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LBNF 1.2 MW TARGET: CONCEPTUAL DESIGN & FABRICATION*

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Abstract

Fermilab's Long-Baseline Neutrino Facility (LBNF) will utilize a modified design based on the NuMI low energy target that is reconfigured to accommodate beam operation at 1.2 MW. Achieving this power with a graphite target material and ancillary systems originally rated for 400 kW requires several design changes and R&D efforts related to material bonding and electrical isolation. Target cooling, structural design, and fabrication techniques must address higher stresses and heat loads that will be present during 1.2 MW operation, as the assembly will be subject to cyclic loads and thermal expansion. Mitigations must be balanced against compromises in neutrino yield. Beam monitoring and subsystem instrumentation will be updated and added to ensure confidence in target positioning and monitoring. Remote connection to the target hall support structure must provide for the eventual upgrade to a 2.4 MW target design, without producing excessive radioactive waste or unreasonable exposure to technicians during reconfiguration. Current designs and assembly layouts will be presented, in addition to current findings on processes and possibilities for prototype and final assembly fabrication.

CONCEPTUAL DESIGN

The 1.2 MW fin width has increased from 6.4 mm to 10 mm, with a roughly 5.5 mm expansion in height to accommodate accident conditions and prevent errant beam with a 1.7mm spot size from striking a cooling line. To mitigate the increased heat generation, cooling loop count was doubled. The outer containment tube also increased in size, gaining a 20% larger O.D., (see Fig. 1).

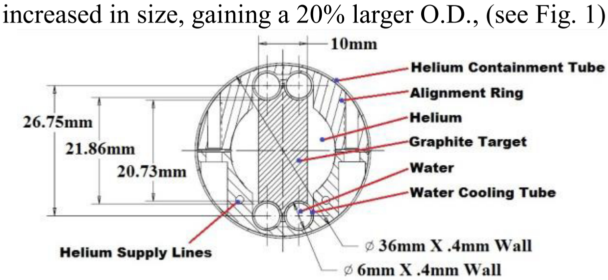

Figure 1: Target core cross section.

Since the design is rooted in a target used on a similar experiment, and with identical focusing horns, some design boundaries apply:

1. Target must be capable of being inserted into horn 1 inner conductor for a low-energy neutrino spectrum.
2. Mass should be kept to a minimum to reduce effects of beam energy deposition on horn conductors.

Target Braze Assembly

The braze assembly consists of twin continuous cooling loops, and forty-seven 20 mm long graphite fins, the first three of which are flared. TiCuNi braze foil at the interface, measuring .05 mm (.002") thick, bonds the assembly by use of specialized fixturing in a vacuum brazing furnace.

Containment Tube

Requirements of the containment tube are that it provide alignment stability, as well as enable the target to withstand a +/-1 atm pressure differential. The target must be pumped down to vacuum for initial installation, then backfilled with helium. This helium flow is piped to the D.S. window for cooling and back out from the target can.

Transition to Down Stream Window

The down stream (D.S.) window will be fabricated from .5 mm (.020") thick beryllium foil, then diffusion bonded to a 3000 series aluminum frame. Transitioning from 3000 series aluminium to grade 2 (CP) titanium requires the use of an explosion bonded or roll bonded Ti-Al bimetal ring. This ring can be fused to the mating halves by means of E-beam welding or micro-TIG welding to achieve a leak tight interface.

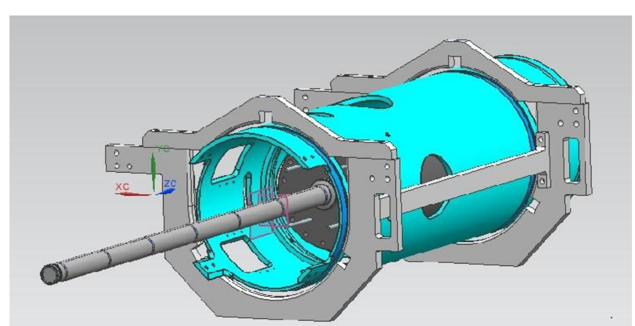

Figure 2: Target core assembly in alignment tube & support frame.

GENERAL LAYOUT & MATERIALS

A notable difference from the NuMI 400 kW design is the absence of a Budal monitor. It was made redundant by vertical & horizontal beam position thermometers located on the U.S. end of the target can. Also present in the 1.2 MW design are additional cooling passages: An outer can water jacket, and a U.S. window and beam position thermometer cooling loop, (see Figs. 2, 3 & Table 1).

