DUNE-ND LArTPC Cryostat Cold Membrane

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U.S. DEPARTMENT OF ENERGY | Office of Science
BERKELEY LAB

Charge # 6.d, 7

Unlike other Cryostat elements, the Cold Membrane is vendor engineered

- Vendor provides design and commercial deliverables
  - Requirements and interfaces
  - Structural and thermal analysis
  - Models and drawings
  - Fabrication and installation cost estimates
  - Approved fabrication vendor list
  - Approved installer list
  - QA/QC processes
- ND Cryostat team provides interface information
- GTT is sole source vendor
  - NDA in place with LBNL and key DUNE members
- Preliminary engineering study complete
- Final engineering study subcontract and statement of work are in final stages of review

Cold membrane is made of polyurethane foam insulation and a corrugated stainless steel membrane

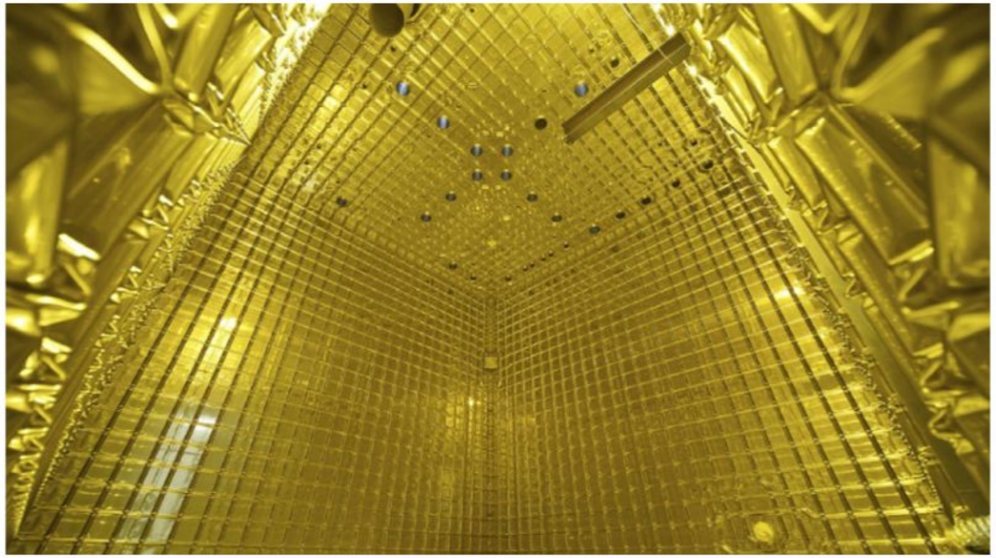

Figure 1.19: Cryostat cold membrane example, ProtoDUNE cold membrane shown above.

