GERDA

Technical Proposal

Draft of Version 0.2

The GERDA Collaboration

Version 0.2 - DRAFT of June 23, 2006

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Technical Proposal V0.2 - DRAFT

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Contents

1 Preface to Version 0.2

The GERDA experiment [Ger 04] searches for neutrinoless double beta decay of ^{76}Ge. Germanium diodes made out of isotopically enriched material are suspended in a superinsulated copper cryostat filled liquid argon (LAr) or liquid nitrogen (LN2). Because of its radiopurity the cryogenic liquid does not contribute to radioactive backgrounds and serves as a shield against external radioactivity. The shielding is completed by an outer layer of water, i.e. the cryostat is mounted in a water vessel. A clean room on top of the water vessel will house an air-tight lock. The latter is part of the cryostat volume and houses all mechanics for the diode suspension.

This Technical Proposal for GERDA serves several purposes. First, it contains the available information relevant for the safety review at LNGS: the current design of the cryogenic vessel, the cryogenic infrastructure, and the water vessel. The latter also includes the support structure for the above mentioned clean room and lock.

In a later stage, a complete report will describe the design of the entire experiment and will then serve as a reference for the built detector.

This document will therefore become available in several iterations and different chapters will be added once the corresponding design is finalized. This approach was chosen to allow for a timely construction of the experiment and to facilitate the safety discussion with the LNGS laboratory.

The technical drawings of components of the GERDA experiment in this version of the Technical Proposal are preliminary, unless otherwise expressly stated. Compared to version 0.1 the present version contains major updates in the chapters on

- Water Tank,
- Cryostat,
- Safety Aspects.

which reflect that the water tank has been ordered and that the GERDA cryostat has been decided to be fabricated from stainless steel rather than from ultra-pure copper.

2 The Sites of the GERDA Experiment in LNGS

The **Main Experimental Site** of the Gerda experiment is located in Hall A of the Lngs underground laboratory in front of LVD. The **LN_2 Storage Area** and an **Auxiliary System Area** are both located in the TIR tunnel section between Hall A and Hall B. In addition, Gerda uses the Gerda **LArGe** facility for detector storage and refurbishment in Phase I. This facility is located in the Interferometer Tunnel close to LUNA II(ex LENS). All these Gerda sites are indicated in Fig. 1. Additional laboratory space is

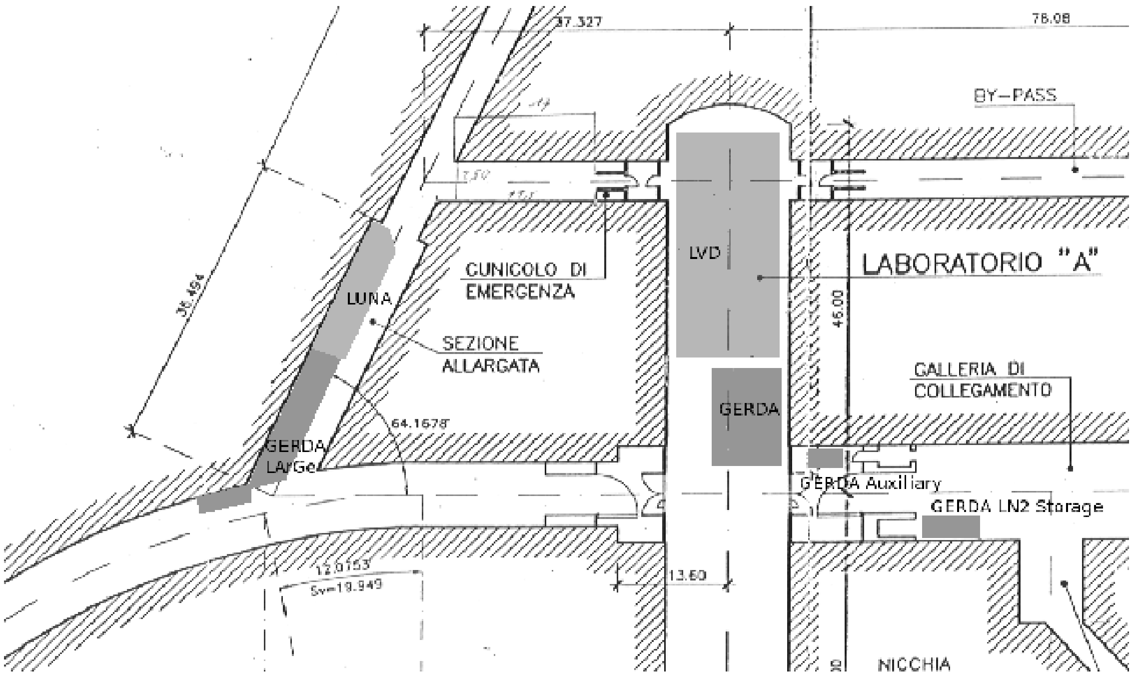


Figure 1: The sites of the Gerda experiment in the Lngs underground laboratory.

needed aboveground for the control of the experiment, detector tests and material storage.

