4.2.8 Target/baffle Carrier Design

4.2.8.1 Carrier Definition

“Module” refers to the heavy shielding module that supports beam components below it, and has positioning motors mounted on top of it. The target/baffle carrier is a frame mounted on shafts through the target/baffle module. The module provides motion control of the target transverse to the beam by moving the shafts vertically and horizontally. The carrier supplies precision motion control of the target along the beam. When maintenance is required that cannot be done in situ, the entire module with carrier and components still mounted on it is moved to the work cell. The module, carrier, target and baffle are shown **in Figure 4.2-19** and **Figure 4.2-20**.

Please refer to the engineering drawing set for up-to-date definitive dimensions and layout. The integration drawing for the modules, carrier, and horn 1 is **8874.000-ME-363028**. The final carrier drawings have not been made yet.

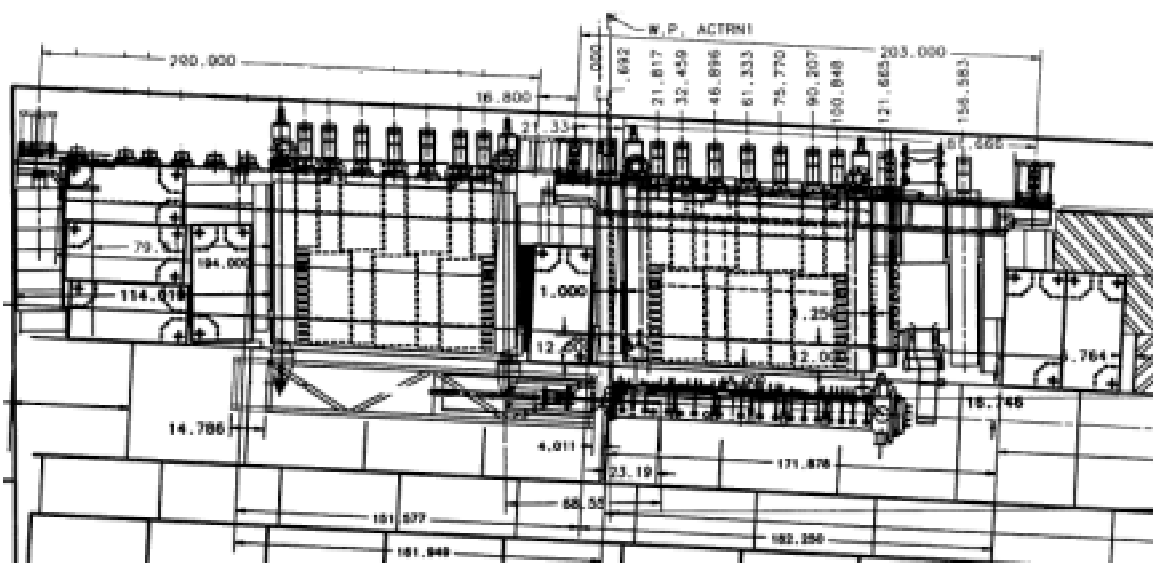

Figure 4.2-19 Modules in target hall shielding. Target/baffle carrier mounted below target/baffle module, with target and baffle extended into the low energy position. Also visible are carriage cross beams, steel shielding, horn 1 mounted below horn 1 module.