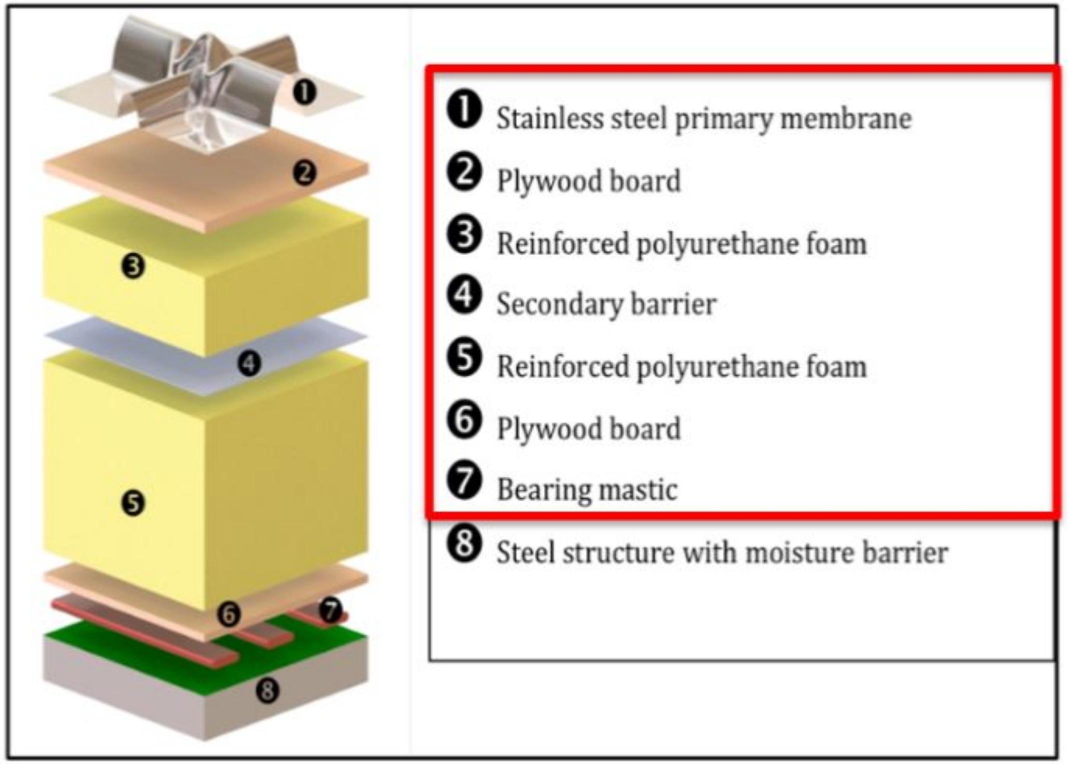

Figure 1.20: Cryostat cold membrane through-wall construction.

Preliminary Study Goals

Technical

- Design description
- Preliminary bill of materials (BOM)
- Thermal analysis
- Warm structure dimensional and structural requirements
- Example P&ID for dry N_2 purge of insulation volumes
- Density map

Commercial

- Approved vendor lists for fabrication and installation
- Installation schedule
- Cost estimates for final study, fabrication and installation

Cold Membrane initial specifications captured in DU-1001-3496

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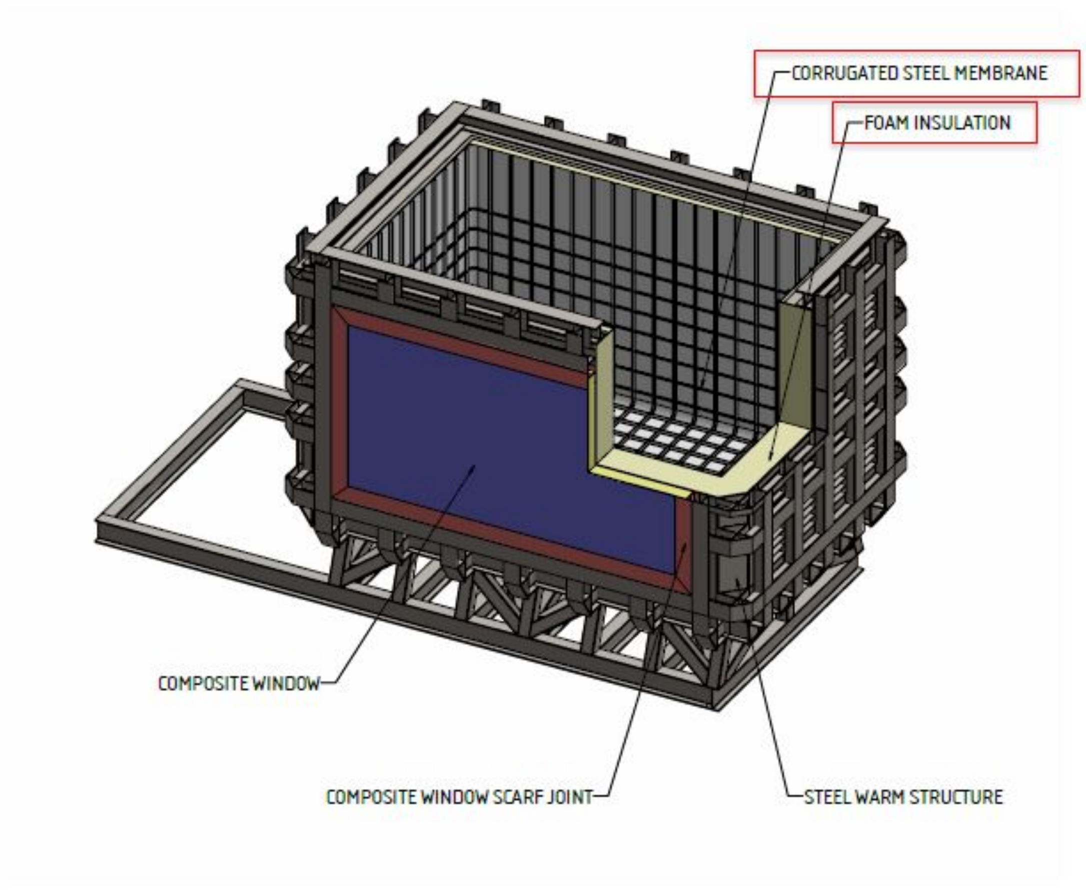

