# MERCURY HANDLING FOR THE TARGET SYSTEM FOR A MUON COLLIDER*

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*Abstract*

The baseline target concept for a Muon Collider or Neutrino Factory is a free-stream mercury jet within a 20-T magnetic field being impacted by an 8-GeV proton beam. A pool of mercury serves as a receiving reservoir for the mercury and a dump for the unexpended proton beam. Design issues discussed in this paper include the nozzle, splash mitigation in the mercury pool, the mercury containment vessel, and the mercury recirculation system.

## INTRODUCTION

The baseline target concept for a Muon Collider or a Neutrino Factory is a free jet of mercury impacted by a 4-MW, 8-GeV proton beam within a 20-T magnetic field [1]. The magnetic field is produced by a coaxial array of cryogenically cooled superconducting (SC) coils and water-cooled resistive magnets. During operation, the Target Module resides within a shielding module that protects the SC coils from the impinging radiation. The arrangement of these modules inside a cryostat is shown in Fig.1.

Recent work suggests that a 15-T field may provide adequate pion capture [2], which permits replacement of the resistive magnets by additional tungsten shielding. The Target-Module concept discussed in this paper assumes a 15-T field.

## TARGET MODULE DESCRIPTION AND REQUIREMENTS

Particle production studies [3] have indicated that maximum production occurs when both the mercury jet and the proton beam are at small downward angles to the magnetic axis during their interaction. The current baseline angle is 137 mrad for both the jet and the beam; the jet and the magnetic axis are in the same vertical plane, but the proton beam enters the target region from the side. The baseline jet has a diameter of 0.8 cm and a velocity of 20 m/s.

The primary function of the Target Module is to place the jet nozzle in the correct spatial location such that the center of the jet/beam interaction region is in the location of the highest magnetic field. A secondary function is to provide SC coil shielding in addition to that provided in the outer shielding module.

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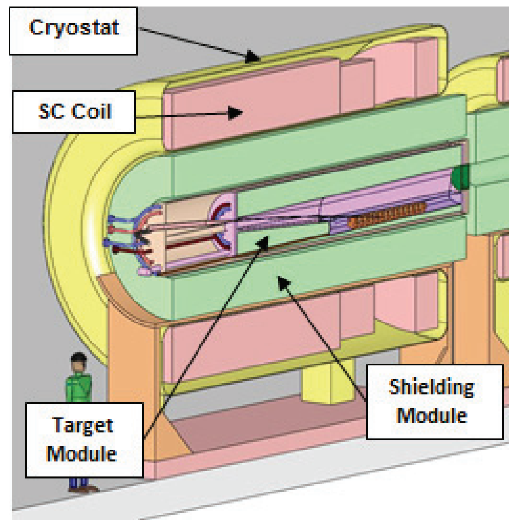


Figure 1: Target cryostat, coils, shielding and Module.

There are several Target Module design requirements and operational features that will allow the module to perform its intended function. These include:

- Providing accurate and repeatable placement within the Shielding Module in a remote environment.
- Providing double containment of the mercury.
- Providing a mercury pool that serves as a dump for both the jet and the proton beam remaining after target impact.
- Minimizing mercury splashes and waves within the pool.
- Providing provisions for adequate mercury draining and venting of the gas volume above the pool.
- Incorporating a means of cooling the chamber and its internal shielding.
- Providing upstream and downstream beam windows, with the upstream window being a remotely replaceable maintenance item.

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- Designing with no elastomeric seals that would limit its lifetime.
- Providing long lifetime through the elimination of radiation-sensitive electronics or sensors.

## TARGET MODULE DESIGN ISSUES

There are several aspects of the Target Module design that are mechanically challenging, some of which are described in this section. Figure 2 shows a vertical cross section through the Target Module which highlights many of the design features.

