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Design Requirements Document and

Interface Control Document

for the

High Power Mercury Jet Target System

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1.0 Functional Requirements

The primary function of the target system is to deliver a 1-cm diameter mercury jet, in the form of a continuous stream, into a high field (15 Tesla) solenoid while simultaneously intersecting a high-energy (24 GeV) proton beam. The duration of the jet must be sufficient to interact with the proton beam for TBD seconds. The target system must provide the means for discharging the jet, and collecting and recycling elemental mercury through a pump, in a double-contained system. Figure 1 is rendering of the high power mercury jet target system.

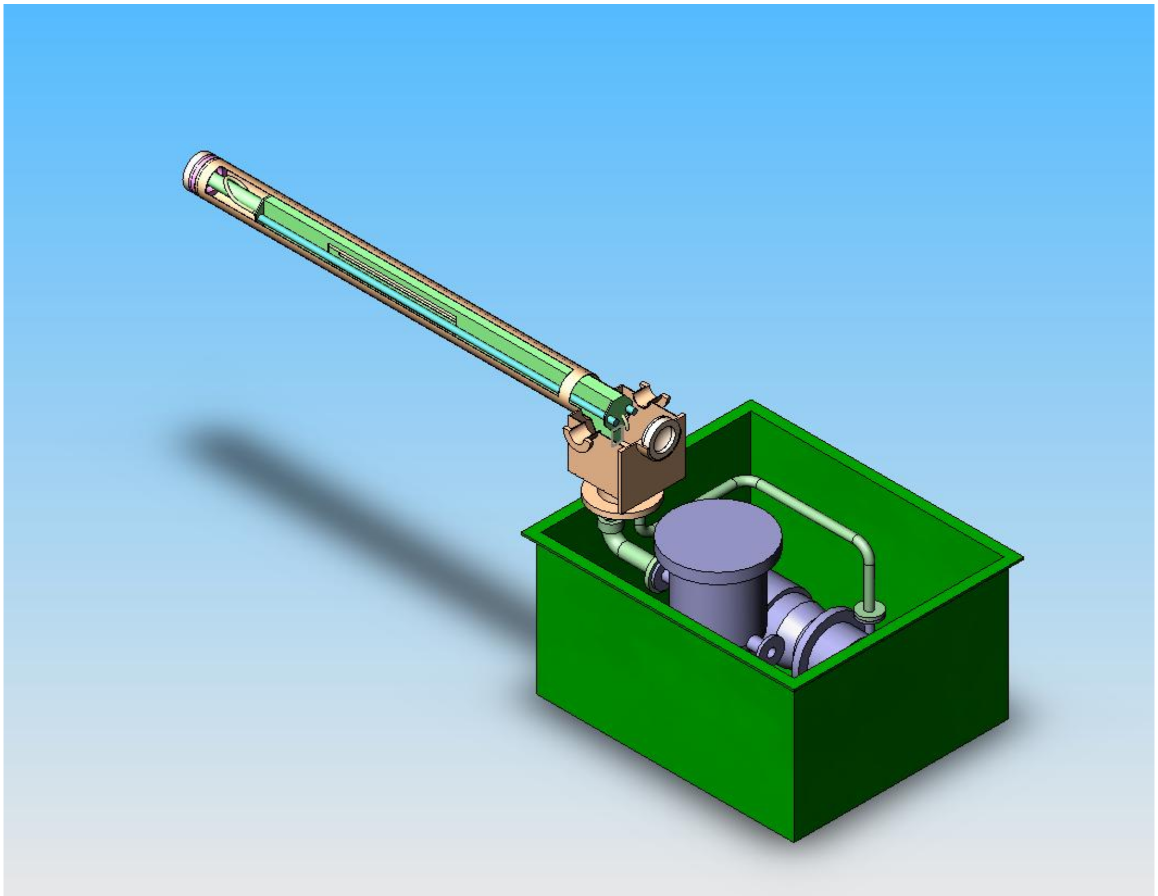

Figure 1. Hg target system

2.0 Design Description

The target system is part of the proof-of-principle experiment for a high power production target station as needed for a Neutrino Factory or a Muon Collider. It consists of a free mercury jet situated inside a 15 Tesla (T) solenoid, to be installed in the TT-2A tunnel at CERN. The target system will be double-contained and capable of delivering more than 40 free-jet cycles into a proton beam line.