Figure 1: Cryostat assembly (lid not shown). This specification document and request for budget estimate is specifically for the Corrugated Steel Membrane and Foam Insulation.

PENETRATION REQUIRED FOR DUNE APPLICATION

LAR PUMP PENETRATION

An external pump is used to circulate LAr from the cryostat through a filter in order to maintain adequate purity for the detector function. The supply line for the pump passes through the wall of the cryostat near the bottom of the liquid level. The penetration for this line may influence the configuration of the insulation panels and the cold stainless steel membrane weldments. There is flexibility in the positioning of this penetration to minimize any required change in the primary membrane pattern. A nominal location and size of this penetration is shown in Figure 4.

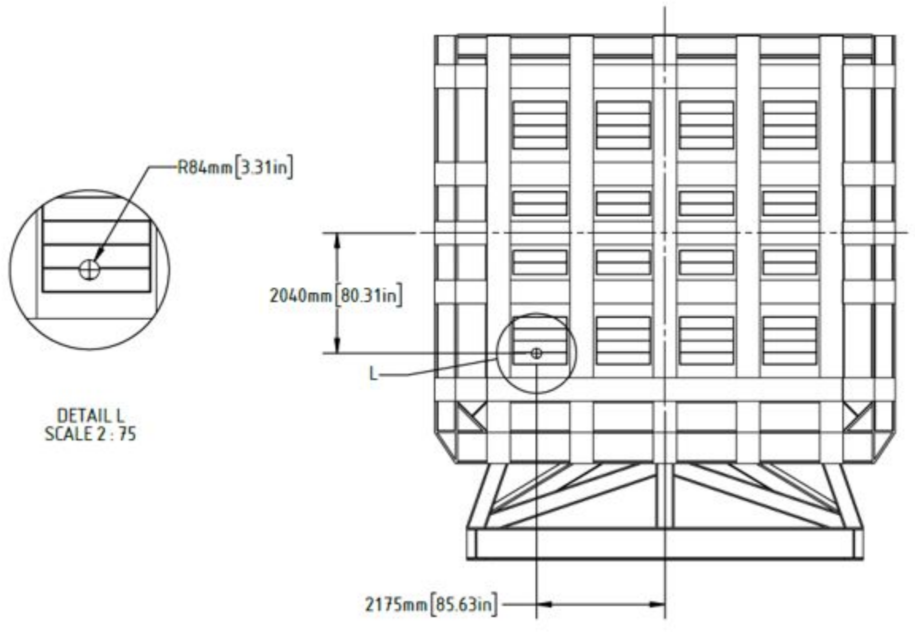

Figure 4: LAr Pump Protego Valve Penetration

Preliminary Study - Input Information to the SOW

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a) The required inner volume defined by the primary membrane on walls and bottom and by the top cap vapor barrier at the top is: 5500 mm * 5400 mm * 9000 mm (height*width*length).

b) Tank capacity is defined by the thickness of the GTT cold vessel layout and is expected to be around ~ 300 tons

c) Residual Heat Input (RHI): Thermal fluxes are to be controlled so that the unitary value calculated in unidirectional model is below 10W/m2 on the wall and floor in contact with liquid.