2.1 Main Experimental Site of GERDA

The layout of the main experimental site of Gerda is shown in Figs. 2 and 3 - see also Figs. 4 to 7 for more details and dimensions. The water vessel containing the cryostat with the germanium detectors is placed close to the TIR tunnel at the maximum possible distance from the LVD experiment. The so-called Super-Structure consists of a three floor laboratory building between water vessel and Lvd, and a frame extending over the water vessel providing thus the support structure for laboratory room above the cryostat. The footprint of the Gerda installation is now definitive, and has been slightly modified, both in dimension and position, compared to the previously presented Technical Proposal V0.1 to allow

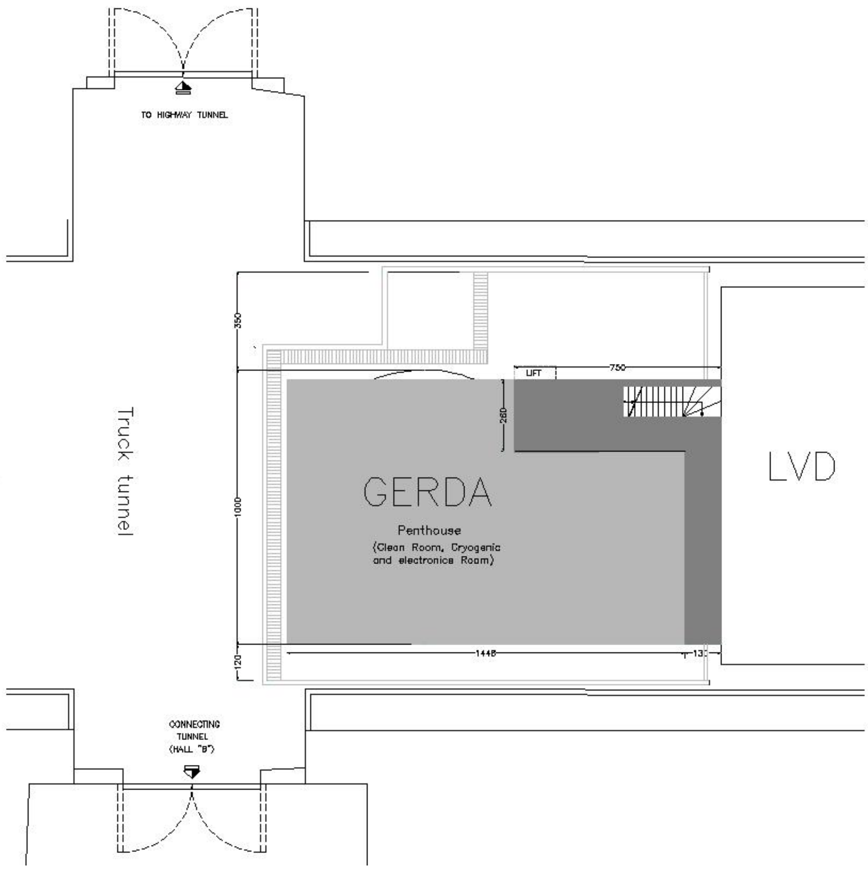


Figure 2: Layout of the Main Experimental Site of GERDA in Hall A (dimensions in cm).

- proper distance from the LVD experiment;
- the removal of LVD tanks in case of decommissioning of the LVD experiment; the distances have been agreed with the LVD collaboration and the LNGS SPP. In this case, after removal from its tower, the LVD tank, suspended at the hall A main crane hook, will reach the TIR tunnel trough the 3 m wide corridor at the west side of the GERDA water tank;
- to keep the escape way of the proper size on the east side of the water tank, for people coming from the LVD installation and/or from hall B installations through the safety door connecting hall B to hall A.

The position and dimension of the GERDA installation have been checked with a three dimensional CAD in order to not interfere with other installations and with the crane movements.

The ground floor (7.80×4.60 m^2) of the laboratory building contains the **Machine Room** with vacuum and cryogenic equipment. Also the equipment for the water treatment is located in this area.

The first level (6.65 x 4.60 m^2) hosts the **Service Area** of GERDA. In consists of the Control Room and laboratory space for on site repair and maintenance. In addition, space for a workplace of the LVD experiment is foreseen on this floor.

The second level with the same area as the first level hosts the **Detector Laboratory** which is needed for the production, assembly, test and repair of the GERDA detectors.

The third level named "**Penthouse**" extends over the whole water vessel. It hosts the lock through which the detectors are inserted into the cryostat, a clean room for detector string assembly and an electronics room for data acquisition. Its layout is described in detail in section 6.

A **stair case** incorporated in the Super-Structure provides on each level access to open galleries which are located between GERDA and LVD. These galleries of a width of 1.20 m are shared by GERDA and LVD; they allow the access to the experimental areas of GERDA and serve also as emergency exits for the LVD experiment.

The Super-Structure is mechanically decoupled from the water vessel and the cryostat. The **admitted load** for all floors is 1000 kg/m^2 while in the area of the inner lock (item 8 in Fig. 14) a load of totally 6000 kg is foreseen. In this area, the support structure of the penthouse keeps a clearance of Ø = 1.80 m for the neck of the cryostat.

An electrical **hoist** with a maximum load of 1500 kg is mounted on the third level. In addition all levels have docking positions which allow to bring in bulky equipment like furnitures with a mobile elevator (see Fig. 3). A special lift (max. 200 kg) will connect the Phase II Detector Laboratory and the clean room areas of the Penthouse.

As can be seen from Fig. 4 the dimension of GERDA allows for the passage of the crane from the north to the south of Hall A. However the hook of the crane must be moved to a lateral 'east' position. Safety systems have to be installed and operational procedures have to be implemented in order to avoid collisions between the hook and the GERDA experiment.

