DARKSIDE-20k CRYOSTAT and AAr CRYOGENICS

TECHNICAL SPECIFICATIONS - CAPITOLATO TECNICO

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1. THE DARKSIDE-20K CRYOSTAT AND CRYOGENICS

The DarkSide-20k detector will be located inside the two membrane outer cryostats, operating with an atmospheric argon fill refrigerated with the AAr cryogenic system. The two-phase Time Projection Chamber (TPC) serving as the dark matter detector operates with a fill of low radioactivity underground argon (UAr) at the center of the liquefied AAr bath. The TPC is surrounded by the active veto detector. Both the TPC and the active veto detectors are supported by the top cap of the AAr cryostat.

Plans for the DarkSide-20k cryostat and AAr cryogenics are based on the successful experience of the deployment at CERN of two large membrane cryostats in support of the ProtoDUNE project. The membrane cryostat technology in use was initially developed for the overseas transport of liquefied natural gas (LNG). The specific membrane technology of choice is derived from the French engineering firm Gaz Transport & Technigaz (GTT) which controls 80% of this international market. CERN executed a collaboration agreement with GTT to develop and adapt its Mark III membrane cryostat technology for particle physics detectors.

We expect the DarkSide-20k membrane cryostat to be a close adaptation of the ProtoDUNE cryostats installed at CERN, tailored upon the specific needs of DarkSide-20k.

The DarkSide-20k cryostat will retain all major elements of the ProtoDUNE cryostats, including the stainless steel inner cold vessel that contains the cryogens, insulation panels and a warm steel supporting outer structure. The cold primary membrane tank is made of a stainless-steel, leak-tight liner that contains the cryogenic liquid. This membrane liner is corrugated to provide mechanical relief to strains resulting from temperature-related expansion and contraction. The insulation is composed of two layers of the polyurethane providing a thermal barrier between the membrane at the liquid cryogen temperature and the support structure at ambient temperature. A secondary barrier located between the layers of insulation is a physical protection providing secondary containment to the liquid cryogen in case of a failure of the first membrane. A warm steel structure, consisting of large vertical beams alternated with a web of metal frames and a carbon steel tertiary membrane, surrounds the secondary barrier and provides mechanical support. The main components of the Mark III GTT technology are visible in Fig. 1. A view of the internal part of one of the two ProtoDUNE cryostats at CERN is shown in Fig. 2.

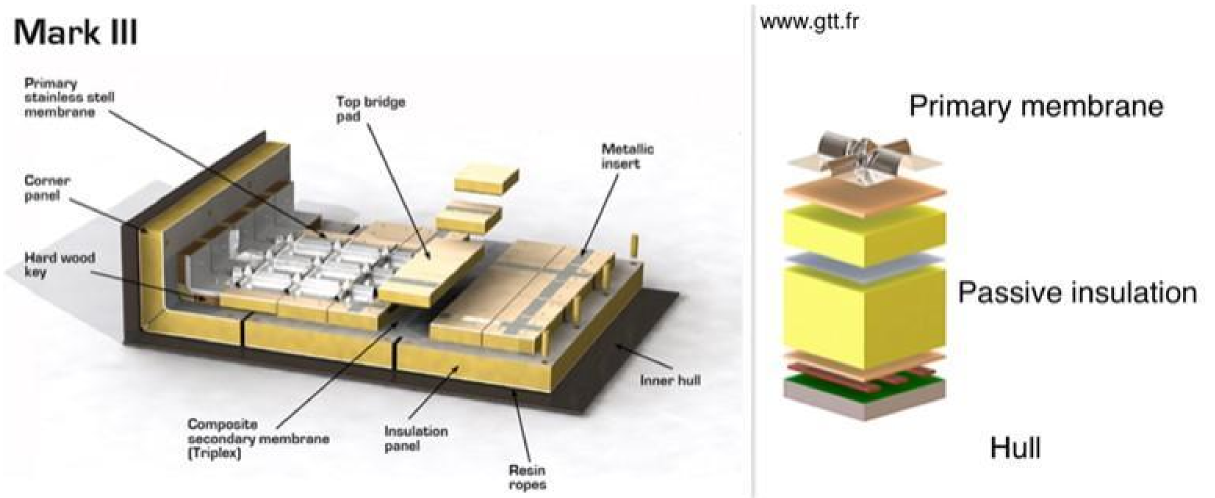

FIG. 1. Membrane cryostat components (Mark III technology from GTT) with a cross-section of the containment system and cold membrane.