d) Insulation density: 90 kg/m3

e) Insulation thickness (all included): 0.800 m

f) Design pressure: Max 1350 mbara / Min 950 mbara. 1350 mbara is the set point of the cryostat Pressure Safety Valves.

g) The atmospheric pressure at the site is: ~1000 mbara.

h) Operating temperature: 86K to 90K

As the cold vessel is based on the GTT membrane technology, the insulation thickness is 800 mm, including the primary and secondary membrane, as per GTT existing design. The GTT membrane technology will provide a first and a second level of containment. There is no requirement at this point to have an additional liquid containment at the level of the warm steel structure. The steel skin of 10 mm thickness, just behind the insulation, will provide an effective gas enclosure, which will allow controlling the nitrogen atmosphere inside the insulation volume. Outer structure will include the same chamfers as LBNF.

The main dimensions (internal membrane and internal 10mm Fe steel) are given on Figure 5

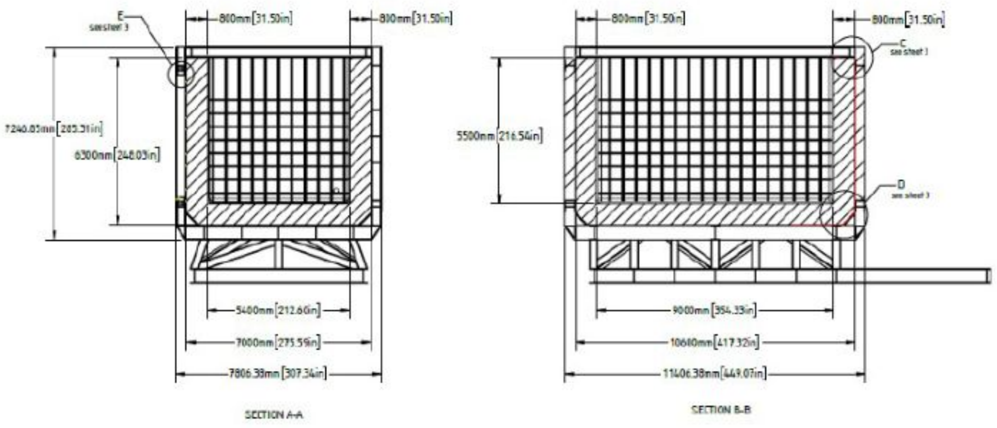

Figure 5: Main dimensions

Designation	LBNL Response	LBNL Document
Project General information		
Applicable norms and standard list	LBNL will provide a list of standards which govern cold membrane design, majority from the Fermilab Environment, Safety and Health Manual (FESHM). LBNL will also provide a list of standards which govern the warm structure design on a reference basis (GTT not responsible for warm structure design).	DU-1001-3496
General specification (already provided by LBNL. Last revision to be sent when contract is signed).	LBNL will update the general specification before feasibility study kick off.	DU-1001-3496
Outer tank specification, including maximum deflection	LBNL will provide maximum warm structure deflection working targets. Ultimate warm structure deflection limits to be defined by GTT and driven by cold membrane requirements.	DU-1001-3496
Seismic data (if any)	LBNL will provide seismic classification of installation site using data provided by United States Geological Survey (USGS).	DU-1001-3496
Tank operating procedure - for information	LBNL will provide a general description of LAr recirculation and pressure regulation, along with a description of the ND-LAr Detector principle of operation.	DU-1001-3496
Atmospheric pressure range at the site (min./max.)	LBNL will provide specifications for atmospheric, liquid argon hydrostatic and argon gas pressure.	DU-1001-3496
Technical general documents		
Characteristics of stored liquid and gas (density, composition, purity, etc...)	LBNL will provide detailed argon specifications.	DU-1001-3496
Top cap design	LBNL will provide conceptual 3D models of the top cap components to represent overall dimensions, interface with cold membrane, and basic feedthrough dimensions. Detector component models to be provided on an envelope basis only. Detailed top cap design will be subject to change as the design matures.	DU-1003-6059?
Reaction loads (effort & moment) from top caps, if interaction with containment system:	[see below]	
-Weight loads	LBNL will provide current estimate of top cap weight plus uncertainty.	DU-1001-3496