All environments are air conditioned. The **air conditioning** of the Machine Room and the Service Area guarantees a standard working atmosphere. The Penthouse and the Detector Laboratory are designed as clean rooms. Thus a separate air treatment is necessary for these rooms. The filter sets and and fan coils of both systems are located on top of the penthouse.

Electrical Power is available on all floors. Power is needed on normal and no break lines and at 230 and 380 VAC. The GERDA collaboration must still decide details on the type of electrical power needed in the different environments of the Super-Structure.

Cooling water is needed for the cooling of the air conditioning systems. In addition, direct water cooling of some electronics devices is considered.

Washbasins are available in the Detector Laboratory and in the Penthouse area. The wast water of these basins is collected in transportable containers of 1 m^3 volume which are located on the ground floor. These containers are exchanged by an authorised company about twice per month.

Sensors for fire, temperature and oxygen loss must be provided in all rooms. These sensors must be inserted in the **LNGS supervision system**. It should be noted

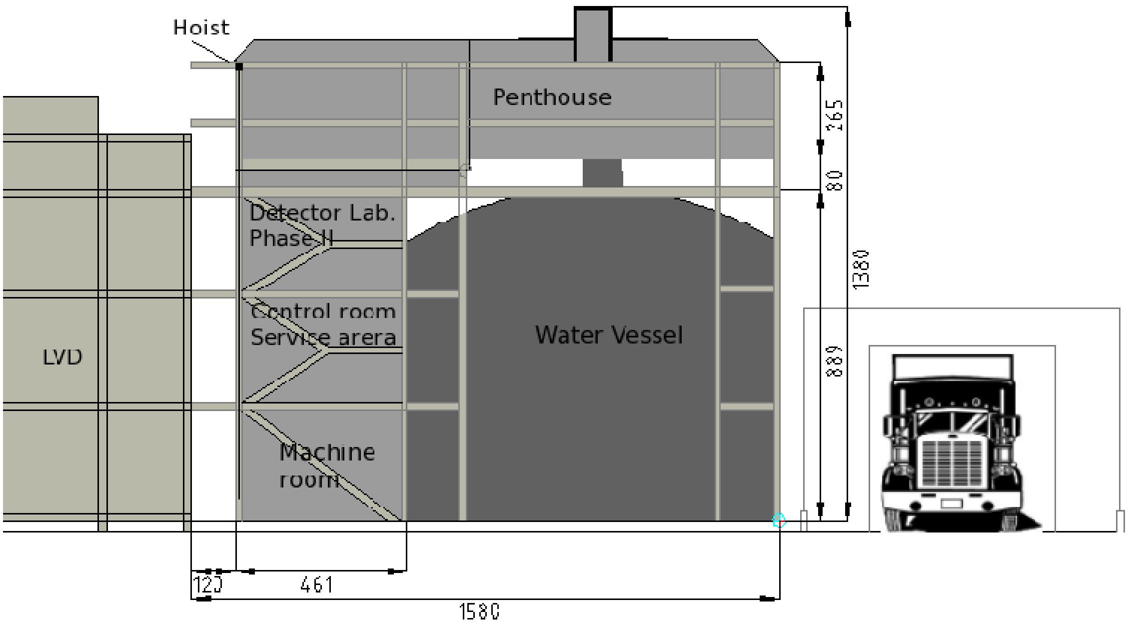


Figure 3: OLD (to be replaced) Lateral view of the GERDA experiment in Hall A (dimensions in cm).

that these basic safety instrumentation is not to be confused with the GERDA Slow Control System which is designed to monitor the status of the experimental apparatus and the related processes. This system will be described in a future section.

Oxygen masks are available in all working environments and in the staircase. A specific procedure will be produced in order to guarantee that every person working in the penthouse has an oxygen mask on site.

An **exhaust line** for blow off of nitrogen gas generated during the normal operation brings the nitrogen to the exit of the Underground Laboratory. This duct also takes the exhaust of the chemical clean benchs in the Penthouse and in the Detector Laboratory.

It may be possible/necessary to use this line also in the exceptional case of emergency blow off. In this case the dimensions of the line have to be dimensioned accordingly.

2.2 Liquid Nitrogen Storage and Auxiliary Equipment

The **LN Storage Area** for GERDA is indicated in Fig. 1. Two 4 m^3 dewars entirely made out of stainless steel are mounted here. Superisolated lines connect these dewars to the main experimental site of the GERDA. The consumption of LN of GERDA is estimated to be of about 4 m^3 per week. This consumption however depends on the details of the design of the cryostat and the related infrastructure.

The **Main Electrical Switchboard** of the experiment and part of the cryogenic equipment, which cannot be placed in the machine room of the laboratory building is located outside Hall A as in Fig 1.

2.3 Space in Overground Laboratory

The complete running of the experiment is controlled from a dedicated **External Control Room** in the outside LNGS laboratory. Here, also the status of the experiment is monitored continuously.

Experimental activities like testing photomultipliers and testing electronics are performed in outside LNGS laboratories in a dedicated **External Experimental Areas**.

During the construction phase material which arrives at LNGS is stored outside the Underground Laboratory until really needed. Only exception are materials which must not be activated by cosmic rays.

