The Hadron Absorber (part of WBS 1.1.4)

Under ideal targeting conditions primary protons interact in the NuMI target and produce several species of hadrons which decay to produce neutrinos and other particles. The focusing system favors those hadrons having the desired momentum and positive charge. Non-interacting protons and secondary particles are intercepted by a hadron absorber at the end of the decay volume and give up their energy in a multi-generation cascade of interacting particles. The energy that isn't absorbed in the absorber consists mainly of muons and neutrinos that exit the rear of the absorber and enter the rock behind the absorber. A small fraction of the energy will exit the absorber as neutrons--in virtually all directions.

A list of objectives for the Hadron Absorber to satisfy is given below

- Accommodate a primary beam intensity of 4×10^{13} protons every 1.9 seconds in order to match the production capability of the Main Injector.
- Absorb most of the energy of the non-interacted protons and other strongly interacting particles that reach the end of the NuMI decay pipe, and transfer the resultant heat to a water-cooling system.
- Maintain the number of neutrons exiting the absorber at a level that doesn't represent a prompt radiation hazard in uncontrolled access areas near the hadron absorber.
- Limit the amount of residual radiation on the beam north and beam east sides to ~30 mRem/hr 10 hours after the beam is turned off. These two sides are where people can be present for quick access maintenance or for emergency egress using the walkway that wraps around the absorber and goes up the stairs into the decay tunnel.
- Limit the energy loss of muons passing through absorber materials to a level such that the DS muon monitor can function properly[1].
- Maintain the number of particles entering the surrounding rock walls at a level that doesn't activate groundwater to levels of concern.
- Keep the number of airborne radionuclides produced in the Absorber Cavern low enough that the total number of such radionuclides exiting the vent stack located above the middle of the decay pipe is not in excess of the allowed limit.
- Accommodate the full Main Injector proton intensity under short-term accident conditions of missing the primary target. Short term is defined as less than one hour.
- Assure long-term reliability, stability, and reparability. The facility needs to be usable for a minimum of 10 years.
- Minimize the cost and difficulty of decommissioning the equipment and shielding, when the time comes that the NuMI facility is no longer in use and the decision is made to no longer run the sump pumps and the ventilation systems.

[1] This is of particular relevance with the LE option for the neutrino beam.

Absorber Design Parameters, Then and Now

In the time of the November, 1998 TDR the absorber conceptual design[2] consisted of a water-cooled aluminum core 24" wide, 36" tall, and 96" in length. It was followed by a steel core with the same transverse dimensions, with length 9.5'. The core had next to it 7 layers of 9.125" thick CCS steel[3] on the beam east side and underneath, 6 CCS layers on the beam west side, and 8 CCS layers on top. Outside the steel was 3' of concrete block. In the longitudinal direction, there was the 8' of aluminum, 9.5' of steel in the core, followed by two CCS layers of steel, and 3' of concrete.

Since then our design has switched from purchase of CCS steel for the bulk steel, and now uses Duratek blocks[4]; these are steel blocks with dimensions 52" x 52" x 26". Excursions of errant beam striking the core became a concern; with NuMI Change Request #43 we increased the transverse core size from 24" x 36" to 42" x 48"—to match the phase space acceptance of the horn protection baffles projected to the absorber position. In the Fall of 1999 we arranged that the IHEP[5] group do a conceptual engineering design of the absorber materials needing active cooling. The report resulting from this design effort is NuMI report B-652. IHEP increased the transverse core size to 52" x 52" (since that matched the transverse dimensions of the Duratek blocks).

The IHEP study's parameters, then, are a core 52" x 52" in the transverse direction. The core consists of 8 water-cooled aluminum modules, each 12" in length, and one water-cooled steel module[6]. For their study they wrapped this transversely with Duratek blocks 52" thick. Longitudinally, they had the 8' of aluminum and 1' of steel in the core, followed by 6.5' of steel[7] that wasn't actively cooled[8].

The method of servicibility favored by IHEP was extraction of a water-cooled module from the side (together with a 52" x 52" x 12" piece of steel next to it). When their study

[2] See report NuMI B-493, "Absorber Conceptual Design for the 11/98 DOE Baseline Review", 4/30/99.
[3] Continuous Cast Salvage steel.
[4] The cost of these is $1, plus shipping from Oak Ridge, Tenn.
[5] Insitute of High Energy Physics, Protvino, Russia.
[6] Subsequent to the IHEP study we have removed the 12" of water-cooled steel and have replaced it with steel that isn't water cooled. At the time of the IHEP study there existed the possibility that a muon monitor would need to be embedded in the core region behind the 12" of water-cooled steel. That possibility necessitated keeping temperatures from being significantly elevated in the vicinity of the muon monitor. A muon monitor inside the Absorber is no longer planned. The RAW water system metals should consist ideally of nothing else besides aluminum and stainless steel, so we decided to eliminate the steel module with water cooling. The steel in the core region behind the 8 water-cooled aluminum modules is now planned to be 10 layers of 9.1 inch thick Continuous Cast Salvage steel, with suitable holes for the cooling pipes.
[7] Three 26" thicknesses of Duratek blocks.
[8] IHEP paid limited attention to the full set of shielding requirements. Report NuMI B-727 considered the shielding requirements for an absorber with cylindrical symmetry. It has provided the basis of the dimensions we have chosen, since we haven't had time to do a MARS study with a rectangular geometry that matches our latest design. The current design adds 3' of concrete shield block at the downstream (beam north) end.

started they considered extraction from the top, but the removal of the building crane from the Absorber Cavern during the WBS 1.2 tunneling contract negotiations in December, 1999 precluded that possibility. After report NuMI B-652 was issued, considerable effort was devoted to studying various options for modifications to the Absorber Cavern--in order to facilitate side extraction of modules--but it was concluded that such modifications would be too costly[9]. The Absorber design now allows for extraction of the core from the beam north end (i.e. downstream)--if there were a necessity for such extraction. The 11/98 TDR went into no detail regarding how the core could be serviced and repaired, if necessary, but otherwise assumed that the building crane would be used to access the core from above.