-Pressure loads	LBNL will provide specifications for atmospheric, liquid argon hydrostatic and argon gas pressure.	DU-1001-3496
-Thermal loads	LBNL will provide current estimate of top cap heat flux. Detailed thermal modeling of top cap will not be complete in time for GTT feasibility study.	DU-1001-3496
Reaction loads (effort & moment) and location from internal piping, if interaction with containment system:	LBNL will provide rough order of magnitude estimates for internal piping loads. Piping design is in the early conceptual stage but is expected to be similar to previous LAr cryostats for ProtoDUNE and SBND.	
-Weight loads	LBNL to provide rough order of magnitude estimate. GTT to provide limit based on cold membrane capability.	DU-1001-3496
-Pressure loads	LBNL to provide rough order of magnitude estimate. GTT to provide limit based on cold membrane capability.	DU-1001-3496
-Thermal loads	LBNL to provide rough order of magnitude estimate. GTT to provide limit based on cold membrane capability.	DU-1001-3496
Vacuum relief valve for tank		
-Set point	LBNL will provide specifications for atmospheric, liquid argon hydrostatic and argon gas pressure.	DU-1001-3496
Diagrams & drawings		
Penetrations' arrangement and detailed crossing pipes (included diameter, thickness, ...)	LBNL will provide a preliminary 3D model and 2D drawing of the warm structure, including location of the single penetration through the GTT membrane.	DU-1003-6059?
General arrangement (main dimensions)	LBNL will provide a preliminary 3D model and 2D drawing of the warm structure.	DU-1003-6059?
Plate arrangement and beams arrangement (3D model of penetrations and outer tank)	LBNL will provide a preliminary 3D model and 2D drawing of the warm structure.	DU-1003-6059?
Location of the outside structure reinforcement	LBNL will provide a preliminary 3D model and 2D drawing of the warm structure.	DU-1003-6059?
Plate arrangement of the outer structure (butt welding arrangements)	LBNL will provide a preliminary 3D model and 2D drawing of the typical weld joint used on the vapor barrier plates of the warm structure.	DU-1003-6059?
Internal LBNL instrumentation arrangement (if any)	LBNL will provide a conceptual instrumentation plan for the cryostat. Instrumentation details such as sensor requirements and exact placement are still to be determined.	Instrumentation plan slides (pull Windchill number and send PDF)
Internal cryogenic pipes & support (if any)	LBNL will provide conceptual 3D model of internal piping. Piping design is in the early conceptual stage but is expected to be similar to previous LAr cryostats for ProtoDUNE and SBND.	DU-1002-3026?

Charge # 1, 7

ND Inputs and Interfaces for GTT refined at the start of the preliminary study

- GTT requested inputs
  - Cryogen properties
  - Internal dimensions
  - Liquid fill height
  - Gas pressure
  - Allowable heat leak
- ICD DU-1004-9188 (EDMS 3161474 v1)

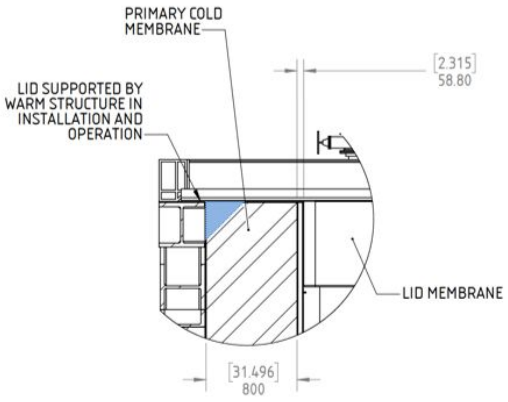

Fig 11: Potential chamfer at top horizontal edge shown in blue

7.2 Technical Requirements

A list of technical requirements and characteristics can be found in Table 3.