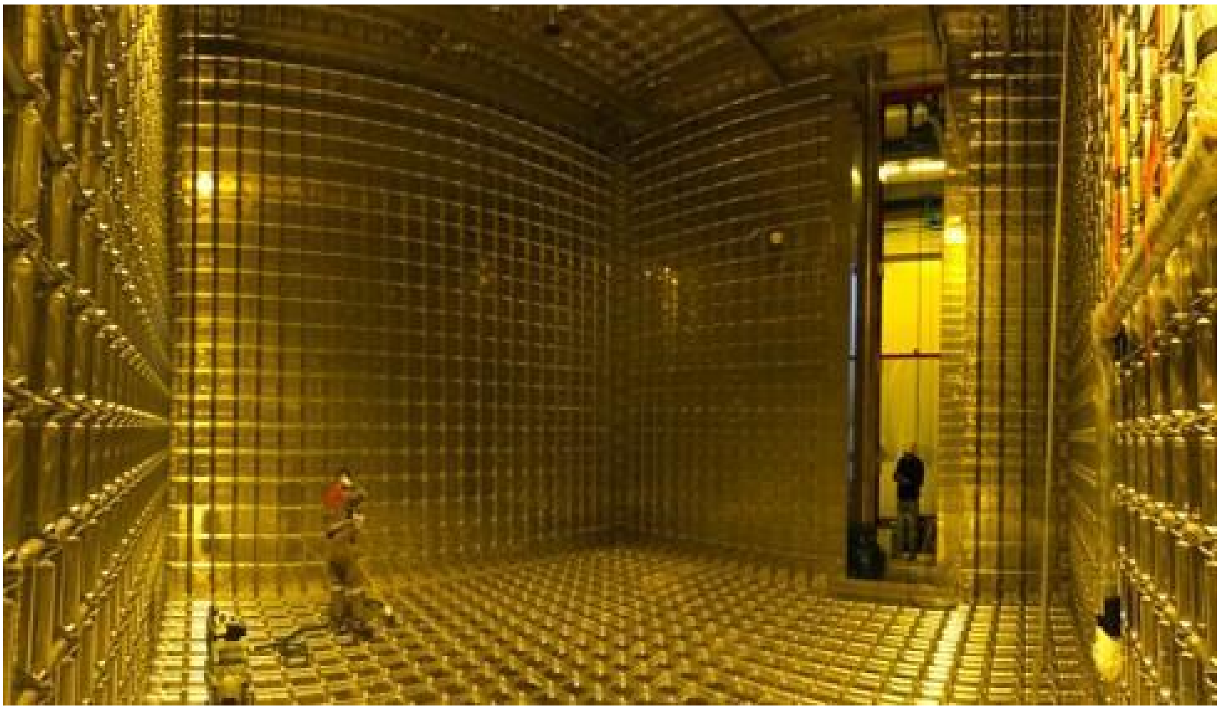

FIG. 2. A view from inside of one of the ProtoDUNE cryostat operating at CERN.

1.1 Cryostat Warm Structure

The outer warm structure, which provides the mechanical support for the membrane and its insulation, consists of a net of vertical and horizontal IPEV600 profiles. The outer structure will be designed to withstand the hydrostatic pressure of the liquid argon, the pressure of the gas volumes and all possible external constraints (e.g. gravitational, seismic, etc.). The warm structure will be fixed to the Hall-C concrete ground with a set of 24 structural steel brackets that will serve as anchorage of the structure against the combined action of horizontal and vertical seismic oscillations according to best practices to meet italian seismic legislation. A bracket element design is shown in Fig. 4; dimensions are 700mm x 1000mm x 618mm (WxLxH). Each bracket is fixed to the ground with 16 bolts.

Inside the steel structure, a skin of carbon steel plates with reinforcement ribs is welded to provide an additional barrier to the outside. The warm structure and the top cap are shown in Fig. 3.

The warm structure of the AAr cryostat consists of two main elements: the lower vessel which will host the liquid and the roof hosting all penetrations for cryogenics and services. The entire vessel will be filled to the 96th percentile of its volume with liquid argon, requiring a fill of approximately 700t. The remaining 4% of the volume will be filled with gaseous argon, at a pressure of about 50mbarg to 70mbarg above atmospheric pressure. The vessel is protected by a gas safety valve, opening at an over pressure of 350mbarg.

1.2 Cryostat Cold structure

The cold vessel is installed inside the warm support structure. It consists of passive thermal insulation, a primary corrugated stainless steel membrane, and a secondary thin membrane to provide primary and secondary liquid containment. Thermal requirements determine the minimum thickness of insulation, including the primary and secondary membranes that provide primary and secondary levels of containment. A 10mm thick carbon-steel skin, just behind the insulation, provides an effective gas enclosure, permitting proper handling of the nitrogen atmosphere inside the cryostat insulation.