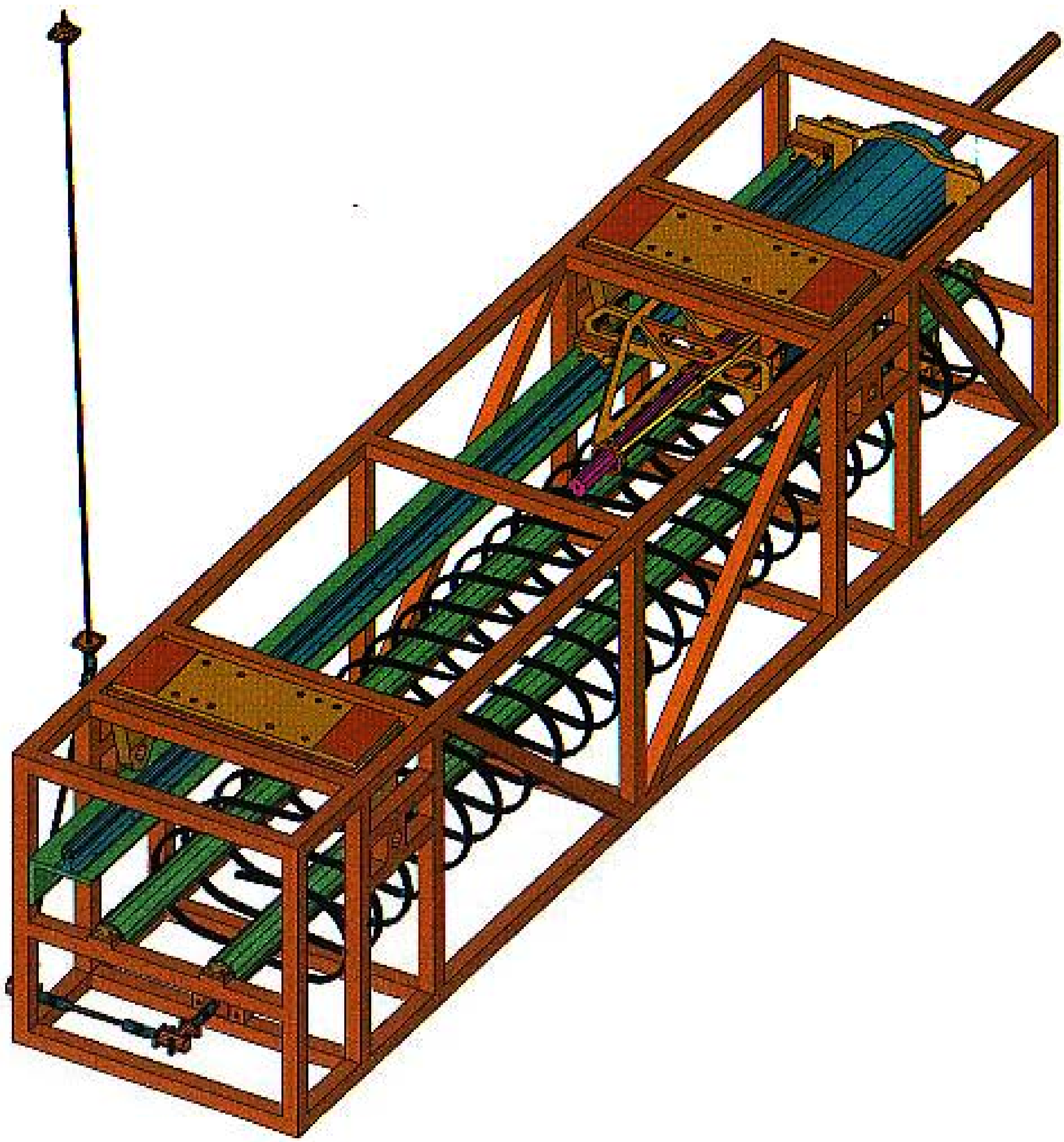

Figure 4.2-20 Target/baffle carrier with target and baffle mounted. Target shown extended into the low energy neutrino beam position

4.2.8.2 Target/Baffle Carrier Functions and Requirements

Target/Baffle Carrier must:

- Remotely drive target into horn along beam axis after module is set in place: target casing extends 66.2 cm into horn, target carrier frame has 7.1 cm clearance to horn, thus minimum of 73.3 cm forward travel.

- Provide target motion capability to 250 cm retracted from the standard low energy running position, to enable changing the energy tune of the neutrino beam.

- Set position of target and baffle to 0.5 mm transversely, and 1 mm longitudinally along beam line.

- Maintain position of target and baffle to 0.5 mm transversely and 1 mm longitudinally under beam heating from $4x10^{13}$ protons / 1.87 sec striking target; this includes other beam energy tunes in addition to the standard low energy beam position.

- Provide the motion capability of the target and baffle utilities: target water supply line, target water return line, target vacuum line, two Budal target monitor electrical lines, 8 thermocouple electrical lines.