Table 3: DUNE ND LArTPC Cryostat Characteristics

Parameter	Quantity	Notes
Liquid Argon Fill Height	4.28 m	
Liquid Argon Hydrostatic Pressure	590 mbar	
Liquid Argon Temperature	86.7 – 88.1 K	
Liquid Argon Flow Rate	875 g/s	Continuous flow during detector operation
Ullage Volume	10 %	
Gas Pressure Relief Valve Setting	350 mbar	
Cold Membrane Residual Heat Input Limit	10 W/m^2	Bulk value across all cold membrane surface area; local variations expected at edges, feedthroughs, etc
Lid Residual Heat Input Estimate	20 W/m^2	Bulk estimate across total lid surface area; local variations expected at gaps, feedthroughs, TPC mounting hardware, etc
Detector Heat Load	8.0 kW	Dissipation of detector elements
Cryostat Heat Load	2.7 kW	Estimated total ambient heat leak into cryostat

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Parameter	Quantity	Notes
Warm Structure Wall Deflection Limit	4.0 mm/m	Measurements taken between sets of three stiffeners, neglecting deformation of vapor barrier plates between (See Figure 6 below)
Warm Structure Stress Factor of Safety Limit	2.0	Von Mises stress / material yield strength

Preliminary Engineering Study Outcome

Charge # 1, 7

- Established working relationship with GTT, sole source for validated LAr cryostat cold membrane technology
- Received cost estimates for all remaining cold membrane M&S (cold membrane represents roughly half of total cryostat M&S)
  - Final engineering study
  - Materials
  - Installation
- Received detailed contractor installation labor hour and calendar time estimates
- Defined requirements which enable preliminary design of warm structure, muon window, and lid
  - Defined warm structure fabrication tolerance requirements
  - Defined warm structure deflection and stress requirements
  - Defined lid membrane corrugation spacing and installation clearance
- Defined interfaces
  - Density map of cold membrane informs physics studies and refines muon window density requirements
  - Cold membrane heat leak calculation informs cryogenic design
  - Lid to cold membrane interfaces enable preliminary design of cryostat lid sections
  - Protego valve position informs cryogenic piping design

Preliminary Study Output Materials

Preliminary Engineering Study Scope (SOW link)
LBNL input requested
4.1 Design Basis and Thermal Analysis
4.2 Steel Outer Tank Requirements
4.4 GST Supplier List
4.5 Companies for GST Erection and Control
4.7 Containment System Preliminary Material Take-Off
4.3 Technical Proposal for LBNL LAr Cryostat - Detailed engineering
4.6 Man Hours and General Construction Schedule
4.8 Design principle: Description of main materials and components View of typical areas (corner, trihedron, flat wall, etc) Requirements/specifications verification matrix Membrane area density at muon window location (typical 1 m^2 grid)
4.9 Commercial proposal for final design
4.10 Procurement and construction cost estimation (+35 / -15%)

