used as critical devices as in the other Areas. This eliminates the problem of having air solenoids which were the cause of the radiation incident mentioned above.

In addition, a new beam dumping arrangement is being studied to divert high intensity beams into a shielded dump when the critical device is activated. This reduces the services problem of personnel exposure to residual radiation.

D. Disciplinary action has been, and will be taken for violations of procedural rules by experimenters.

VI. Conclusion

The Radiation Safety System is a congeries of many items and subsystems. In the Meson Area a program is underway to upgrade the entire system. Particular emphasis is placed on those aspects which have been highlighted by past radiation incidents. Of particular note are:

A. solid-state based interlock system with a specified reliability standard for system components and the whole system. The solid-state system also provides much improved and simplified diagnostics.

B. Improved radiation monitors coupled into the interlock system.

C. Faster, more reliable collimators in the critical device chain. These will be coupled with self-shielded dump for the high intensity lines.

D. High visibility safety fence with improved closure.

E. Clean up of radiation sources through elimination of vacuum windows, installation of larger diameter beam pipe, and installation of local shielding, where required.

F. Single-knob dipole tuning for each beam to inhibit random beam excursions.

G. Improved system documentation and specified maintenance procedures.