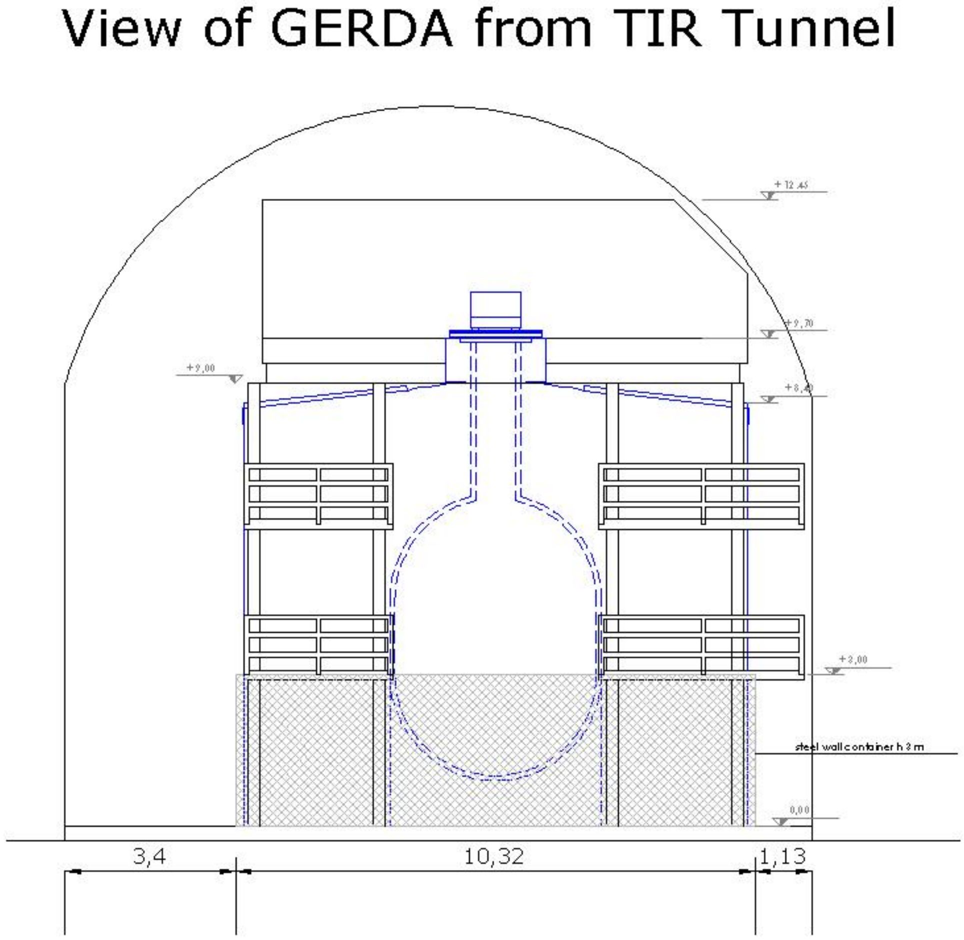


Figure 4: View of GERDA cross section from TIR tunnel.

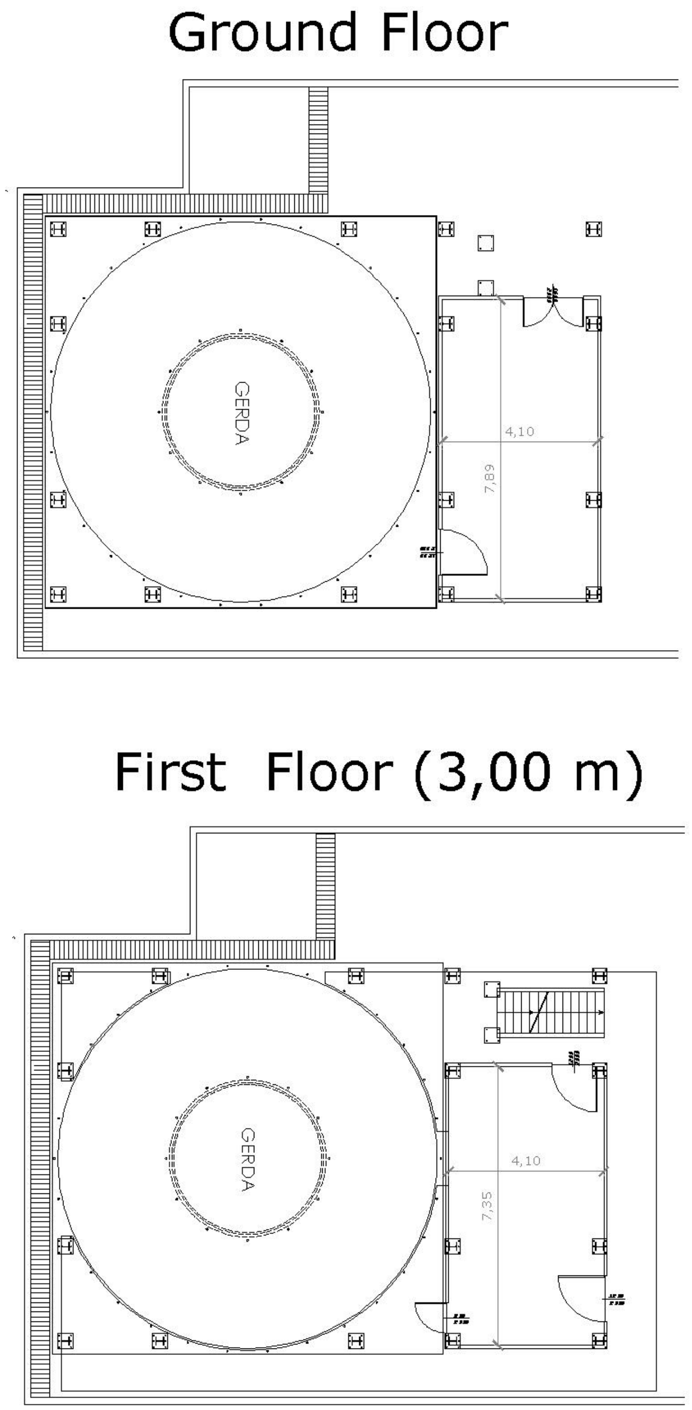
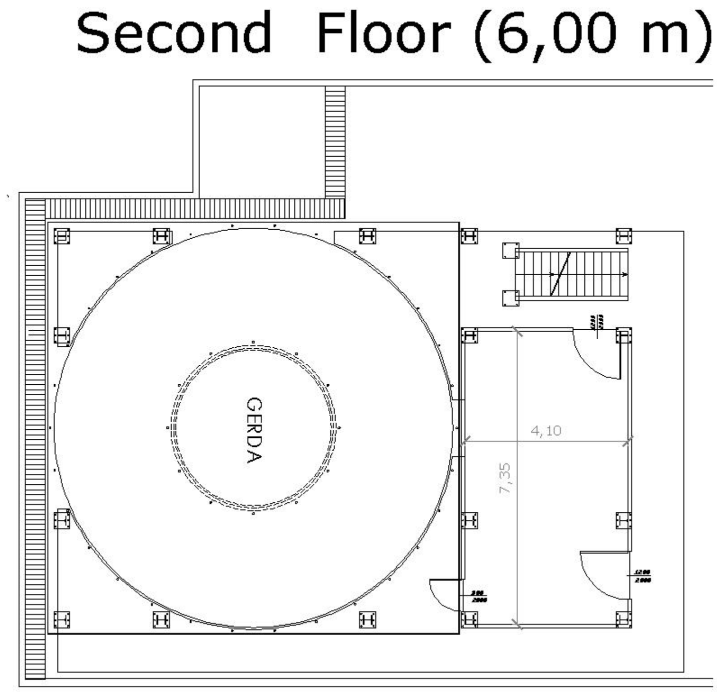