- Maintain 1 inch clearance to target hall chase walls, in addition to the allowance for +/- 8 mm horizontal and +8 mm / -7.5 inch vertical motion of support shafts.

- Provide a 2 cm radius "stay-clear" through the support structure that allows beam scans of downstream components when the target/baffle carrier is remotely lowered off beam axis (by ~ 7.5 inch).

- Survive radiation dose of up to 10^{11} rad/year for up to 10 years (except for the drive shaft end which is above the module).

- Be short enough that it can be extracted through the target module carriage (199 inches) and inserted in the work cell (216 inches) with the target frozen in the extended position, or frozen with the baffle sticking out the back end in the target fully retracted position.

In addition, carrier will provide:

- Four tooling balls for survey, located at beamline elevation, one on each side of the beamline at each module endwall, visible through holes in the endwall.

- A pair of limit switches at each end of the travel of the target/baffle.

- Rotary encoder on drive shaft at the top of the module to give remote readback of location of target along beamline.

- Include baffling to direct part of the chase air stream to the target that is otherwise blocked by the target base and support tube. Airflow must also be maintained over the length of the baffle and the target.

- Rust prevention coating of drive shaft and any other (non-stainless) steel parts.

Note secondary containment of radioactive water leaks is built into the target pile design, and is not a carrier design consideration.

4.2.8.3 Target Motion Capability

Low Energy Target Insertion

For the Low Energy Beam, the target will extend 66 cm into the horn with only 3 mm transverse clearance at the tip. The choice was made not to mount the target on the horn itself for fear of vibration damage to the target from horn pulsing. The target module will be set in place with the target in a retracted position. After the target module is surveyed into position, and the axis of the carrier aligned with the beamline (and horn) axis using the module motor drives, the target will be extended along the beam line into the horn using the carrier motor drive.

Other Neutrino Energy Tunes

In NuMI-NOTE-BEAM-0783 [ref. i], the case was made that by extending the range of motion of the low energy target upstream one obtains the capability to quickly and easily change the energy of the neutrino beam. Such alternate energy tunes are labeled "semi-medium" and "semi-high" energy beams, and produce decent rates and spectra, although not quite the performance that can be obtained with optimized targets and horn 2 positions for the alternate tunes.

When moving the target, one is taking the chance that it could become stuck in some location. The target is in a high-radiation environment (e.g. humidity can turn to nitric acid), and repairs to the carrier mechanisms after being irradiated is mostly limited to replacement. Proper choice of materials can help mitigate this. However, this is a risk explicitly taken, and reinforces the need to have a complete spare target/baffle/carrier unit at beam-turn-on.

Extended target motion by relocating target module

The target carrier allows for 2.5 m of target motion without moving the target module. The target can be moved even further upstream by moving the target module, although this is not a trivial exercise. The current baseline design allows space for one to move the target module 2 m upstream by unstacking some shielding, using the crane to move the 20 ton module, restacking shielding, and then doing a survey to check the final position. This would result in a total target range of 4.5 meters, but the last 0.5 m or so may be precluded by interference between the baffle and target hall upstream wall and beam pipe. (The standard high energy target position was 3.65 m upstream of the low energy position, and is reachable in this scheme.) The target/baffle carriage cross beams which limit the upstream movement of the module can be seen in **Figure 4.2-19**. Three pieces of steel shielding required for this new position are not in the baseline project, and would have to be acquired before the move.

Restriction of motion by carriage, workcell

Carrier frame	**Fixed frame**	**160 in.**
Moving components	**Total moving components**	**315.97 cm = 124.40 in.**
	Baffle length	150 cm
	Baffle to vertical Target fin	68 cm
	Target fin length	95.38 cm
	Target casing beyond fin	2.59 cm
Length normal extraction	**Components inside frame**	**160 in.**
Total length L.E. position	**Frame with target extended**	**188.86 in.**
	Target extension	28.86 in.
	Frame length	160 in
Total length fully retracted	**2.5 m upstream of L.E.**	**193.97 in**
	Baffle extension	33.97 in.
	Frame length	160 in

Table 4.2-10 Length of target/baffle/carrier unit in various configurations.