The target system consists of four subsystems: 1) the primary containment structure, 2) the secondary containment structure, 3) a magnetically coupled motor and centrifugal pump, and 4) the support base structure. The design for each subsystem must take into account the requirements for dealing with mercury, a toxic heavy metal that will be mildly activated once the tests commence, and the requirements for dealing with mildly radioactive structure at the completion of testing.

The system will operate within a 1-atmosphere environment of air in the primary containment, and 1-atmosphere of air in the secondary containment. (Air-activation, i.e. ^{13}N, ^{15}O and ^{41}Ar, will not be an issue for this system since the air environment is not purged after each pulse, and the containment boundaries remain intact for the duration of testing. If there is a need to breach either barrier after test operations commence, 1 hour of waiting will be sufficient for the decay of these isotopes. This approach is much simpler than incorporating equipment to evacuate and backfill with helium because of the complications of installing a mercury ventilation/filtration system.)

3.0 General Requirements

The target system consists of the equipment to operate and contain a continuous mercury jet and the base support structure. It shall be designed such that the elemental mercury in the target is double-contained and mounted on a base structure that supports the target equipment and the solenoid system as an integrated unit. The support structure shall be capable of being manually driven into or out of the axis of the proton beam line, and it shall have provisions to adjust the elevation and pitch of the integrated system.

The target system shall be assembled initially "hands on" but must be maintained and operated with minimal personal contact after beam operations commence. Therefore, design of the target system shall take into account the eventual disassembly and decontamination of the equipment. Design features shall be incorporated into the target system that consider handling mildly activated components that are mercury-contaminated, as well as handling activated mercury, so as to minimize exposure to personnel.

3.1 Design Specification

The target system design shall meet the criteria of ISO 2919, Table 2 "Classification of Sealed Source Performance," Class 2:

ISO 2919, Table 2, Class 2

Temperature	-40º C (20 minutes), +80º C (1 hour)
External Pressure	25 kPa absolute (60 psi) to atmospheric
Impact	50 grams from 1 meter, or equivalent imparted energy
Vibration	3 times 10 minutes, 25-500 Hz at 49 m/s^2 (5 g_n, acceleration maximum amplitude)
Puncture	1 gram from 1 meter, or equivalent imparted energy

Basis: This requirement was established by the CERN Safety Engineering Group.

3.2 Geometry

The geometric configuration of the target system is based on the following criteria:

- Horizontal proton beam 121 cm ±5 mm (47.64 ±0.20 in.) above the tunnel floor,
- Proton beam, solenoid axis, and Hg jet all reside in a common vertical plane,
- Service end of solenoid is "up-beam,"
- Solenoid axis tilted 67 milliradians (3.84°) with respect to proton beam, with service end of solenoid above the beam,
- Hg jet flows from the "up-beam" to the "down-beam" direction, the same direction as the proton beam,
- Hg jet begins below the proton beam at an angle of 33 milliradians (1.89º) to the beam.

Basis: The geometry was established by the Physics Group of the Collaboration to simulate the conditions of an actual target configuration that optimizes muon production.

Figure 2 is a sketch that shows the relative angles between the jet, the proton beam, and the magnetic field axis. Figure 3 shows the overall geometry of the target system.