Figure 5: Plan of water vessel and laboratory building: ground and first floor



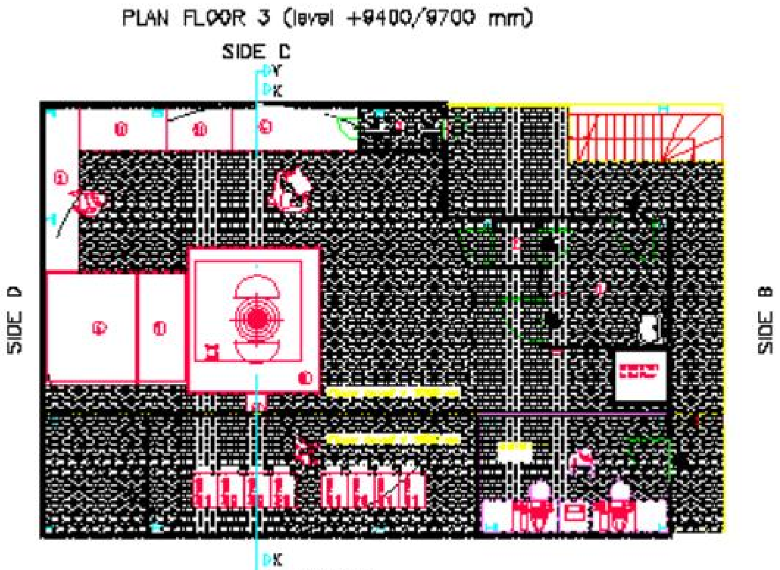


Figure 6: Plan of water vessel and laboratory building:second floor and penthouse