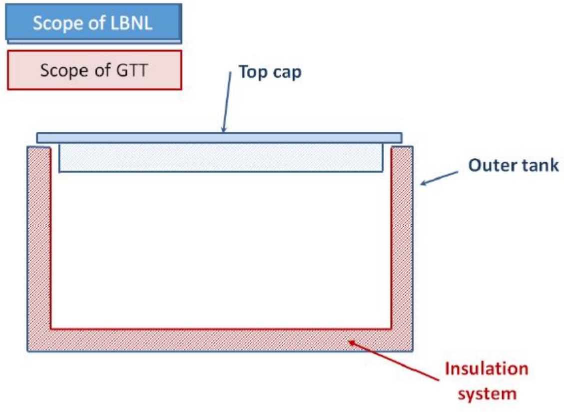


Figure 5: Battery limit for global project

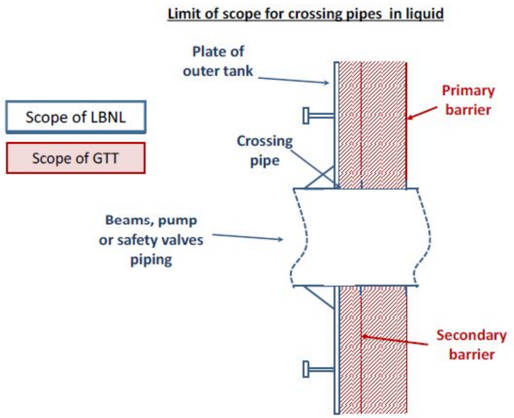


Figure 6: Battery limit at the crossing pipe

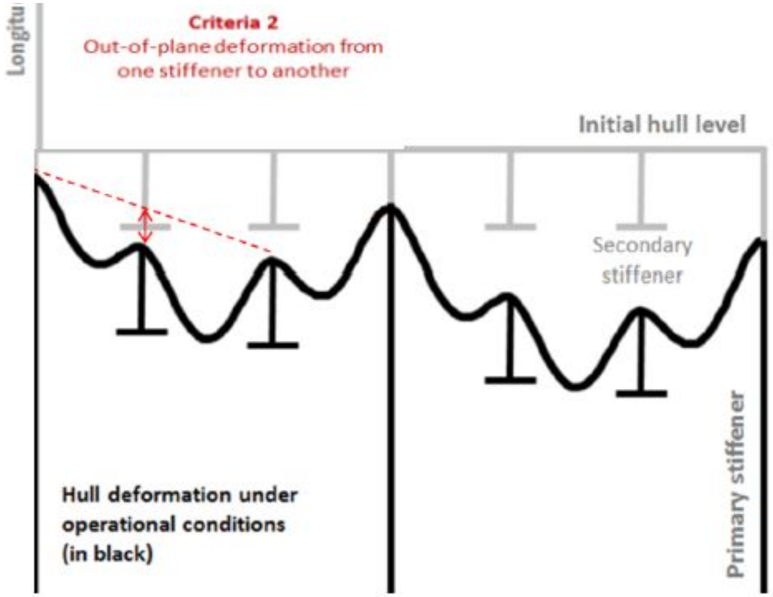


Figure 10: Out-of-plane deformation from one stiffener to another

Preliminary Study Output Materials

The output of the preliminary engineering study was summarized in a document called “Key Information - ND Cryostat Cold Membrane”. Additional level of details on technical information is confidential per NDA with GTT.

Final Study

Status

- Planned for November 2024 – July 2025

Technical Deliverables

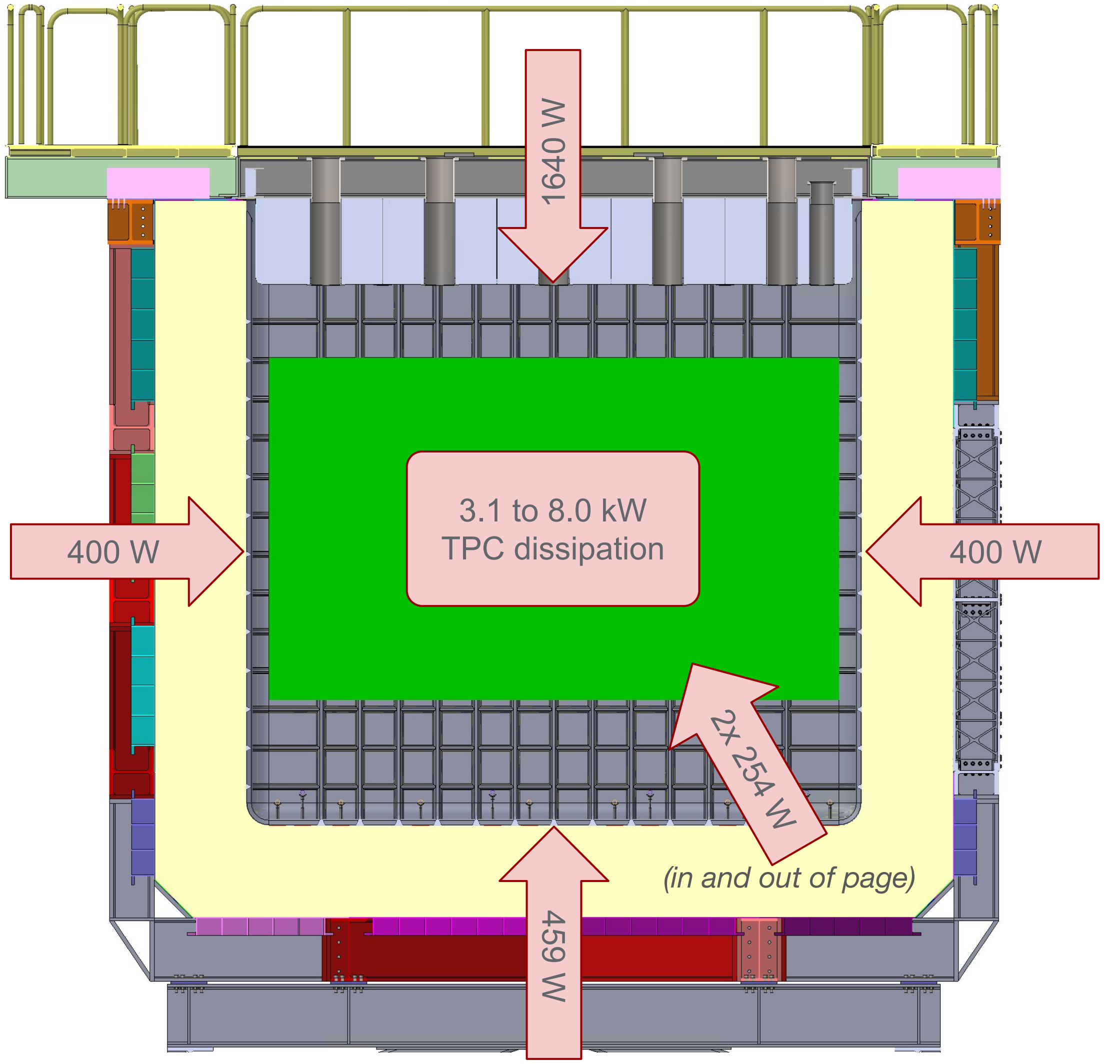
- Detailed 3D model
- Detailed 2D drawings
- Final bill of materials (BOM)
- Thermal analysis
- Warm structure dimensional and structural requirements
- Final P&ID for dry N_2 purge of insulation volumes
- Density map
- Installation and test procedures