The opening in the target carriage shielding is 199.389 inches. The work cell is 216 inches long. These two openings set the maximum length of the target/baffle carrier and range of motion. The module with target/baffle possibly frozen in the fully extended or fully retracted position must be able to navigate through these openings, with operators controlling the crane by camera and remote control due to the high residual radiation.

In the target extended downstream position, the length of carrier plus target is 189 inches. With 250 cm of motion capability, with the baffle extended out the upstream end, the baffle plus carrier is 194 inches long. See also Figure 4.2-21.

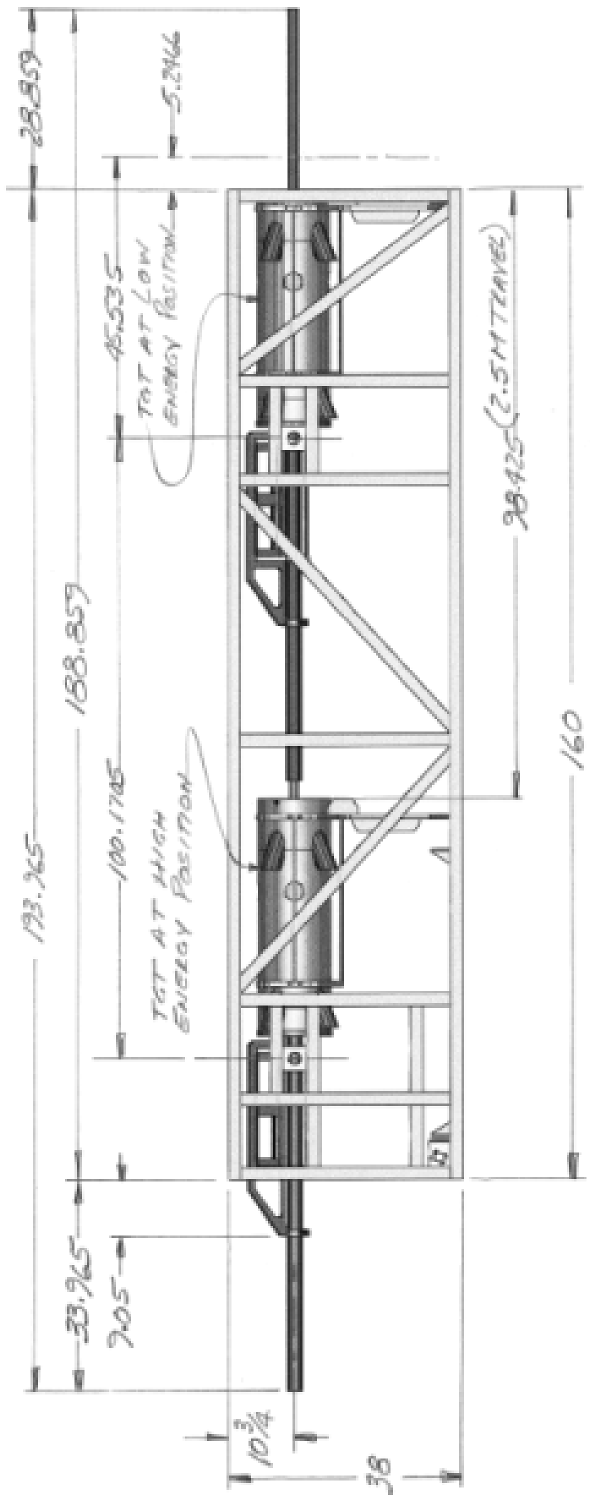

Figure 4.2-21 (Rotated) target carrier side view. Target and baffle are shown in both Low Energy Beam extended position, and in fully retracted highest energy beam position.

4.2.8.4 Target/baffle carrier hardware design

<u>Carrier mechanical design</u>

The target and baffle frames have rollers that ride on aluminum rails, as shown **in Figure 4.2-22**. The rails are at beam height, and are supported by an aluminum tube space frame. Two hangers (sometimes miscalled clamps) connect the space frame to the shafts (not shown in the figure), which come through the module. The mass of the various components is summarized in **Table 4.2-11**.

