Equipment Protection for
NuMI Beam Related Accidents

April 21, 2003

The NuMI beam line is designed to transport the highest power beam produced at Fermilab; $4x10^{13}$ protons every 2 seconds = 400 kW. The potential for beam related accident conditions exists in all operating accelerators and transport lines at Fermilab, however the consequence of unanticipated loss of the intense NuMI beam warrants an evaluation. The intent of this document is to discuss "high impact" accidents that could result in significant cost to the laboratory (greater than $500k), significant loss of Main Injector operations (greater than 1 week), or significant loss of NuMI operations (greater than 1 month). A set of engineering and administrative controls is proposed to mitigate the accident. A committee charged by the manager of the NuMI Technical Components will review the accident scenarios and proposed controls. The presence of these controls will be verified during the readiness review.

This document does not discuss beam related personnel safety and environmental protection. These issues are addressed in the NuMI Safety Assessment Document and radiation shielding assessment.

NuMI Beam Transport

Scenario #1: Full beam loss in the transport line.

A possible accident scenario is the mis-steering of the beam such that the beam punctures a hole in the vacuum pipe. This was analyzed in NuMI-NOTE-BEAM-817 (1/15/2002). Failure may occur in a single pulse with a grazing angle > ~5 mrad or several pulses of beam with a smaller grazing angle. Such angles are possible by incorrect current settings or a turn-to-turn short in the HV101, V108 or V118 bend strings. The NuMI Beam Permit System (BPS) will detect incorrect dipole magnet current settings and remove the beam permit before beam is extracted to NuMI. A turn-to-turn magnet coil short is not detectable (without voltage inputs to the BPS) however. In the worst-case scenario, the vacuum pipe is punctured in one beam pulse. The BPS will inhibit subsequent beam transport by tripping on high beam loss and inadequate vacuum. A fast acting vacuum valve closes to isolate the NuMI and Main Injector vacuum systems.

Such an accident would require several days of downtime in NuMI operations for repair. This falls below the threshold of "high impact". Furthermore, a spare of each type of magnet is stored in the tunnel to minimize downtime. Access requires shutdown of the Main Injector if the damaged magnet is located upstream of the radiation gate in the carrier tunnel.

<u>Proposed Controls</u>: Beam Permit System limits on HV101, V108 and V118 currents, loss monitors and primary beam pipe vacuum.

Scenario #2: Mis-focused beam on the beam pipe vacuum window in the Target Hall chase.

The window is designed to maintain the beam transport vacuum while minimizing beam scattering. The window will be constructed from beryllium or titanium. In the event beryllium is chosen, a backup titanium window ("beryllium catcher") will be installed upstream of the beryllium window to prevent contamination of large areas of the vacuum system in the event the window ruptures. A possible accident scenario is the inadvertent focusing of the beam on the window.

Such an accident would result in no more than one-week interruption in NuMI operations for repair and is not considered a "high impact" accident.

Proposed Controls: BPS current limits on HQ118 – HQ121.

NuMI Target Hall

Scenario #3: Mis-steered beam on the Horn 1 inner conductor

The beam spot size at horn 1 is 1 mm FWHM. The horn 1 inner conductor may be destroyed in one pulse if the beam was mis-steered and the horn was not properly aligned with the target chase beam baffle and the aperture in the target chase upstream shield wall. The 6 cm diameter beam baffle, located on the target/baffle module, prevents beam from inadvertently hitting the target cooling lines and support structure. The 4.45 cm diameter opening in the shield wall prevents errant beam hitting the horn inner conductor.

Proposed Controls: Configuration control on the target chase baffle. Verify baffle and shield wall hole alignment during commissioning.

Scenario #4: Mis-focused beam on the upstream decay pipe window

The effect of focusing the beam on the 1/16" thick aluminum window was analyzed in Engineering Note MSG-EAR-02317. The maximum temperature was found to be 70^{o}C, and the cyclic stresses are well within the maximum allowable stress for a fatigue lifetime of 30 years of NuMI operation.

Proposed Controls: None required

NuMI Decay Pipe & Absorber Hall

Scenario #5: Mis-steered beam on the vacuum decay pipe wall

There are no aperture restrictions that prevent the beam from hitting the wall of the decay pipe. The probability of occurrence is low since two or more pre-target quadrupole magnets would need to be set to specific values and the beam would need to miss the target and baffle. Furthermore, beam scattering in the target chase air and upstream decay pipe window broadens the beam size to approximately 6 cm. Failure of the decay pipe wall could potentially occur if the accident persisted for several hours. The impact of such an accident is high however since there is no simple means of repairing the decay pipe. The only fallback solution would be to fill the decay pipe with helium gas at atmospheric pressure.

Proposed Controls: Software alarms on rates in the downstream hadron monitor, muon monitors or MINOS near detector.

Scenario #6: Mis-steered beam on the hadron absorber shielding steel.

The absorber core is 54" square but the decay pipe is 2 meters in diameter. Mis-steered beam could miss the absorber core and hit the steel shielding surrounding the core. In the absence of any cooling, a 10-ton shield block will reach 1000^{o}C with approximately 5 hours exposure to un-interacted beam. There is no clear impact from such an unlikely accident however. The residual radiation on the absorber shielding would be high for several months but access to the upstream end of the absorber is considered rare.

Proposed Controls: Software alarms on rates in the downstream hadron monitor, muon monitors or MINOS near detector.

Scenario #7: Hadron absorber RAW system cooling failure.

The absorber core consists of 8 solid aluminum modules. Cooling water circulates through two independent gun-drilled passages in each module. The module would be cooled by conduction into the adjacent modules in the unlikely event that both cooling lines are plugged. The only credible accident scenario is for the undetected failure of the RAW cooling system.

Proposed Controls: BPS limits on RAW water level, pump status, RAW temperature, RAW supply pressure, absorber core temperature.