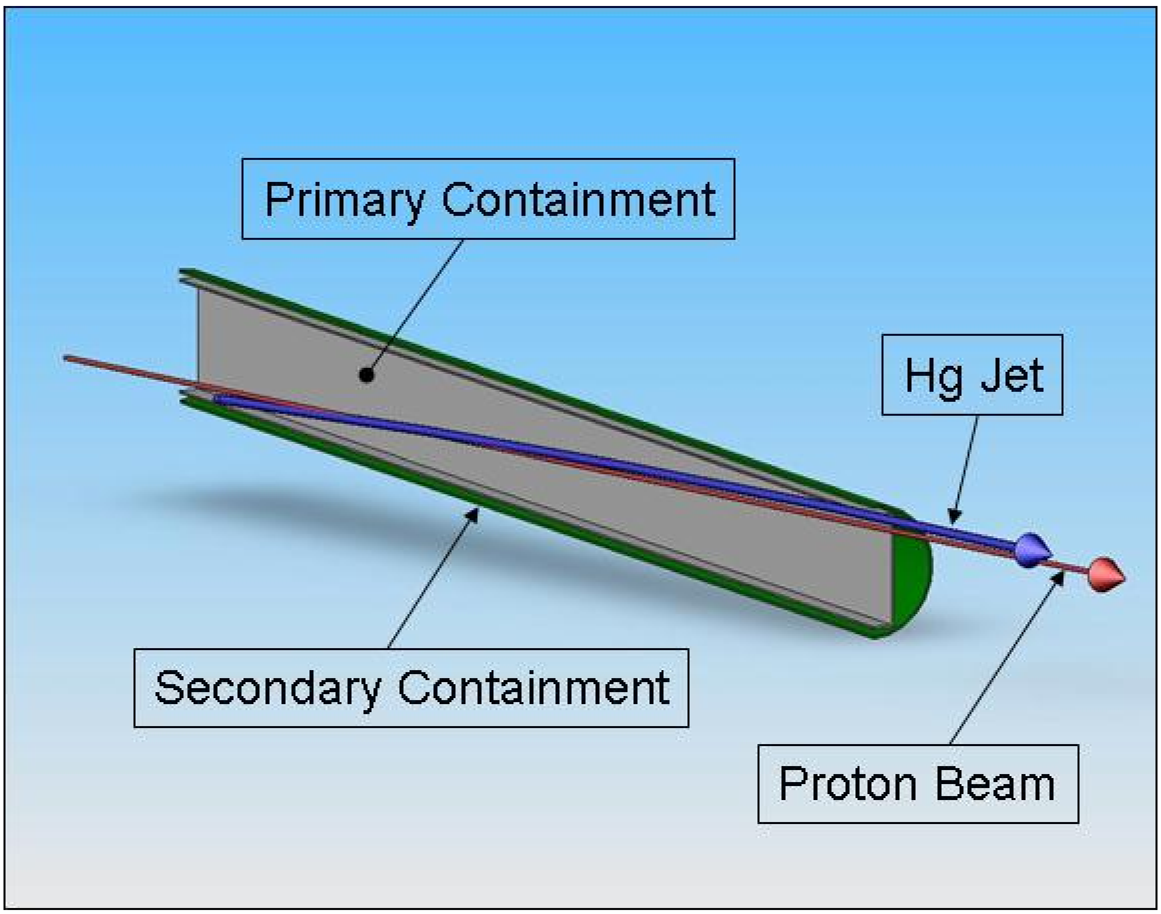

Figure 2. Proton beam and Hg jet trajectories

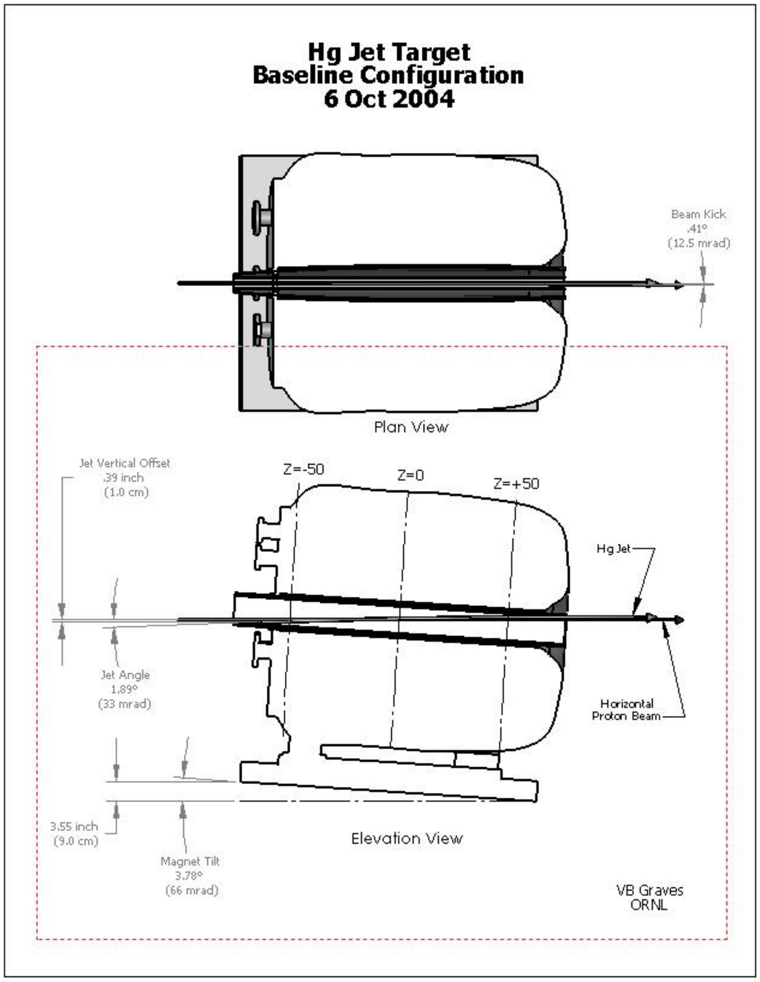

Figure 3. Baseline geometry configuration

3.3 Materials Compatibility

All materials of construction for the target, except for windows, shall be austenitic stainless steel, type 316 or 304. Fasteners and miscellaneous items shall be non-magnetic. Gaskets shall be non-reacting with mercury, and capable of radiation tolerance to at least 10^4 rads. The base support structure may be fabricated from painted carbon steel.

Basis: Non-magnetic material shall be used wherever possible to minimize J x B forces; mercury dissolves metals such as copper that are normally used for flange gaskets; and, gamma doses due to neutron activated materials in the target structure will be much less than 10^4 rads.

3.4 Primary Containment

The primary containment boundary is defined as that which is mercury-wetted hardware. The primary containment includes the insert tube that contains the nozzle and related tubing, the proton beam windows and optical diagnostic windows, the sump tank, the pump, and the connecting hardware. The primary containment shall be designed for a 1-atmosphere overpressure and shall make minimal use of valves and fittings to reduce the possibility of leakage. Figure 4 is a schematic of the primary and secondary containment boundaries.