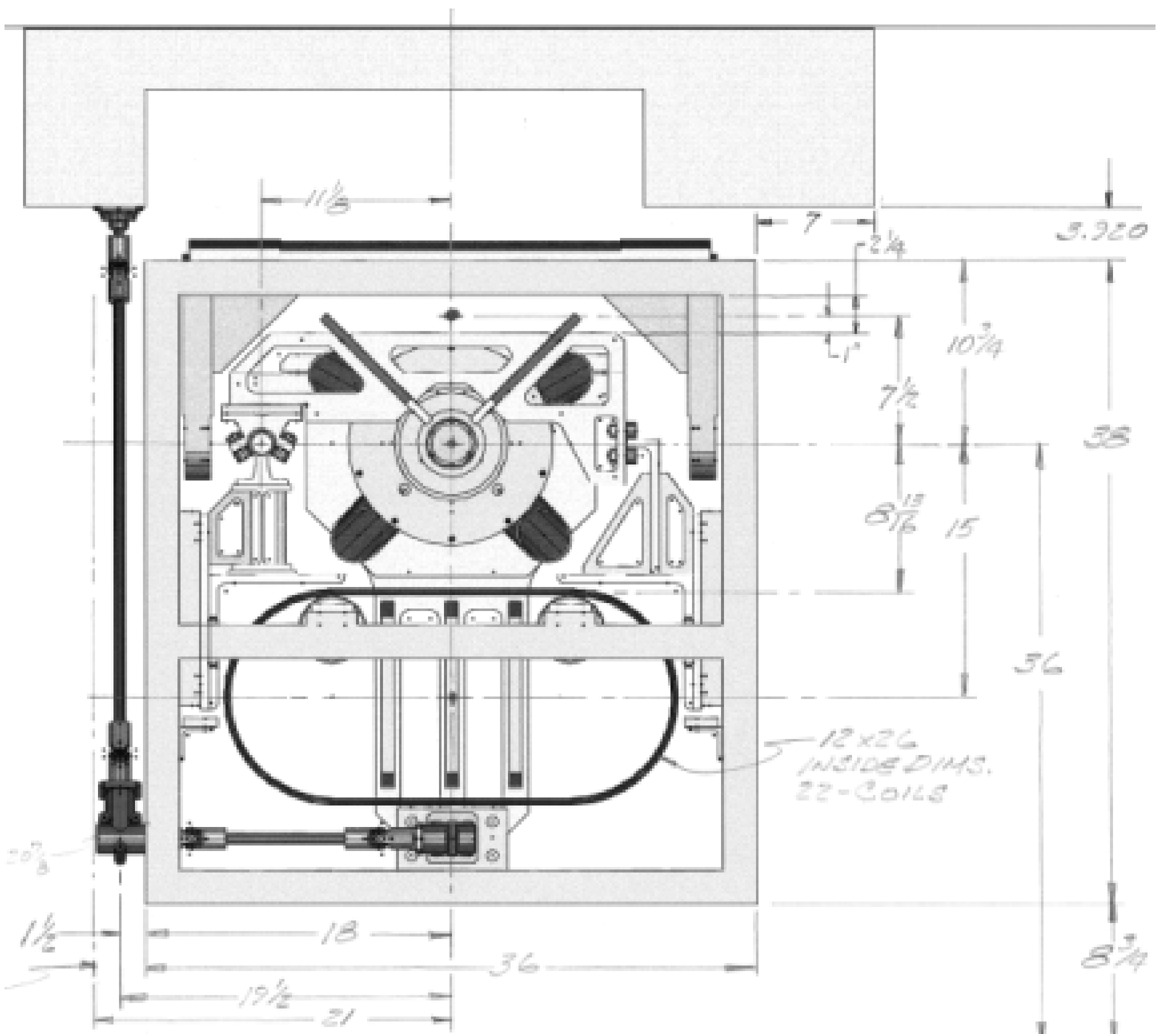

Figure 1.2-22 Target carrier end view.