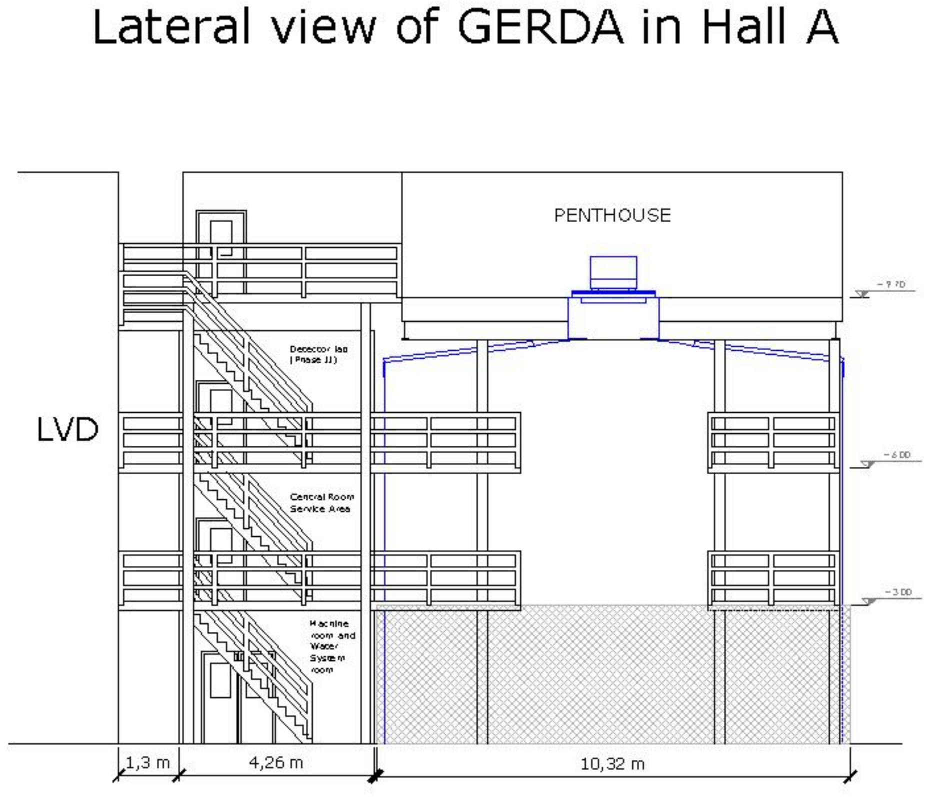


Figure 7: Plan of water vessel and laboratory building: lateral view

3 Water Tank

The GERDA water tank provides the outer shielding shell for the GERDA experiment which has the thickness of 3 m. The vessel houses in its center the cryostat in which the Ge diodes are operated. The water serves in addition as Cherenkov medium for the muon veto system.

3.1 Layout and Specifications

The main features of the GERDA water tank are summarized in Table 1 and cross sections are shown in Fig. 8.

The water tank consists of a cylinder of 10 m diameter and 8.4 m height covered by a frustum-shaped roof which extends up to 8.9 m; the water level is at 8.4 m. The roof has a hole of 1200 mm diameter through which the cryostat's neck can be connected with the lock located in the penthouse above the water tank. The gap between neck and the roof must be closed by a flexible membrane such that neither Radon nor light can enter the water volume. Further Radon rejection is achived by a slightly over-pressurized nitrogen blanket between water and roof. To read out the Cerenkov light produced by the muons crossing the water, a structure holding about 80 photomultipliers will be fixed at the inner side of the water tank's shell. For optimum light collection the walls of cryostat and water tank have to be covered with a reflecting foil. Access into the water tank is possible through a manhole of 1400 x 800 mm diameter.

The water tank will be projected following the API 650 regulation, and the Eurocodice 8 for the seismic acceleration, and built following the italian safety regulations (*DL 626* and following). The water tank construction is planned to start in autumn 2005, from a qualified company that will win the dedicated tender procedure. The BOREXINO water tank is a reference concerning the safety aspects and the quality of the final product.

Due to its dimensions the water tank will be built on site. The procurement of material and the needed technical gases will be procured by the company. To build the water tank the needed equipment in Hall A will be:

- the 40 t crane of Hall A, and eventually another crane provided by the collaboration will be necessary to install and keep in position the inner cryostat while the WT is constructed. In fact due to their geometrical dimensions the WT will grow around the cryostat.
- electrical power .?. kWh
- water (inlet and outlet)

3.2 Water Plant

The BOREXINO water plant will be used for producing the about 650 m^3 of purified water needed to fill the GERDA water tank. The water will be transported by a pipeline from BOREXINO to GERDA as shown in Fig. ?tobeprepared?.

To maintain the quality of the water in the GERDA water tank continuous recirculation of the water at about 2 to 3 m^3/h and adequate water processing is foreseen. Details of this water plant are to be specified.

3.3 Shielding Materials in Water Tank

The limited height of the water tank implies insufficient vertical shielding which will be compensated by layers of radiopure copper or lead. These layers have to be installed below the cryostat at the bottom of the water tank.

The optimization of these shielding layers is done by Monte Carlo simulations.

3.4 Safety aspects related to Water Tank

As stated elsewhere in this document the top events related to the presence of $\approx 600\,\mathrm{m}^3$ of water in the water tank operation

- spilling of water in hall A, either from tank or from pipes connected to WT. In this case the grid in the floor (see Fig. 9) will collect the water floating on the floor and drain it. Moreover in the WT project a containment wall of 3 m height is foreseen (see f.i. 7 all around the WT, to contain severe water spilling; this wall is somehow redundant with the grid therefore its presence has to be discussed with LNGS SPP.

- loose of vacuum of the cryostat insulation layer. In this case the water has to be removed as quickly as possible to reduce the heath capacity of the medium surrounding the cryostat outer shell.

Draining of the WT is planned through a dedicated DN250 pipe running below the TIR tunnel that will collect the water outside the underground labs, as shown in figure 9 . Given its dimension, slope, roughness etc. the max flow rate of the pipe is $\approx 65\,\ell/s$, of which only $\approx 55\,\ell/s$ are allowed for GERDA draining, as $\approx 10\,\ell/s$ of water are continuously collected along the TIR tunnel spilling from rocks. Given the allowed flow rate, the time needed to completely drain the water tank is ≈ 3.5 hours.