While the liquid argon is contained by the primary stainless steel corrugated membrane, a second membrane is also present as a safety backup should the innermost membrane experience a leak. Both membranes are part of the cold vessel structure. The volume of the insulation is operated in a nitrogen atmosphere, at a pressure of a few mbar above atmospheric pressure. A 1cm thick carbon steel plate attached to the structural beams contains all the nitrogen gas blanketing the insulation space and acting as a *de facto* tertiary membrane. The structural beams are made of a special carbon steel alloy S460ML (1.8838), able to maintain its mechanical properties down to 220K.

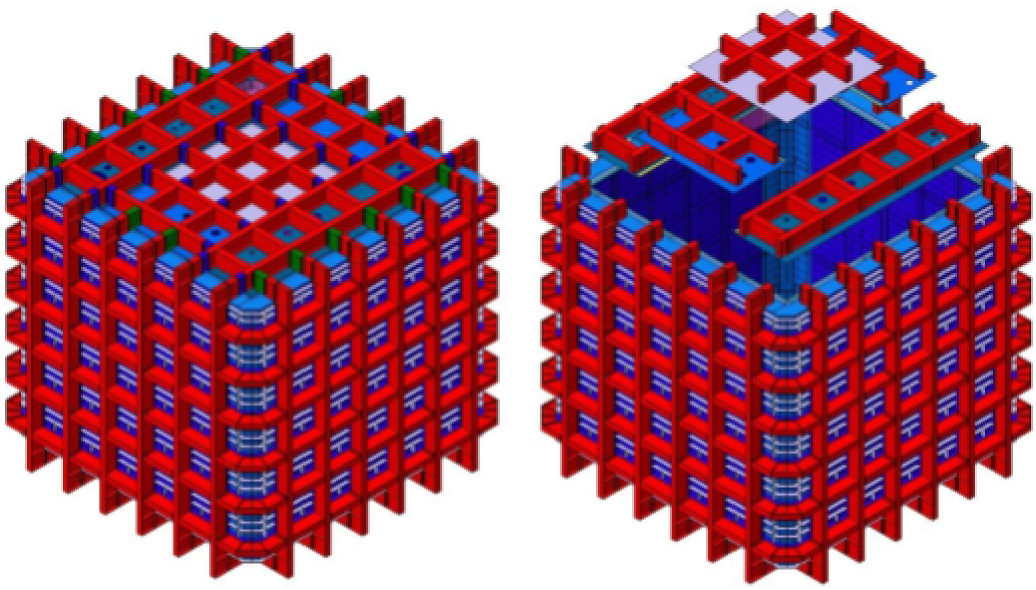

FIG. 3. Cryostat warm structure and top cap, ISO view.

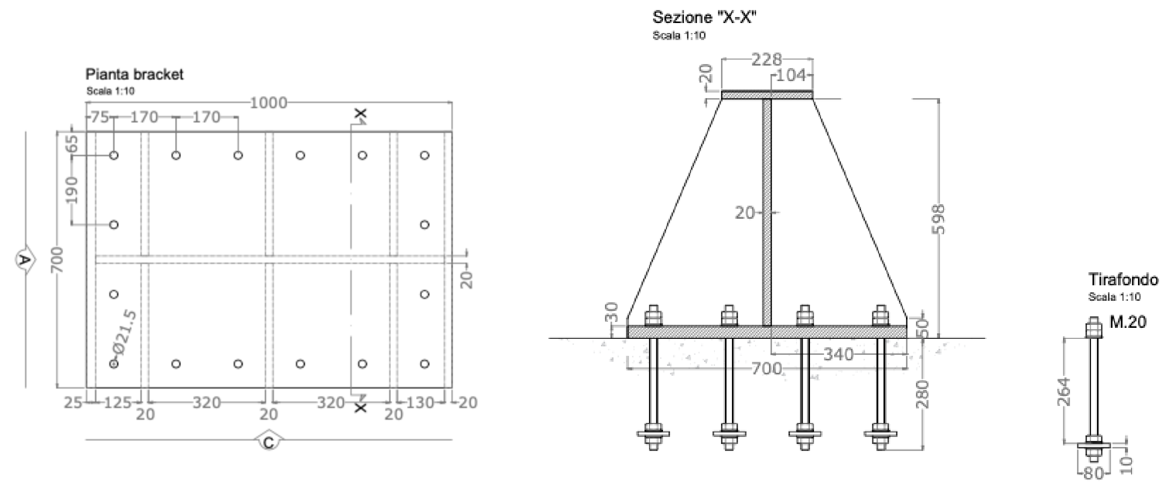

FIG. 4. Cryostat warm structure bracket element views.