Components			215 lb
	Target Assy.	150 lb	
	Baffle Assy.	65 lb	
Coils			47 lb
	One steel loop	0.581 lb	
	Water in loop	0.194 lb	
	3x22 steel loops	38.3 lb	
	2x22 water loops	8.5 lb	
Carriage Assy.			598 lb
	Frame Assy.	231 lb	
	Target baffle left support	120 lb	
	Target baffle right support	110 lb	
	Shaft support	44 lb	
	Coil support	23 lb	
	Drive system	70 lb	
Drive shaft loads			82 lb
	Components on 0.058 slope	12 lb	
	Rolling friction (0.05 coef.)	11 lb	
	Coil contraction, max.	30 lb	
	Friction coil on supports (0.61 coef.)	29 lb	

Table 4.2-11 Approximate mass of carrier components, and loads.

The aluminum rails are coated with tungsten-disulfide to provide a tough surface for the rollers to ride on.

The rollers are commercially available cam-followers, black oxide coated steel in an aluminum housing. (These may be replaced with stainless steel if we can locate a vendor). They will be run dry, i.e. without grease. It is expected that the target location will only be changed a few hundred times, so the number of cycles is relatively small.

The drive shaft is 1-inch diameter 17-4 PH heat-treated stainless steel.

Carrier thermal considerations

When running in the ME or HE locations, some of the target support shafts and rails will be downstream of the target, and thus receive substantial energy deposition from the secondary beam. MARS was used to calculate the energy depositions [ref. ii, see Figure 5 for summary of study]. In order to maintain thermal position stability, several measures are taken.

Water cooling is supplied to the downstream module-to-carrier hanger (sometimes known as the clamp, in analogy to its use for horn 1), and the lower part of the support shaft is made of low-expansion steel. The water-cooled clamp design is copied from the horn 1 module design [ref. iii]. The bearing between this clamp and the carrier is on beam-centerline vertically. The clamp water cooling is not required for low energy beam running. Thus its water loop is separate on the module from the target water loop, so that failure in this system would not require replacing the target for low energy running.

The carrier frame and rails are made of minimal volume to surface ratio aluminum and are kept at larger radius to the beam centerline. For initial design studies, a frame constructed of ¼ inch thick wall ¾ inch square aluminum tubing was assumed. The beam-heating of the tubing plateaus about 1 m downstream of the start of the target (**Figure 4.2-23**). At a radius of 25 cm from the beam, the energy deposition in the aluminum is around 0.032 watts/gram. Assuming a heat transfer coefficient of 10 w/m^2K to the 18 deg C air flowing in the chase, the asymptotic temperature calculated was 55 deg C, which is acceptable for the frame. The final design uses thinner 1/8 inch wall 2 inch square tubing, and thus should experience less than half the temperature rise. The beam heating upstream of the target is negligible.

The drive shaft is placed at a radius of 40 cm from the beam-centerline. At that radius and downstream of the target, it is estimated that its temperature will be between 100degC and 150degC. The part that sets the target location is upstream of the target, and will remain cool. The downstream end of the shaft can be constrained transversely, but allowance must be made for a 2 mm longitudinal expansion of the downstream part when running higher energy tunes.