Table 1: GERDA Water Tank main features

Reference regulation for structural project:	API650
Further verification for seismic hazards:	Eurocodice 8
Quality certification of construction process:	ISO9001
Quality certification required for company:	ISO14001
Tank height / external diameter:	8.9 m / Ø 10.0 m
Height of the water level:	8.4 m
Effective capacity (m^3):	633 m^3
Water tank bottom:	flat, plates head welded
Water tank roof:	conical from the shell, (Ø 4.5 m)
Water tank shell:	cylindrical, plates head welded
Water tank sheet-metal plates:	≈2 m
Angle between shell and roof:	≈6°
Bottom renforcement:	yes, at 1 feet level
Renforcement rings along the shell:	yes, 1 or 2
Water tank Material:	stainless steel AISI 304 L or 304 LN, or carbon steel plus appropriate coating
Thickness of the shell:	12 to 9 mm
Connections between plates:	welded
Welding type:	external MIG, internal TIG without filler metal
Welding certification:	certified by the executing company fully X-ray tested
Approximative length of welds:	400 m
Flanges	
1 600 x 1400	elliptical manhole in the shell
1 DN 1200	in roof for cryostat neck equipped with custom flange
2 DN 500	manhole in roof for level,
2 DN 200	pressure and depressure safety devices
1 DN 50	net fit connection for N inlet
1 DN 300	for total drain compensation
2 DN 250	in roof for photomultiplier cables
2 DN 300	to drain tank completely in 20 h
2 DN 80	lateral for water recirculation
Weight of water tank (tons):	<20 tons
Weight of filled water tank:	650 tons
Operational over/underpressure:	±20-30 mbar
Safety device:	pressure/depressure ±20-30 mbar
Water recirculation:	yes, 2-3 m^3/h
Water recirculation plant:	deionization, Radon stripping, particulate removal

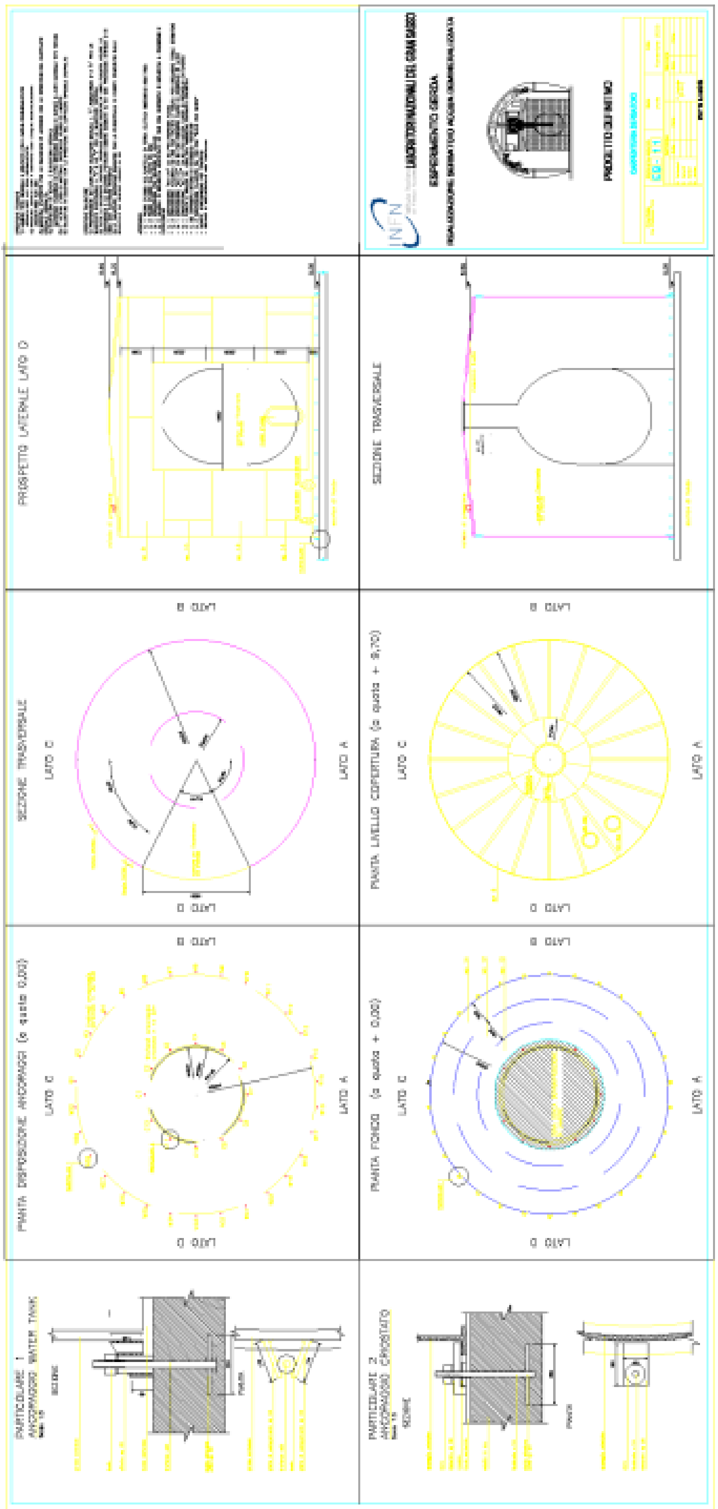


Figure 8: GERDA Water Tank cross sections and anchorage details.