### *Jet and Beam Entry*

To contain mercury vapors within the Target Module, an inner, primary containment vessel was designed. The jet and proton beam enter this volume through pipes upstream of the interaction region. There is very little clearance between the jet nozzle and the beam entry pipe, as shown in Fig. 3. Also, multiple beams are under consideration to supply the total 4 MW of beam power, so the issue of nozzle/beam-pipe clearance could become more complex in the future.

### *Mercury Containment*

The mercury jet is produced using a closed-loop process, with a pump, heat exchanger, and storage tank being the major external components, shown in Fig. 4, along with the piping, nozzle, and mercury pool vessel within the Target Module. The external components will be located in a hot cell adjacent to the beam line with its own remote maintenance capabilities. Mercury leaks within this area will be more easily contained, but provisions for double containment of the mercury will be required within the supply and return piping and mercury pool vessel. This double-wall requirement introduces an interstitial space that can either be filled with tungsten shielding or be left empty, but in either case the space must provide a mechanism for cooling the inner wall.

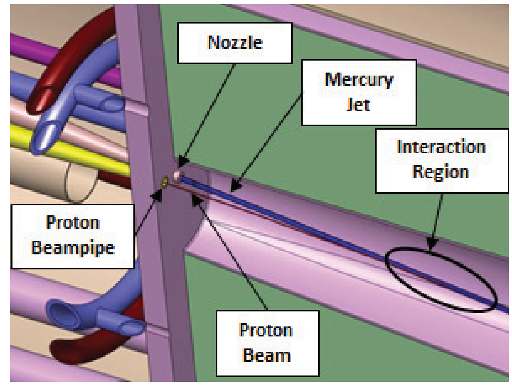


Figure 3: Interior of the Target Module showing the mercury nozzle and beam-entry pipe.

### *Mercury Splash Mitigation*

The mercury dump is a liquid pool at the downstream end of the inner containment vessel. It serves as a dump for both the mercury jet and the remaining portion of the proton beam. To serve as a beam dump, the mercury must have sufficient depth for four interaction lengths (120 cm) along the proton-beam trajectory, as defined by the height of the overflow drains shown in Fig. 2. In practice this may be difficult to achieve in that the beam and jet will both impact the pool and may create "holes" in the fluid that reduce the effective beam-stopping distance. Mechanical features within the chamber will be required to minimize splashing and waves that might impact the downstream beam window as well as reduce the effective pion yield. As this mercury pool will be heated by the decay radiation, it is critical that no stagnation zones develop within the pool and that the mercury drains properly. Due to the high ra-

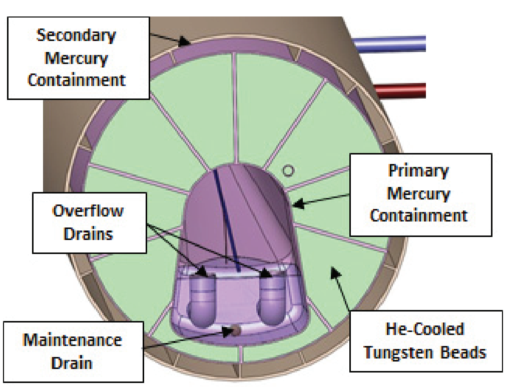


Figure 2: Vertical cross section through the Target Module at the mercury pool.

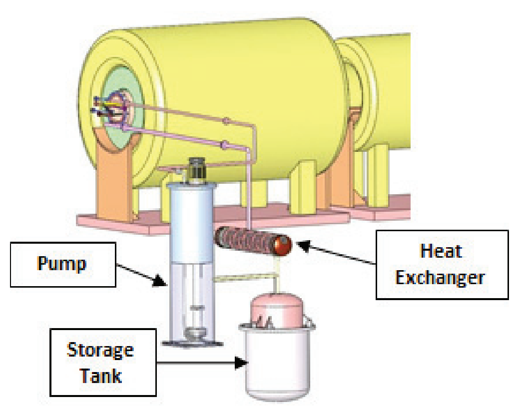


Figure 4: The external components of the mercury-flow loop.