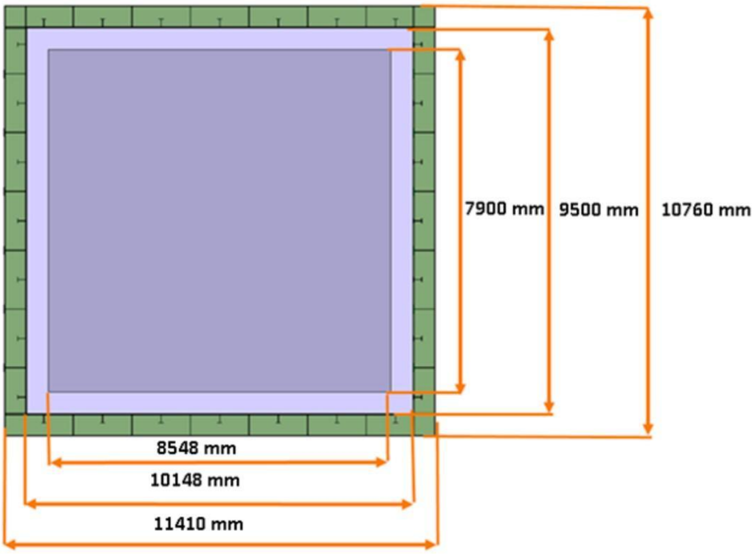

FIG. 5. DarkSide-20k Cryostat front view cut with the foreseen dimensions. The membrane flat internal dimension does not include the space used by the corrugation

1.3 Cryostat Top Caps

The roof structure is composed by five pre-assembled modules called "Top Caps": one central top cap (4.1 x 4.1m), and four lateral top caps of two different shapes and sizes. These top caps will be bolted together and to the lower vessel through several roof links modules and eventually the use of shims to ease the installation phase. Each top cap consists of the steel IPEV600 beam frame, the 10mm thick steel plate (warm skin), the thermal insulation and a thin metallic plate to support the insulation (cold membrane), pipes and flanges for penetrations, welded to the warm skin. A picture of the five top cap modules connected through the link modules is shown in Fig. 5.

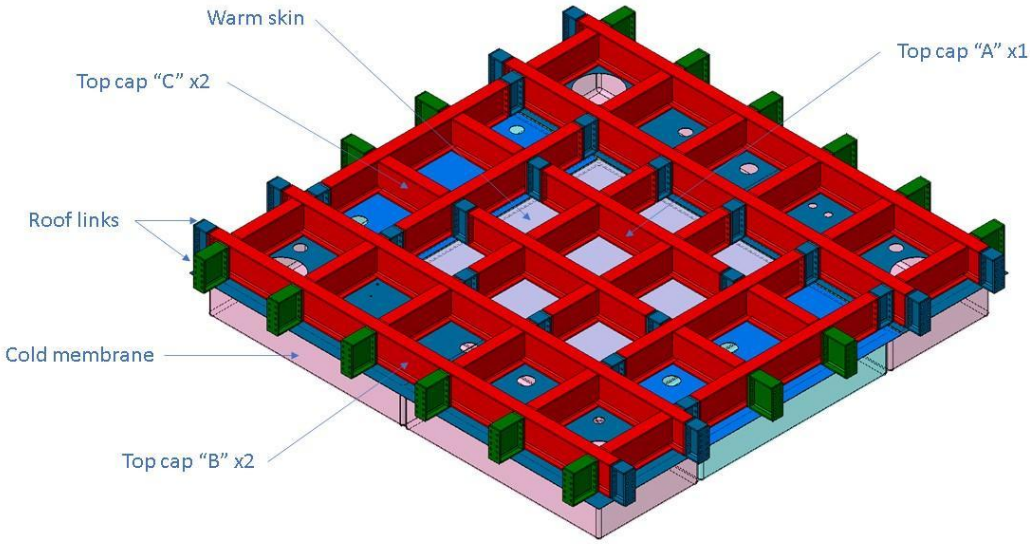

FIG. 6. Top cap modules components.

1.4 AAr Cryogenic System

The AAr cryogenics system combines the expertise of ProtoDUNE and DarkSide-50 experiments. The system uses liquid nitrogen as refrigerant to cool and liquefy AAr. After purification in the gas phases, the argon in the recirculation is collected in the phase separator and then returned to the cryostat via a guide system designed to achieve the desired temperature uniformity across the entire volume. Radon emanated from warm components like the chimney feed-throughs on the roof of the cryostat is captured by an active charcoal-based cold radon trap in argon gas re-circulation loop, prior to its liquefaction and re-injection in the cryostat.