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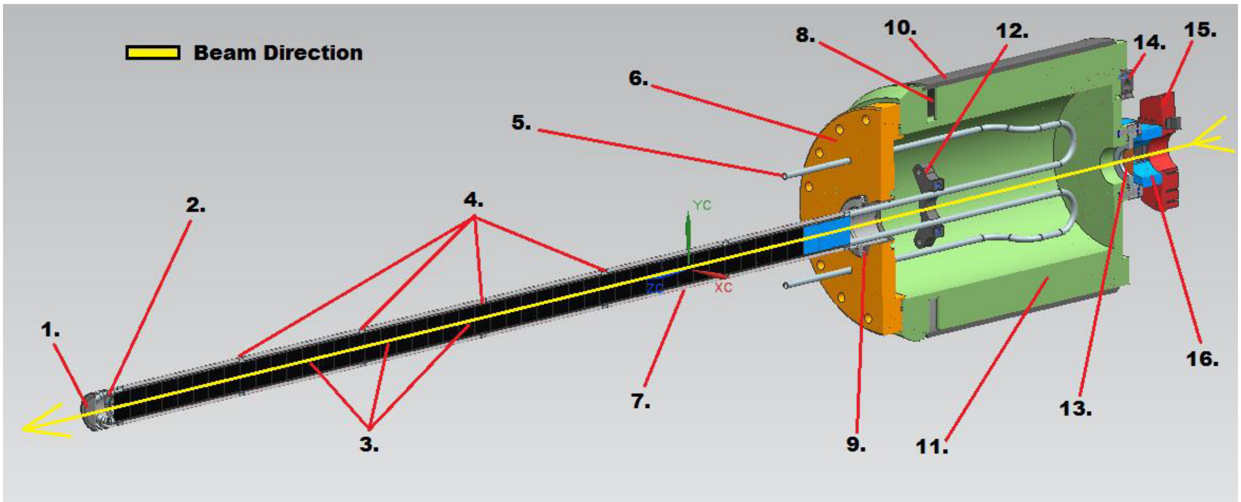

Figure 3: Half symmetry conceptual target core & can layout.

Table 1: Component & Material Listing

Item	Component	Material
1.	D.S. Window Assembly	PF-60 Be / 3000 Al
2.	Transition Ring	CP Ti / 3000 Al
3.	Graphite Fins	POCO ZXF-5Q
4.	Locating Clamps	6061-T6 Al
5.	Cooling Loop (1 Side)	CP Ti
6.	Mounting Flange	6061-T6 Al
7.	Containment Tube	CP Ti
8.	Outer Cooling Channel	6061-T6 Al
9.	NW40 Flange	CP Ti / 6061-T6 Al
10.	Outer Cooling Jacket	6061-T6 Al
11.	Target Can	6061-T6 Al
12.	Cooling Loop Clamp	6061-T6 Al
13.	U.S. Window Assembly	PF-60 Be / 316 SS
14.	U.S. Cooling Ring	6061-T6 Al
15.	Vert. Beam Thermometer	6061-T6 Al / S-200F Be
16.	Horiz. Beam Thermometer	6061-T6 Al / S-200F Be

D.S WINDOW AND TRANSITION RING COOLING

Energy deposition from 1.2 MW beam at the D.S. end of the target containment tube and window assembly created unacceptably high steady state temperatures in early analysis efforts. To mitigate this, shims were added between the cooling lines and the outer containment tube, in addition to extending D.S. towards the transition ring and beryllium window frame; (see Fig. 4).

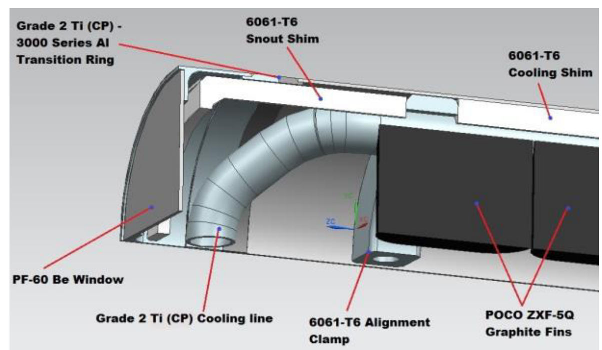

Figure 4: Quarter symmetry snout design.

Cooling Shim Spacing

Heat transfer at cooling shim locations strongly depends on contact status or gap size between components. Cooling shim placement between the cooling lines and outer containment tube is a tight slip fit, so good thermal contact can be expected at that location. The snout shim which extends towards the D.S. window and transition ring however, will have a slight gap between adjacent surfaces.

Although direct contact is not possible at these joints, known spacing can be used to determine the thermal conductance through the helium gap. ANSYS modelling input for thermal conductance is $W/m^2 \cdot °C$, which can be obtained by simply dividing the thermal conductivity of helium at a specific operating temperature by the gap length between components.

DESIGN ANALYSIS

1.2 MW target operation presents unique operational challenges. This is due in part to increased beam energy deposition in the fins & support material, as well as space and cooling limitations carried over from the NuMI style target geometry. Continued refinement requires well understood temperature and stress profiles.