Commercial Deliverables

- Approved vendor lists for fabrication and installation
- Installation schedule
- Cost estimates for final study, fabrication and installation

Heat Leak Summary

- Cold membrane ICD limits area specific heat leak to 10 W/m^2
- Lid heat leak is higher due to conduction through feedthroughs and membrane walls, estimated at 36 W/m^2
- TPC array dissipation is majority of heat load at 3.1 to 8.0 kW (see EDMS 458088 v1)



Description	Q
Cold Membrane Heat Leak (W)	1767
Lid Heat Leak (W)	1640
TPC Array Dissipation (W, min)	3100
TPC Array Dissipation (W, max)	8000
Total (kW, min to max)	6.5 to 11.4

Charge # 3, 4

Cold membrane risks have significant impacts but are being actively mitigated

RI-ID	Title	Probability	Schedule Impact
RT-131-ND-257	ND Cryo: Cold membrane design fails downstream density requirement due to tech limitation	30%	6 -- 9 -- 12 months
RT-131-ND-295	ND Cryostat: Tight TPC alignment clearances drive tight Cryostat tolerances	50%	0 months
RT-131-ND-308	ND Cryostat: Revert Cryostat Muon Window to Composite Design	20%	12 months
RT-131-ND-294	ND Cryostat: Cryostat Cold Membrane Single Vendor	35%	3 -- 6 -- 9 months
RT-131-ND-330	ND-LAr: TPC modules damaged during installation into Cryostat	15%	3 months
RT-131-ND-327	ND Cryostat: Cryostat deflection during pressure test differs from analysis results	25%	1 -- 3 -- 6 months
RT-131-ND-328	ND Cryostat: Cryostat fails pressure test due to leak rate	5%	3 -- 6 months

- Cold membrane is expected to meet physics requirements based on GTT's preliminary study results
  - GTT's final study and physics study of ND-LAr / muon window / TMS joint acceptance will provide final answer
- Cold membrane single vendor risk now reflects extended subcontract negotiation time rather than failure to establish commercial relationship
- FNAL risk registry

Charge # 7

Final engineering study with GTT follows directly after this PDR

- Prepare updated interface documents as inputs to GTT final study
- GTT to execute final study
- Use study deliverables to inform Cryostat final design