2. SPECIFICATIONS

2.1 Specifications for the Cryostat Warm Structure

The cryostat warm structure executive design signed off by Eng. Luigi Fico (FMC Engineering s.r.l.) and approved by "Genio Civile dell'Aquila" in date XX/YY/2021, is provided by INFN and attached to this technical specification document.

The cryostat warm steel structure production and erection shall be executed in accordance with EN 1090-2:EXC3 with the following supplementary requirements:

Material certificates

- The beams and the plates shall be accompanied with material certificate in accordance with EN 10204:2004 Type 3.2

Beams welding inspections:

All welds shall be inspected for imperfections and verified to meet the quality level for EXC3. The tests to be performed and the extent of the testing is as it follows:

- 100% of the full penetration welds shall be controlled by visual inspection
- 50% of the welds shall be controlled by dye-penetrant test
- 25% of the flange welds shall be controlled by magnetic particle testing.
- 10% of the flange welds shall be controlled by ultrasonic test.

Warm Skin welding inspection:

All welds shall be inspected for imperfections and verified to meet the quality level for EXC3. The tests to be performed and the extent of the testing is as it follows:

- 100% of the welds shall be controlled by visual inspection;
- 25% of the welds shall be controlled by dye-penetrant test.

Fasteners:

- All fasteners shall be Grade 10.9 high strength bolt assemblies for preloading, in accordance with EN 14399.
- The fasteners shall be accompanied with material certificate in accordance with EN 10204:2004 Type 3.2.

2.2 Specifications for the Cryostat Cold Structure

The Cold structure of the AAr cryostat inner component is the primary membrane, that will be in direct contact with the liquid argon bath. The primary membrane will ensure the right expansion of the metal structure versus the temperature changes, especially during the filling and during the emptying of the cryostat. The primary membrane will need to withstand all the loads and fluctuations of the liquid argon into the cryostat.

The insulation is instrumented with gas inlets, outlets, temperature and pressure sensors. The details of the routing and position of such sensors is part of the engineering contract between the Contractor and the licensed company.

The contractor will need to ensure the agreement with the licensed company of the GTT technology, for all the engineering studies to be accomplished and for the realization *in situ* of the cold structure.

A detailed installation plan shall be developed for the cold structure, including all the subsequent phases:

- Description of facilities and services, such as scaffolding, lightning, electricity and compressed air, needed to perform the work;
- Tertiary membrane dimensions survey and eventual correction of the deformations;
- Installation of the insulation panels;
- Installation and testing of the secondary membrane;
- Installation, welding and testing of the primary membrane.

The contractor will be responsible for the engineering and construction, assembly and test of the cold structure. A special emphasis needs to be made on the thermal fluxes and storage characteristics. Specifications are listed in Table I.

The inner volume defined by the internal surface of the 10mm thick carbon steel wall shall be [LxWxH]		10.148 mm x 10.148 mm x 9.500mm
The inner volume defined by the internal 1.2mm flat membrane to provide the adequate LAr shielding to the detector shall be [LxWxH]		8.550mm x 8.550mm x 7.900mm
TIG welding torch electrode shall be		Lanthanated electrodes (thoriated electrodes are disallowed)
Inner liquid phase AAr volume (capacity at 96% filling of the cryostat)		554m^3
Ullage volume as fraction of cryostat volume		4%
Inner absolute pressure operating range shall be		950-1100mBara
Cryostat relief pressure shall be set at		350mBarg

TABLE I. Specifications for the cold structure.

2.3 Specifications for the Cryostat Top Caps

The contractor will be responsible for the engineering, construction, transportation and installation of the top cap modules. The design must guarantee enough clearance for detector parts insertion in the cryostat, via the central hole and the two manholes. The modules must be transportable and liftable with the available lifting equipment in the Hall C. The top caps, once assembled to the rest of the warm structure, must be able to safely support the dry static weight of the full assembled detector.

The top caps should be able to host all the required penetrations for services and readout cables. The design of the primary membrane should not restrict penetrations positions and should safely withstand all the existing mechanical loads while minimizing the thermal link between cold and warm surfaces. The list of penetrations, their dimensions and positions will be agreed with the Collaboration. The current design for the penetrations is attached to this document in Fig. 6. The final design will be delivered by the collaboration to the contractor in time for the production of the executive design.

The top caps insulation system will be designed such to contribute to the global thermal requirement of the cryostat and AAr cryogenic system.