Energy deposition in target support structure

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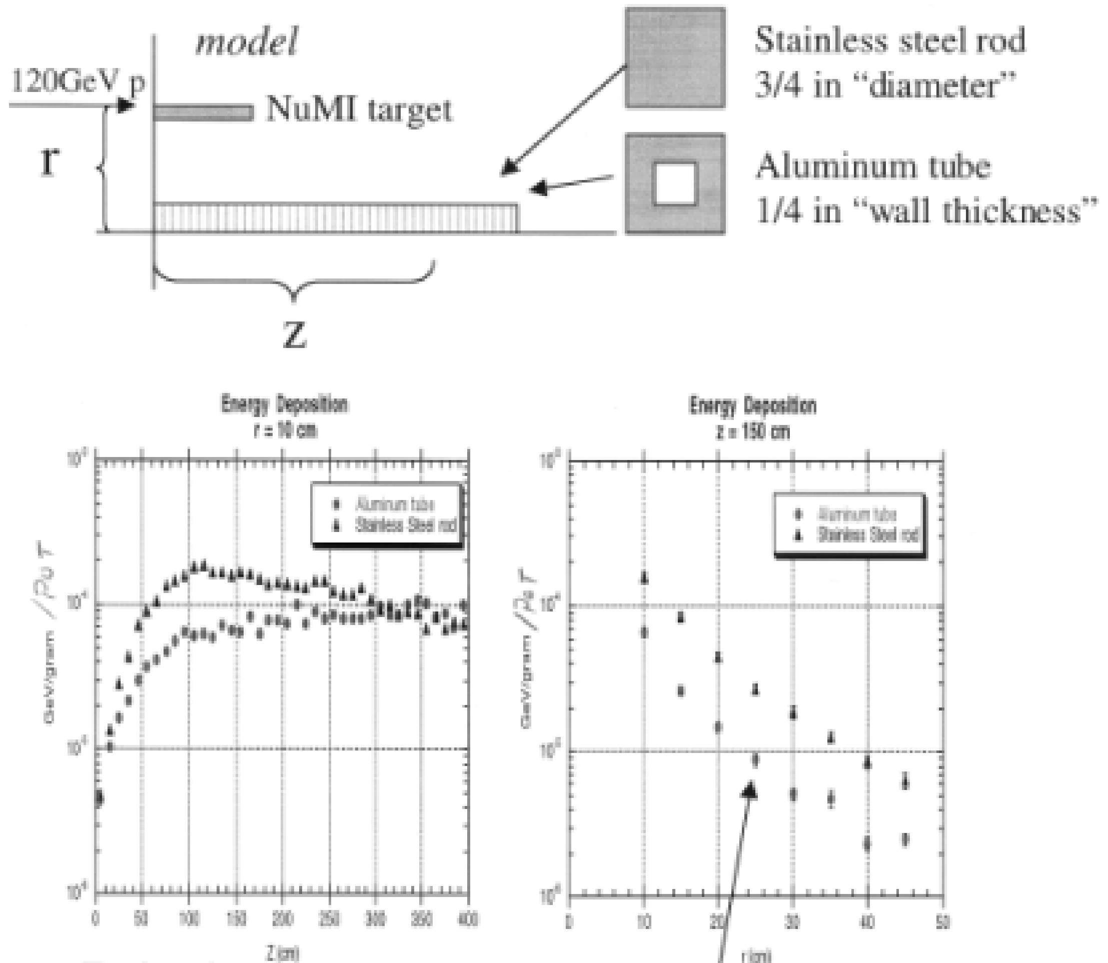
B. Lundberg
March 2002



Each point represents a "zone" of 10 cm in length.

Material	ρ (g/cm³)	Vol (cm³)	Watts/cm at z=150 cm; r=25 cm	Watts/cm³	Watts/gram
Aluminum	2.7	3.23	0.28	0.087	0.032
Stainless Steel	8.02	3.63	2.8	0.77	0.096

(for 4e13 ppp)
1.87 sec rep. rate

Figure 4.2-23 Summary from study of beam energy deposition in carrier using MARS.

Carrier Frame Stiffness

Analysis of carrier support frame distortion has been carried out for three positions of the target; fully extended, fully retracted, and halfway in between. The vertical mis-alignment of points on the target and baffle due to changes in the loading of the carrier frame was at most about 0.2 mm.

During the assembly of the target on the carrier frame, the target will be aligned such that the upstream and downstream ends of the target fin are vertically on axis; because of the sag of the target tube due to gravity, the middle of the target will be a fraction of a mm above the beam axis.

The sag of the drive shaft is 5/16 inch when the target is in the fully extended position.

Flexible utility lines

The 2.5 m travel of the target is accommodated by compressing a coil of 22 loops of pipe, 3/8" O.D. 0.028" wall stainless, total length 38 m per line. Three lines are used: water supply, water return, vacuum. In the LE position, the coil is unloaded. Fully retracted by the 2.5 m, the coil force is of order 30 lbs. The drive shaft is kept under tension, eliminating worry about buckling. (Putting the drive shaft in compression might have forced use of a larger diameter shaft, exacerbating cooling problems due to the larger volume to surface ratio). The maximum stress on the water line is calculated to be 18 ksi, which is below the yield stress with shear factor of 35 ksi x 0.577 = 20 ksi.

