Linac Beam and Equipment Interlocks

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This paper describes the present linac interlock system that prevents beam from being accelerated in the Linac. It further describes how this system will apply to the Upgrade to prevent safety and equipment problems.

The existing 200-MeV Linac is protected by several hardware and software interlocks that prevent beam from being accelerated whenever a critical device interferes with beam or goes out of tolerance, or an event happens that requires the beam to be disabled. The beam stop and the pulse shifter are the normal devices for turning off and controlling the beam.

The beam stop is the primary safety device that prevents beam from being accelerated in the Linac when inserted. It is responsible for both personnel safety and equipment protection. It is located about one meter before the first linac tank in the 750-keV line of the preaccelerator. At this location the beam energy and power is sufficiently low that no damage to the beam stop can occur. The beam stop is controlled by the linac radiation safety system located in the Central Accelerator Radation and Electrical Safety System (CRESS) and maintained by the Safety Group. Removing a key for access to the linac enclosure, opening a door or gate to the linac enclosure, having a linac interlock failure, or a failure in a downstream (Booster, Main Ring, etc.) critical device will activate the beam stop. The preaccelerators (the Cockcroft-Walton high voltage sets for the ion source) serve as a backup and will shutdown if the beam stop does not indicate closed when activated.

The pulse shifter normally controls the accelerated beam in the Linac. It is intended for normal operation and equipment protection, and not for personnel protection although it is often referred to as secondary to the beam stop. The pulse shifter normally maintains a one millisecond timing delay for the ion source and beam chopper with respect to the rest of the linac timing. This delay is sufficient to prevent beam from being accelerated in the Linac while cycling all systems at 15 Hz and allowing beam to be switched on quickly for any given pulse. As such it is useful where there is a need to disable the beam on the following pulse rather than during the pulse. To permit accelerated beam, a beam enable pulse from the Main Control Room or Neutron Therapy must occur at linac start time (two milliseconds before beam). The shifter is designed to prevent more then twelve continuous pulses of beam for HEP operation; the maximum that will fit into the Main Ring. The shifter will only run continuously for Neutron Therapy or operator controlled 15-Hz operation. Circuits within the shifter check for errors and overcounts and insert the beam stop through the safety system if problems occur.

Several hard-wired interlocks feed into the pulse shifter and prevent beam on the next pulse when a fault occurs. The linac vacuum gate valves are hard-wired to the shifter. When closed the valves are directly in the beam path and would quickly be damaged while causing high radiation problems. Therefore, unless all beam line gate valves are in the fully open condition the pulse shifter will inhibit beam. As soon as any valve begins to close the shifter will prevent further beam until the problem is corrected.

Hard-wired inhibits to the pulse shifter also come from the Neutron Therapy Facility. Unless the NTF bending magnet is on and at the correct value, beam will not be accelerated for therapy. Likewise unless the magnet is completely off beam cannot go to the Booster and is inhibited for HEP. The main radiation safety system (CRESS) provides a hard-wired inhibit to the shifter. Also a common hard-wired line from the microprocessors for the linac control system will inhibit beam whenever one of the processors detects an error or stops working. Through software within the processors any device can be monitored to inhibit the shifter if it goes beyond a preset high or low value or has the wrong status. Through this mode the gate valves would also inhibit beam since they must show a normal open status to the control system. Likewise the rf level or the quadrupole settings are monitored with a one or two percent tolerance from a nominal value and inhibit beam if they go beyond this range. All devices that could affect beam in the Linac are so monitored by the control system.

These systems have worked very well to prevent damage in the existing Linac. The only beam induced damage has been to a steel bar shielding the 200-MeV booster septum and to a vacuum gate valve before linac tank five. The steel bar was melted through during studies due to a physicists error and later removed. The vacuum gate value was pierced in a few minutes with a one-eighth inch hole through quarter inch aluminium exactly on center. This happened following a shutdown in which interlock jumpers were not removed and NTF modifications were miss-wired permitting beam. In all cases the beam has only damaged objects that have come directly in its normal path.

The residual activity of the linac components has remained very low. With the exception of NTF and the 200-MeV areas the activation at the wall of the linac tanks is very small and only a few one meter regions in tanks three, four and nine ever approach ten mrad/hr. This could correspond to several rad/hr at the drift tube within the tank. At the NTF magnet, levels of 100 mrad/hr exist and in the 200-MeV area 40 to 100 mrad/hr is typical in many places and 500 mrad/hr exists at the spectrometer magnet where some (0.2%) Lorentz stripping of the H- ions occur.

To further reduce present radiation losses and to anticipate the need for improved radiation control in the Linac Upgrade the beam pulse length was recently reduced by ending the linac beam when the Booster off-chopper fired. At this time there is no need for further beam and the Linac low energy off-chopper is fired terminating beam in the Linac and the 200-MeV dump.

For the Linac Upgrade all of these systems will remain in place and in some cases will be improved and extended for the Upgrade. They are useful and necessary for preventing damage to the Linac, quickly detecting failures and reducing downtimes, minimizing activation of the linac structure, and preventing radiation problems around the linac enclosure. The beam stop and pulse shifter will remain to prevent and control accelerated beam. Hard-wired interlocks to the pulse shifter will remain and be extended to the Upgrade beam line components as necessary, e.g. the vacuum valves.

Fault and tolerance monitoring and inhibiting of critical devices will remain a major part of the new control system for the present Linac and the Upgrade and will be improved to give better information and recording of problems. The off-chopper firing line which was recently implemented from the Booster off-chopper and is able to terminate the beam in a few microseconds (within the beam pulse) will have significant usage in the new linac. Whenever an rf station crowbars, sparks or otherwise turns off; the chopper will be fired and the remaining beam terminated. This will significantly minimize stray beam in the linac structure and reduce radiation, activation and possible equipment damage. Any device that could affect the beam within the pulse could be connected to this line.

Considering the experience with the present Linac and the safeguards that exist and will be implemented in the Upgrade, there should be little problem operating the new structure in a protected and safe manner. Experience with the linear accelerator has shown that when a device malfunctions the beam which is deposited in the structure is spread over several tens of meters rather than in a small localized spot. This is significant to prevent damage. Whenever the rf or a quadrupole trips off the beam spreads over a large distance and no observable damage is done. Even trim steering magnets will be too weak to direct the beam locally into the structure. The only device likely to cause such damage is the NTF dipole magnet. It is located before tank five which will remain and is well interlocked.

Beam loss in the operating 200-MeV Linac is very low. Beam current monitors (toroids) located between each tank show no loss in beam from capture in tank one to the output at tank nine. Radiation loss monitors between the high energy tanks have very small signals indicating very little beam loss except during studies or tuning. To the level of measurement it appears that no more than one or two tenths percent, if that, of the beam is normally lost in the Linac. For the Upgrade structure the aperture is smaller (3 cm versus 4 cm) but the optics are figured so the beam fits within this aperture. With better controls and beam position diagnostics in the Upgrade, beam should not normally be lost. Normal beam loss should be less than one percent according to the beam dynamics studies of L. Oleksiuk and J. MacLachlan.

Abnormal beam loss however could be very large. When an rf system goes off all the beam will momentarily be sprayed several meters downstream and produce very large radiation problems although for a rather short time (few microseconds) before the beam turns off. The integrated dosage outside the enclosure should be small. The chance that the machine will run for hours, minutes or even seconds with serious losses is extremely remote. The devices to turn off beam and the redundant levels of interlocks provide considerable protection and safety for the Linac Upgrade.