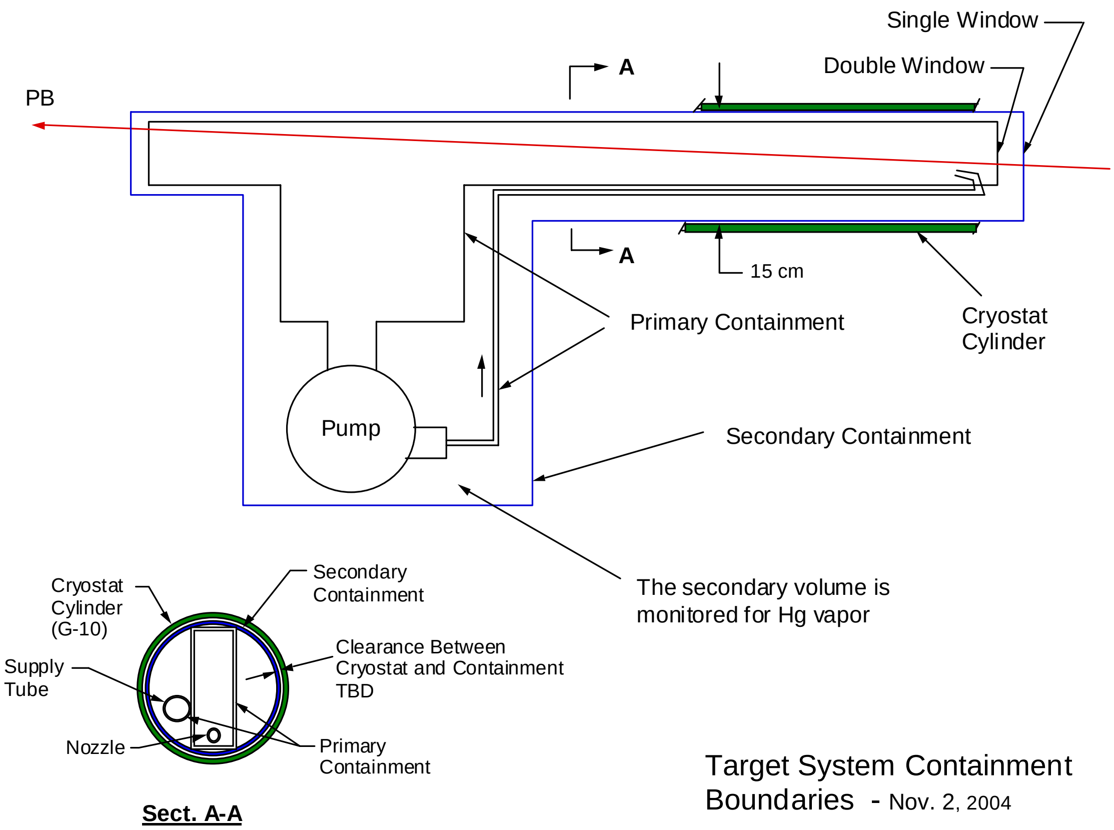

Figure 4. Target system containment boundary schematic

3.5 Secondary Containment

The secondary containment provides the means to monitor for the presence of Hg vapor should a leak develop in the primary containment boundary. The secondary containment shall be designed for a 1-atmosphere overpressure.

3.6 Windows

Primary Containment Windows

There are two types of windows that are fitted to the primary containment boundary, the proton beam windows and the diagnostic windows. The proton beam windows for primary containment shall be double-layered without interstitial pumping/monitoring, made from Ti6Al4V material, and will be interchangeable from one end to the other. They will be provided by others and designed to meet the interface requirements at the upbeam and downbeam primary-boundary locations.

The diagnostic windows shall be optically transparent, single layer, made from quartz material, and interchangeable from one side to the other. They will provide the ability to view the entire interaction region along the axis of the proton beam. The diagnostic windows will be provided by others and designed to meet the interface requirements of the primary-boundary locations.

Basis: The window materials were established by BNL.

<u>*Secondary Containment Windows*</u>

The proton beam windows that are fitted to the secondary containment shall be optically transparent, single layer, made from polycarbonate material (i.e. Lexan®), and interchangeable from one end to the other. The secondary containment windows will be provided by others and designed to meet the interface requirements of the secondary-boundary locations.

Basis: The window materials were established by BNL.

3.7 Assembly, Installation, Shipping

The design and fabrication of the target system shall allow for ease of assembly and disassembly, considering that the system will be shipped to CERN. There shall be provisions on each major component for overhead lifting, pallet-like handling, and the base support structure shall have casters for moving the assembled target system.

Basis: The major components that make up the target system are heavy and require provisions for rigging; for example, the pump weighs approximately 300 lbs (135 kg), the motor weighs approximately 900 lbs (270 kg), and the assembled pump, motor, and base plate weigh approximately 1700 lbs (770 kg).

4.0 Testing and Operations

4.1 Filling/Draining Mercury

The target system shall have provisions for installing mercury by using either a separate vacuum pump or separate peristaltic pump. The sump tank will be sized to hold TBD liters of mercury. The system design shall avoid low points or traps where mercury can accumulate, and if drain valves are used, they shall be protected from the possibility of damage due to handling, and drain nipples shall have Swagelok® caps, or equivalent.

Basis: The approach to "pour" mercury from shipping flasks is judged to be risky and prone to spillage. Evacuation and peristaltic pumping were successfully demonstrated at ORNL. Drain caps are required in conjunction with valves to avoid the possibility of leakage due to inadvertent valve opening.

4.2 Maintenance

The target system shall be assembled initially "hands on" but must be maintained and operated with minimal personal contact after beam operations commence. Therefore, wherever possible the design shall incorporate the use of connections, fasteners, and hardware amenable to minimizing handling time, and the need for maintenance.

Basis: ALARA requirement.

4.3 Design Life

The target system shall be designed to operate for a minimum of 10,000 start/stop cycles. A typical operating cycle will have a duration of 1-3 minutes. Hence, the total maximum operating design life for the hardware equipment and the controls is 500 hours.

Basis: The test procedure calls for a minimum of 40 pulses; the required number of start/stop cycles during the equipment lifetime exceeds 40 pulses because of extensive testing of the system; the estimate for start/stop cycles and total life are well within the mean time between failures (MTBF) of the components.

4.4 Operating Cycle

The target system shall be capable of delivering a 1-cm (0.39 in.) diameter mercury jet, sustained for up to 3 minutes, every 30 minutes.

Basis: Physics requirement.

5.0 Other Subsystem Requirements

5.1 Pump System

The pump shall be a magnetic-drive motor coupled to a centrifugal pump. The drive motor shall be 75-hp (tentative), and the pump shall deliver 25 gpm (tentative) at a nozzle velocity of 20 meters per second, into a 15 T magnetic field.