The current design, then, has a core with transverse dimensions 51" x 51", with eight water-cooled aluminum modules 12" thick, followed by 10 layers of CCS steel each 9.1 inches thick—all mounted on a 6" thick carrier plate that is supported on rollers. Each aluminum module has two water circuits. The cooling pipes are connected by welded connections and are arranged on either side of the core. They are routed out the beam north end to a manifold. Between each pair of aluminum modules is left 3" of space. This provides space for welding the cooling pipes to the module on the upstream side. In the unlikely event of a water leak in one of the two circuits to a module, that circuit could be shut down—since the remaining circuit would provide sufficient cooling. More unlikely is a failure in the second circuit to a module, after failure in the first circuit. In this case there is sufficient heat transfer to the two adjacent, water-cooled modules that temperature in the aluminum module with no water cooling is not high enough to be structurally destructive.

The outer shielding of the current design is based upon the shielding study described in NuMI report B-727. It also must satisfy the constraints of fitting in the Absorber Cavern (whose dimensions and position are those from the December, 1999 negotiations with SA Healy).

Material Handling

Installation of the steel and concrete shield blocks and other Absorber pieces will make use of the Minos shaft crane. This crane will also be used for Near Detector installation. Installation of the Near Detector steel and scintillator will require 6 months of heavy crane usage for two shifts a day. The installation crew for the Near Detector is planned to be Fermilab technicians. For the Absorber we plan to utilize a fixed-price rigging contract (Davis Bacon). The contract period would be about 1.5 months, if two shift operation is utilized; otherwise, for one shift operation it would be about 3 months in duration.

In the Absorber Cavern the removal of the building crane was accompanied by a lowering of the ceiling height from 32.5' to 20'; the floor elevation stayed the same. To install

[9] Experience with adding cooling water pipes next to the Decay pipe steel convinced us of this.

shielding blocks we now plan to erect a Mini-Jack crane[10] that employs two, 10 ton capacity telescoping hydraulic lifting jacks—at either end of a bridge that is designed to clear the rock ceiling by only two inches at full lift height[11]. The bridge will support a low-headroom hook carrier that engages the lifting pins in the Duratek blocks[12]. Transverse positioning on the bridge will be done with a hydraulic chain drive mounted on the bridge. Longitudinal motion of this crane will accomplished by installing special rails[13] which both support the moving Mini-Jacks and provide a channel for hydraulically driven drive wheels. This substitute crane will be slower in operation than a normal building crane; this difference in speed results in increased expenses for material handling.

The current plan for transporting shield blocks and other Absorber material from the bottom of the Minos crane shaft, up the ~650' long, 10.8% slope ramp to the Absorber Cavern, is to employ a battery-powered forklift. For concrete shield blocks a special fixture will be made, which attaches to the forklift mast and which engages the side hook on a shielding block. With this fixture it will be possible to transport 6 and 7.5 foot tall blocks in the vertical position.

The Decay Pipe (WBS 1.1.4 & WBS 1.2)

The original scope of WBS 1.1.4 included the design, fabrication, and installation of the ends of the Decay Pipe. In addition WBS 1.1.4 includes the writing of the engineering note that describes the shell calculations for the main pipe. However, the actual design of the decay pipe is done by the tunnel contractor, SA Healy (actually, its sub-contractor for the decay pipe--Chicago Bridge & Iron--did the design). CB&I has completed a design; their design has been submitted to Fermilab and has been approved[14]. The FESHM note is in preparation, for both the shell calculations for the main pipe, and for the End Caps.

An addition to scope was made in July, 2001. WBS 1.1.4 will now provide 100% oversight of the QA inspection of the weld joints between decay pipe sections.

The design of the downstream Decay Pipe End Cap has a full-diameter, ellipsoidal window which consists of carbon steel 0.25 inches thick. The End Cap also has a 24" diameter access port and a pump-out port. The access port is only intended for use if a serious leak develops[15] and robotic equipment exists that can repair the leak. The robotic equipment would be introduced through the access port.

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[10] Here is a web address for theMini-Jack crane: http://www.lift-systems.com/2020sc.htm .
[11] The Mini-Jack full range of vertical motion is 10', from 7' to 17' measured from the base.
[12] In this configuration the block could not be lifted from a position where it rested on the floor; it would have to first be staged to a higher elevation by other means.
[13] Both the Mini-Jack crane and the rails are commercially available.
[14] The CB&I design did not account for the extra stress that would be present during the concrete pour. It has been revised to take this stress into account. Another round of review and approval is underway—as of 10/17/01.
[15] An alternative under consideration is to fill the Decay Pipe with helium. The helium would have to be changed periodically—in order to avoid excessive buildup of triton.

The upstream Decay Pipe End Cap will be full-diameter. It will also be carbon steel, but the thickness will be 3/16”. At either end, the End Caps are not being designed to be removable. The design of both End Caps meets the standards of the ASME pressure vessel code.