The top cap modules structure shall be executed according to the requirements of EN 1090-2. The execution class of the steel structure is EXC3 according to EN 1090-2:2008. The list of relevant standard, properties of supplied constituent products, fasteners and welding requirements is already specified above in Sec. 2.1.

Central top cap minimum clearance		4.12m x 4.12m
Manholes minimum inner diameter		ID > 835mm
Top Caps modules maximum weight to be moved with 20 + 20 tons Hall-C crane		40tons
Delivery in LNGS Hall C		All modules shall be compatible with Hall C entrance door dimensions 4.6m (W) x 4.4m (H)
Detector dry static load to be supported via top caps		30tons
Manholes:		number of penetrations = 2
Calibration pipes:		number of penetrations = 4
Detector support:		number of penetrations = 4
TPC signals and power supply ports:		number of penetrations = 8
Veto signals and power supply ports:		number of penetrations = 4
TPC high voltage:		number of penetrations = 1
UAr cryogenics:		number of penetrations = 5
Spares:		number of penetrations = 4

TABLE II. Top Caps specifications

2.4 Specifications for the Cryostat Materials Radio-purity

Radiogenic neutrons originated by ^{238}U and ^{232}Th contamination of detector materials can produce an irreducible background for the experiment. The goal of a 10-year physics run with a negligible neutron background (less than 0.1 events after analysis cuts) poses very specific requirements to DarkSide-20k in terms of radio-purity of materials. Although the cryostat is far from the active volume, its large mass compared to the other detector components makes it necessary to carefully assess the contamination of the materials prior to the construction of the cryostat. The collaboration should be provided with a sample of the cryostat's candidate materials for radio-assay. The DarkSide-20k materials working-group will be responsible for making the necessary radio-purity measurements and calculating the impact of the cryostat contamination on the background of the experiment. The most crucial material radio-purity requirements are listed in Table III. Once the suitable material has been identified as specified in Table III, it will be necessary to use only that material from that manufacturer, ensuring the use, when possible, of materials from the same production batch.

For all Cryostat candidate materials		At least one sample for each material must be provided to the Collaboration for radio assay and elemental analysis.
Composition of rigid secondary barrier material		Use of SS sheet only is requested.
Flexible secondary barrier material		Elemental composition must be provided. Minimize the use of Al and Mg for structural materials. Li, Be and B free components. Use of fluorine free elastometer for flexible barriers should be preferred.
Insulating foam material		A Fluorine free foam growth fabrication process should be used. Elemental composition of the foam must be provided as well as a samples for radio assay. The full foam used should come from assayed batches.
Fiberglass materials		Minimize use of fiberglass. No fiberglass with Boron is allowed.
Structural materials		Minimize use of Al and Mg

TABLE III. Radio-purity and composition specifications for the cryostat materials.

2.5 Specifications for the AAr Cryogenics

The AAr cryogenics not only handles the AAr, but also functions to maintain the TPC with its UAr fill, which is immersed in AAr volume. The pressure of the AAr and UAr baths must be always balanced and controlled synchronously in all operation conditions, including emergency mode with total power failure, in order to ensure stable operations of the TPC, as well as the safe accommodation of UAr. Detailed requirements for the AAr cryogenics system are listed in Table IV. In particular, Table IV specifies the net available cooling power for the AAr cryogenics, once the heat loads from the detector have been subtracted to the cooling power that will be available in the LNGS Hall C for DarkSide-20k.
All argon filled into the cryostat must pass first through a hot zirconium getter and then trough an activated charcoal trap operating near liquid argon normal temperature. A viable alternative could a cold filter made of oxygen-free high conductivity copper (OFHC) pellets, whose operation would need to be demonstrated through suitable R&D program. Based on past operational experience the use cold filters based on molecular sieves and/or alumina pellets covered by copper is disallowed on the basis or contamination from ^{222}Rn. General cryogenic system slow control will be included.

All argon recirculated during run time must pass first through a hot zirconium getter and then trough an activated charcoal trap operating near liquid argon normal temperature. Online QA sampling on levels of contamination of O_2 and N_2 filled or circulated must be guaranteed.

Heat load from the cryostat walls:	5.0 kW
Heat load from the cryostat roof:	1.0 kW
Heat load from AAr cryogenics liquid recirculation	2.0 kW
Gas argon circuit (transfer lines and heat transfer inefficiencies):	1.0 kW
Total uncertainty:	1.0 kW
Total (no liquid recirculation):	**8.0 kW**
Total (with liquid recirculation):	**10.0 kW**

TABLE IV. AAr cryogenics power requirements during operation, for the AAr cryostat and AAr cryogenics.