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diation in this area and the difficulty in providing remote maintenance, no powered means of pool circulation is anticipated, so the chamber concept and drain configuration must be tested and verified prior to final design.

### *Drainage*

Drainage of mercury from the Target Module is a major design consideration. To allow the module to be removed as a single component, the mercury is drained from the upstream end of the module. Two separate drains are incorporated into the module: overflow drains are used during operation to guarantee an adequate pool depth, and a maintenance drain (also shown in Fig. 2) tangent to the floor of the sloped chamber floor allows complete draining during shutdown. The maintenance-drain piping must incorporate a flow-control valve to allow a small flow through the maintenance drain during beam operation to eliminate potential boiling in static mercury.

### *Utility Services*

In the baseline concept of the Target Module, it incorporates both mercury containment features along with shielding for the SC coils. Recent studies [4] have indicated that up to 1.5 MW of heat is generated in the mercury-containment and the tungsten shielding of the Target Module. The baseline cooling medium for these components is gaseous helium. The Target Module requires numerous utility services, shown in Fig. 5, and these services will be attached at the upstream end of the Module for easier access. It is assumed that the mercury system would be located on one side of the beam line and that the helium and cryogenic services would be located on the other. Providing adequate space for these services within the Target Module will continue to be a mechanical challenge in the design.

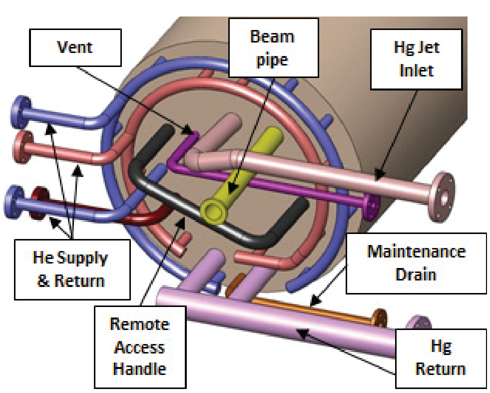


Figure 5: Utility services on the upstream face of the Target Module.

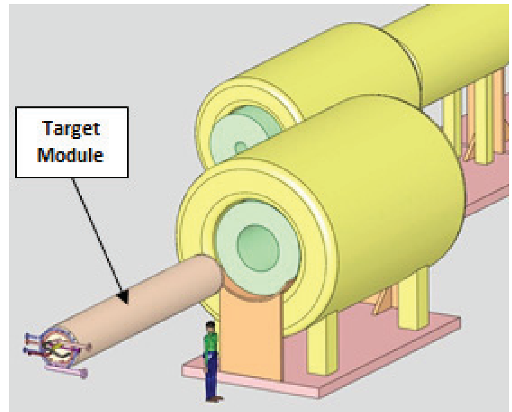


Figure 6: Target Module extracted from Cryostat 1.

### *Remote Handling*

The high radiation levels and presence of hazardous, activated mercury vapors requires that all maintenance within the Target Facility be performed in a totally remote fashion. A dual-arm servomanipulator system such as that incorporated in the Spallation Neutron Source Target Facility at the Oak Ridge National Laboratory is likely to be required, along with additional tooling and remotely controlled mechanisms. The Target Module will be designed such that it is a self-contained module which can be handled separately from the Shielding Module and the Cryostat. It is currently envisioned the Target Module will be removed from the cryostat longitudinally, as shown in Fig. 6. Due to its length and the potential for interference with upstream final focus magnets, it is likely that the entire Cryostat will have to be laterally displaced from the beam line before the Target Module could be removed. A special-purpose mechanism would be placed behind the cryostat in order to install or remove the Target Module.

## FUTURE WORK

The Target Module concept is early in its development, and many issues have developed as the concept progressed. Future efforts will focus on separating the shielding function from the mercury-containment function with the goal of reducing the complexity of the Module's design.

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