Radiation hard thermocouple cable is produced commercially, consisting of a stainless steel sheath encapsulating a pair of wires in magnesium oxide insulation. We will use this cable for all electrical routing on the carrier. The flex necessary for the target motion will be obtained in similar fashion to that for the utility lines, i.e. a coil that expands or contracts, resting on an immobile support shaft. The voltage standoff required is reasonably modest. The target tube may see a voltage of order 50 Volts from the horn, since it follows the horn voltage closely due to beam ionization of the air between the horn and target tube. The Budal monitor may be run with a bias voltage of up to 75 volts, although a smaller bias (down to zero) can be used if necessary.

Target Module Endwall Penetrations

The Horn 1 module upstream endwall has six penetrations for utilities, as shown in **Figure 4.2-24**. Target module upstream and downstream endwalls will copy this, with the assignments for usage shown in **Table 4.2-12**.

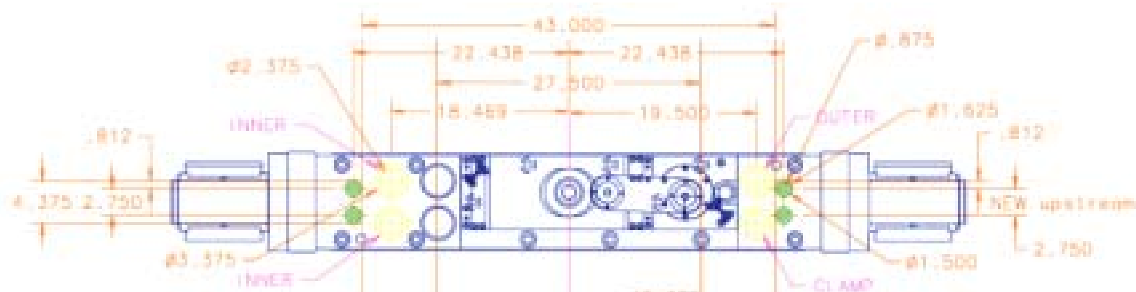


Figure 4.2-24 Top view of Horn 1 module upstream endwall, which will be copied for the target module. Utility penetrations include those labeled clamp, outer, inner, and the two large holes to the right of those labeled inner.

Upstream endwall	
1	Upstream Left Survey Port
2	Upstream Right Survey Port
3	Drive Shaft for 2.5 m motion
4	Target water supply
5	Target water return
6	Target vacuum/helium line
Downstream endwall	
1	Downstream Left Survey Port
2	Downstream Right Survey Port
3	Clamp water supply
4	Clamp water return
5	Electrical feed through #1
6	Electrical feed through #2

Table 4.2-12 Allocation of target-module endwall utility penetrations.

Each electrical feed through contains five two-pin plugs. Connections are as show **in Table 4.2-13**, where the third baffle thermocouple could be re-allocated if some other electrical connection is required.

Plug	Pin 1	Pin 2
1	Target Budal horizontal fin	Shield for horizontal fin signal
2	Target Budal vertical fin	Shield for vertical fin signal
3	Carrier thermocouple 1	Carrier thermocouple 1
4	Carrier thermocouple 2	Carrier thermocouple 2
5	Baffle thermocouple 1	Baffle thermocouple 1
6	Baffle thermocouple 2	Baffle thermocouple 2
7	Baffle thermocouple 3 (or spare)	Baffle thermocouple 3 (or spare)
8	Wire from target vacuum jacket	Ground for limit switches
9	U.S. limit switch 1	U.S. limit switch 2
10	D.S. limit switch 1	D.S. limit switch 2

Table 1.2-13 Target carrier electrical pin allocation.

References

[i] Proposal for Continuously-Variable Beam Energy, M. Kostin, S. Kopp, M. Messier, D. Harris, J. Hylen, A. Para, NuMI-NOTE-BEAM-0783, 10/17/01.

[ii] Energy deposition in target support structure, R. Rameika, B. Lundberg, 3/02.

[iii] Thermal Analysis of Clamp Using MARS Analysis Heat Generations, Bob Wands, 9/12/01.