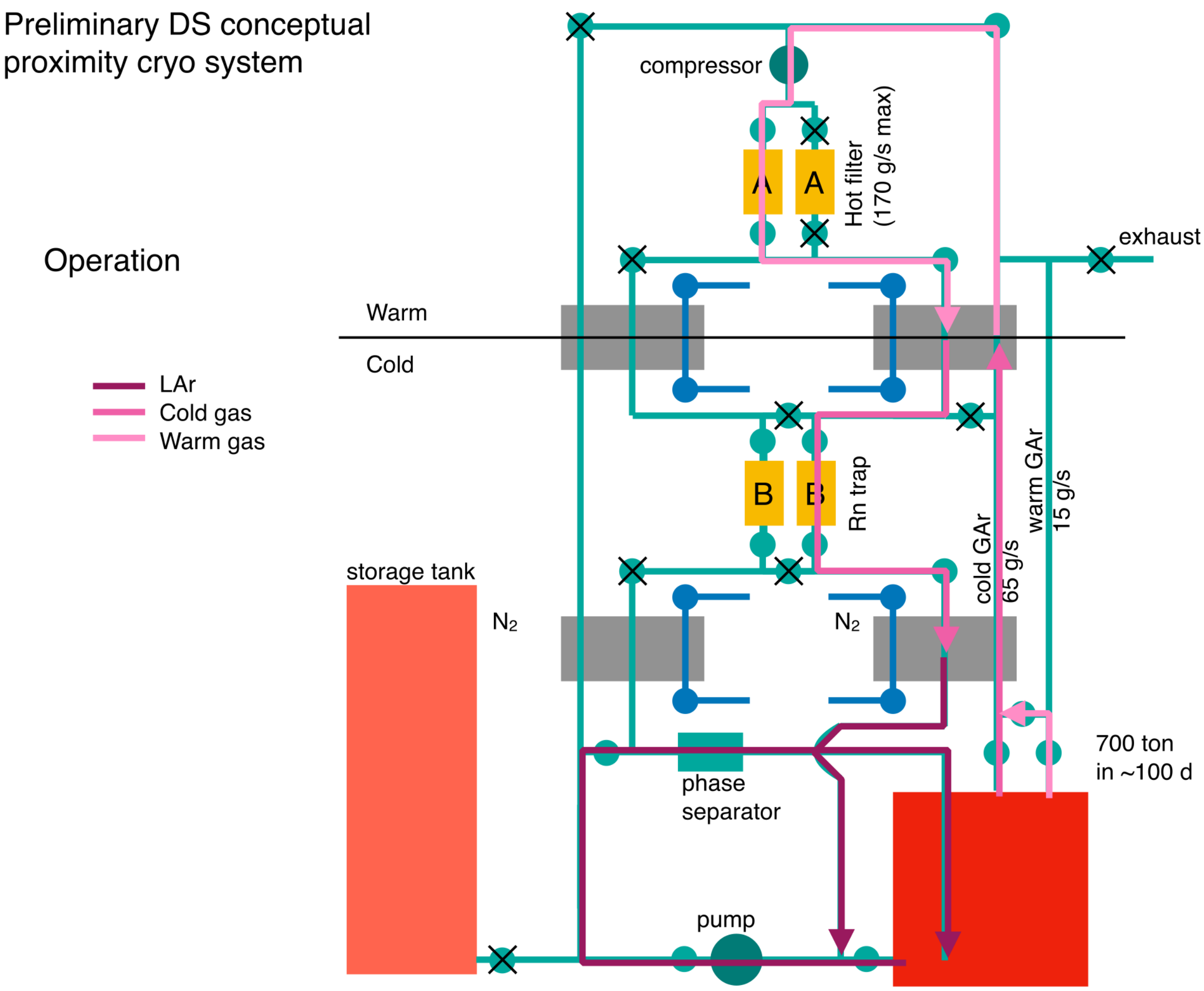

FIG. 7. AAr Cryogenics conceptual schematics

Table IV presents the most probable cooling budget necessary. During filling the estimated necessary cooling value is 14 kW. The AAr cryogenic system is designed to cope with a total heat load of up to 15 kW from the system itself and from the heat load coming from the detector. All cooling activities and the related N_2 project is not part of the contractor responsibilities.

Fig. 7 shows the conceptual schematic that is considered for the AAr cryogenic system. during operation. The paths highlighted refer to the operation phase, with liquid circulation, but no purification. Purple lines are for liquid argon, the one in dark and light pink are for cold and warm argon gas.