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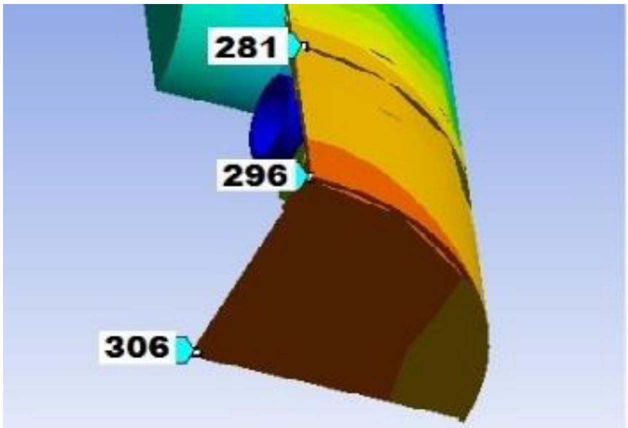

Figure 5: Target tube & window temp, deg. C.

Steady State Temperatures

The maximum steady state temperature occurs on the titanium containment tube just prior to the cooling shim. This is acceptable, as 6Al-4V titanium should be kept under 400°C. High temperatures remain at the transition junction and braze region, (see Fig. 5), which will likely cause premature failure unless lowered. Further extension of the D.S. window cooling shim will increase the thermal conductivity, which is expected to resolve this issue.

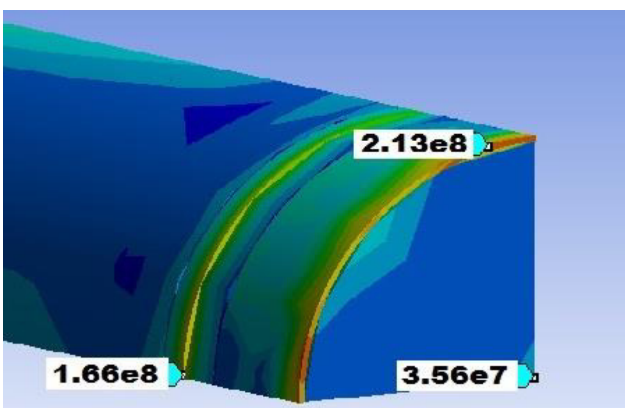

Figure 6: Target tube & window stress, Pa.

Steady State Stresses

Operational stresses are generally quite low, however unacceptably high stresses occur at the junctions between dissimilar metals, (see Fig 6). This is caused by the difference in thermal expansion coefficients, exacerbated by high temperatures from the steady state analysis.

Table 2: Summary of Analysis Results

Component	Max. Temp.	Max. Stress
Ti Tube	337°C	87.5 MPa
Be Window	306°C	35.6 MPa
Ti-Al Trans.	281°C	166 MPa
Be-Al Trans.	295°C	213 MPa

FABRICATION PROCESSES

Brazing of Target Fin to Titanium Cooling Loop

Bonding of the POCO Graphite ZXF-5Q target fins to the Grade 2 titanium tube will be accomplished by use of TiCuNi active braze foil. This method was successfully prototyped during investigations into an emergency spare target for use in the NuMI experiment. Brazing is completed at 1000°C, with a final service limit at 800°C.

Core & Can Assembly

Assembly of the brazed core to the main target can commences with mounting of the titanium support tube to the main flange. This junction will be completed through the use of nested NW-40 (KF40) vacuum flanges, with an aluminium knife edge seal/ chain clamp configuration to provide leak tight service, (see Fig. 7)

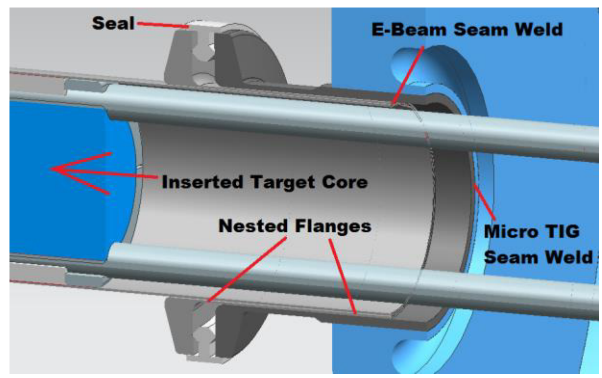

Figure 7: Core & can assembly cross-section.

CONCLUSION

There are few technical or fabrication challenges for the conceptual design, most of which should be well understood after additional prototyping. Techniques for joining the titanium containment tube to a D.S. beryllium window exist, but are dependent on lowering the operating temperature of the aluminium window frame and Ti – Al transition material for continued operation. These efforts are ongoing, and if successful, will yield a target assembly capable of being completed on-site, with minimal processing required from specialized, but well-known vendors with an existing procurement history.

Based on the current analysis results summarized in Table 2, and the proposed design improvements, it appears likely that the current 1.2 MW target can be further refined to provide an acceptable service life.

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