Basis: The magnetic drive coupling eliminates the possibility of mercury leakage through a typical shaft coupling thereby preventing mercury contamination of the motor; the nozzle velocity is a Physics requirement.

Electrical Power

The target system pump motor will require 3-phase, 460VAC/90A, 50/60 Hz electrical power.

Basis: Manufacturer's specification.

Control Drive

The target system shall have a variable frequency drive capable of providing manual or computer control in order to have the capability to interface with the magnet control system and/or the proton beam line control system. It shall be capable of operating the mercury pump over the full range of pump power from zero-hp to 60-hp (45 kW), under varying time conditions up to 3 minutes, and under varying magnetic field conditions, from zero T to 15 T, to maintain the jet at a constant velocity of 20 m/s (66 ft/s). The control system shall be capable of remote operation from a control room located 60 meters away.

Basis: Physics requirement; flexibility to program the control system to operate under different conditions.

5.2 Base Support Structure

The base support structure shall be capable of supporting the dead weight of the combined solenoid and target system: the solenoid/cryostat weighs approximately 4-tonnes, the target system weighs approximately 1-tonne. The base support structure may be fabricated from painted carbon steel. In addition, it shall have the following features:

- provide the mobility to manually move the solenoid/target assembly into and out of the proton beam line, with a precision of 1.0 mm (0.040 in.),
- manual adjustment capability to change the elevation and pitch of the integrated solenoid/target system, with a precision of 0.5 mm (0.020 in.),
- the means to manually move the target insert into and out of the cryostat bore, along the axis of the cryostat, and
- provisions for overhead lifting, pallet-like handling, and movement using casters.

Basis: The magnetic material of the base support structure produces a vertical, in-plane attractive force on the magnet that modestly adds to the gravity load; the cost for this material is significantly less than non-magnetic material; the assembled components require precision positioning to align with the proton beam line.

6.0 Interface Requirements

The target system has five interfaces with other systems, equipment, and facilities. They are: 1) the solenoid system provided by MIT, 2) the proton beam windows provide by BNL, 3) the diagnostic windows and fiber optic/laser diagnostic equipment provided by BNL, 4) the base support structure, and 5) test facilities at ORNL, MIT, and the CERN target hall and control room.

6.1 Solenoid System

The insert portion of the target fits into the 15.0 cm clear bore of the G-10 cylinder of the cryostat. The outside diameter of the insert shall be 14.XX (TBD) cm ±0.5 mm, and have a straightness of ±0.XX (TBD) over the length of the insert, to ensure no interference with the cryostat. The G-10 cylinder shall be capable of supporting a weight of TBD lbs to account for the target system insert and in-process Hg. The solenoid shall provide a means of leveling its axis to the base support structure. The method of attachment to the base support is TBD.

6.2 Proton Beam Windows

An interface exists for the proton beam windows that are part of the primary and secondary target containments. BNL shall be responsible for developing window configurations that are compatible with the target system design, and will provide drawings accordingly. The proton beam windows, the flange bolt pattern, bolt size, and type of gasket shall be shown on the target assembly drawing.

6.3 Optical Diagnostic Equipment

An interface exists for the diagnostic windows, the arrangement for fiber optic cables, and the cable penetrations through the secondary target containment. BNL shall be responsible for developing a diagnostic configuration that is compatible with the target system design, and will provide drawings accordingly. The installed diagnostics components will be shown on the target system assembly drawing.

6.4 Base Support Structure

The base support structure interfaces with the three mounting pads of the solenoid system, and the support pads for the target system. The interfaces shall include the means to provide pitch & elevation adjustments as noted in section 5.2.

6.5 Facilities

The base support structure with the assembled solenoid and target systems shall be able to be installed in facilities at ORNL and MIT to accomplish integrated systems testing. Since the target system will have an integral secondary containment system, any facility with a suitable floor load capacity, the means for venting and filtering mercury vapors, and proper electrical power supplies will be acceptable.

In addition, the same facility conditions apply for installing the equipment at CERN, namely, the ability to reach the test area in the TT2A tunnel.

The following CERN interface items require resolution and are TBD:

- power supply/frequency for pump system,
- electrical cable … who provides 60 meters length,
- target hall (tunnel) dimensions, doorways, turning radius, …,
- control room size and location.