2.6 Leak Tightness Tests

- The process volume of the cryostat (primary membrane) and the cryogenics system will have to be leak tight;
- Leak tightness of each component of the AAr cryostat and of the AAr cryogenics will be checked and certified by the contractor;
- AAr Pipes and the AAr cryostat vessel will be certified for a leak tightness better than 5×10^{-6} mbar.L/s ;
- Primary membrane should be tested and certified for a leak tightness better than 5×10^{-6} mbar.L/s;

- The contractor will detail the leak test procedures and its validation criteria.

2.7 Construction Standards

The contractor will respect the “good construction standard” (buona norma costruttiva) and will follow the italian regulations when applicable.

2.8 Maintenance Protocol

The contractor will provide a detailed system maintenance manual as well as the maintenance manual for all ancillary equipment directly related to the AAr crostat and cryogenics.

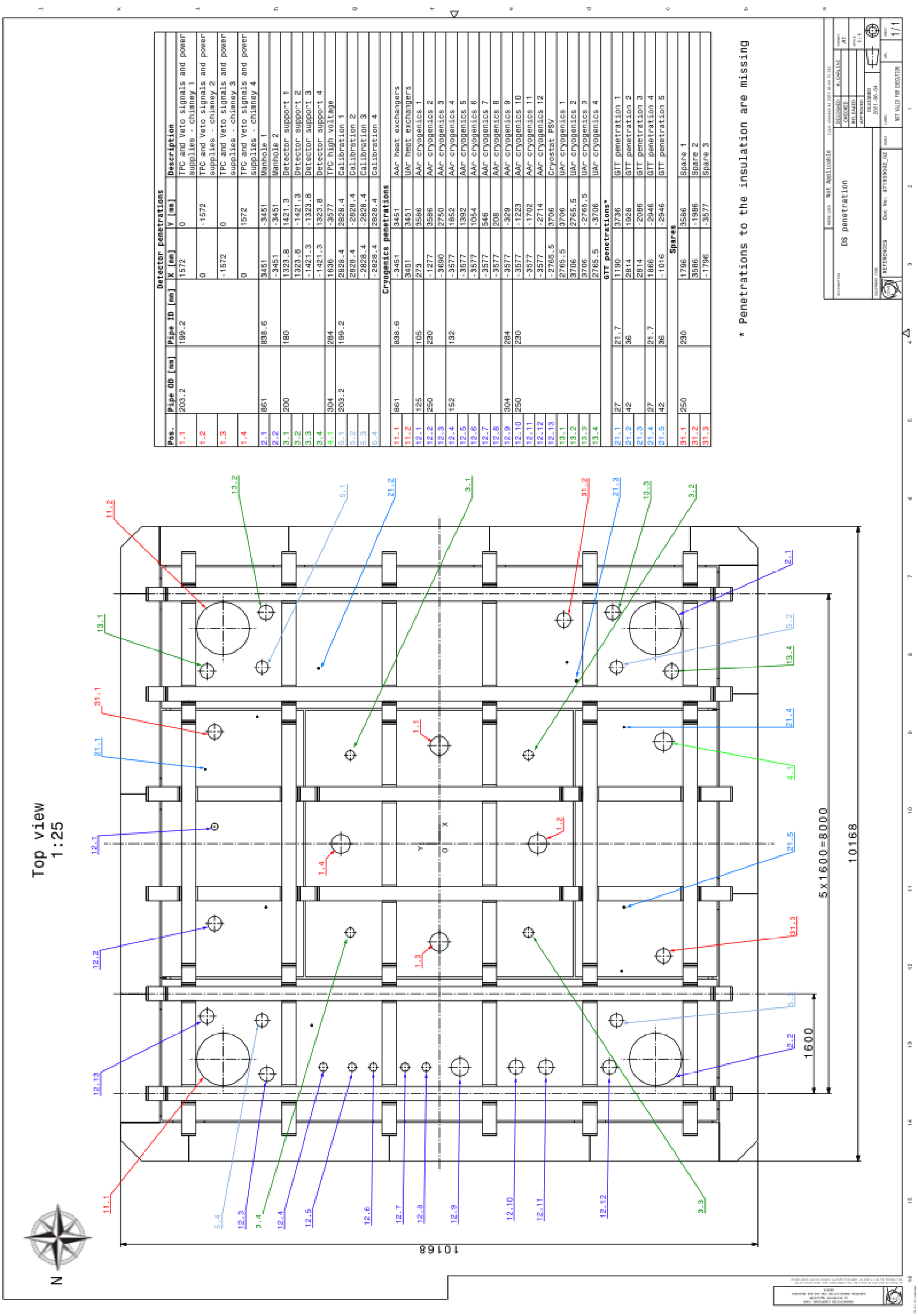

FIG. 8. Cryostat top caps penetrations.