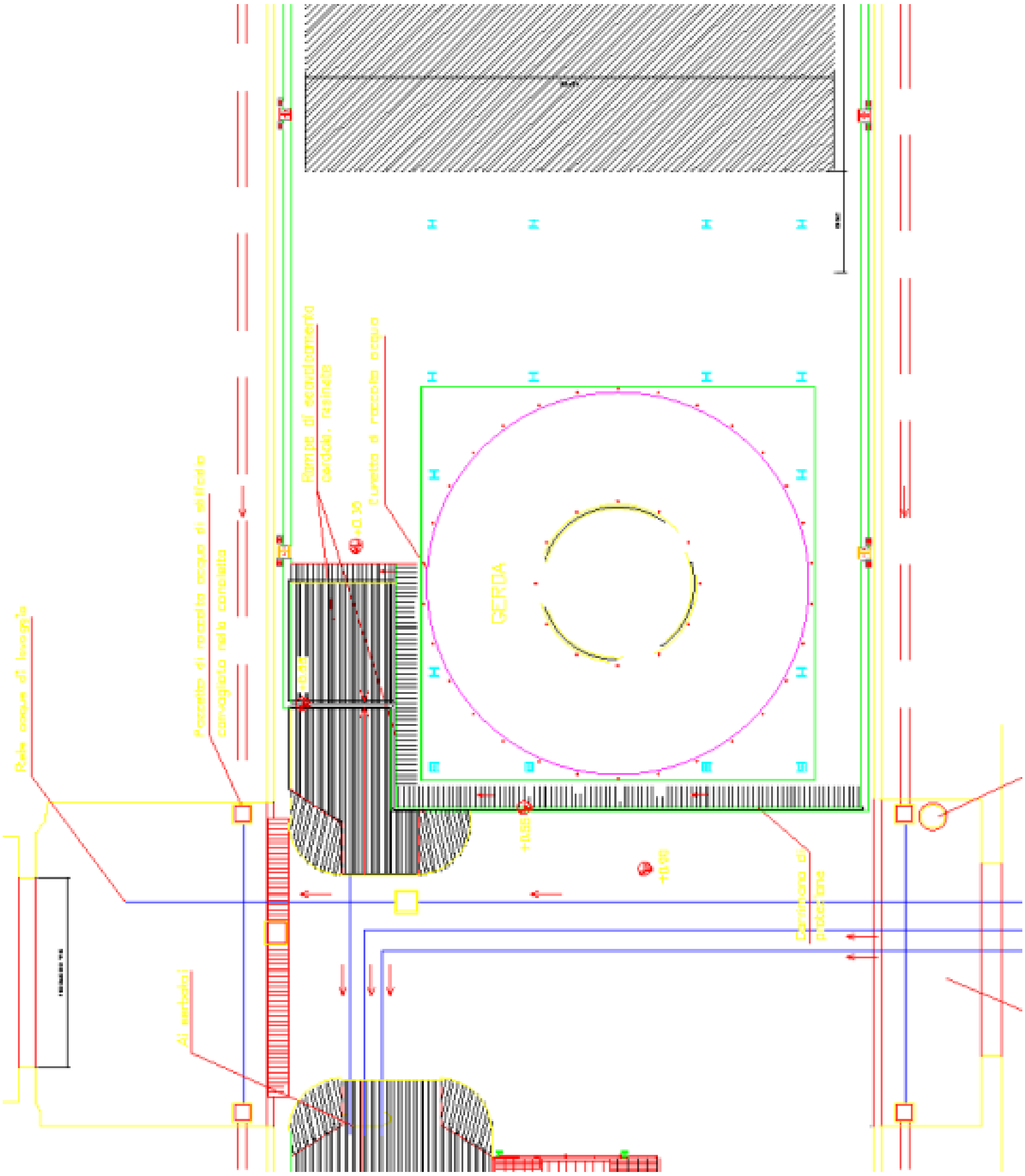


Figure 9: The pipe system devoted to drain the water tank, running below the TIR tunnel.

4 Cryostat

The GERDA cryostat serves as container for the liquid argon (LAr) or nitrogen (LN2) in which the Ge diodes are operated. The cryogenic liquid serves simultaneously as a shield against the remnants of the external γ background penetrating the surrounding water shield and of the cryostat's own radioactivity. In order to prevent any radon contamination via the air, the cryostat will be operated at a slight overpressure of 49 kPa (490 mbar). A thermal shield system reduces the heat load from the surrounding environment (water) such that less than 0.2% cryogenic liquid are evaporated per day.

As outlined in the Proposal, the production material of the baseline cryostat was almost completely copper of extremely low radioactivity. To keep the radiopurity of the copper material, electron beam (EB) welding in a vacuum chamber was chosen as welding technique. By February 2006, the designs of the cryostat and the requested copper 3rd wall were practically finalized and all TÜV EB welding certifications including bending tests of EB welded copper plates were successfully passed; moreover 70t high purity copper were ordered. In March 2006, the MPI Heidelberg received from the EB welding company the definitive quote for the manufacture of the copper cryostat. This quote was by a factor of four higher than the initial estimate received in September 2004. Thus, the total cost became higher than the available budget.

As to this new situation, the GERDA collaboration decided in a meeting on Mai 29 that the Proposal's backup solution, a stainless steel cryostat with an internal copper liner, should be taken as the GERDA baseline design. **This choice implies that LAr has to be used has cryogenic shield in order to obtain the desired background index of 10^{-3} cts/(keV·kg·y).** However, if stainless steel of sufficiently low radioactivity can be purchased, the use of LN2 could be possible at slightly enhanced background index. Thus, the following chapters will discuss relevant issues for both LAr and LN2.

4.1 Specifications and Engineering Description

Fig. 10 shows the cross section of the superinsulated cryostat designed in accordance to the German codes for cryogenic and pressure vessels and taking into account the indicated load cases; the construction material is type 1.4571 stainless steel or equivalent. A summary of specifications is given in Table 3.

The cryostat consists of two coaxial vessels which are built from torospherical heads (diameter of vessels are 4.0 m and 4.20 m) and corresponding cylindrical shells of about 4 m height. Both vessels have a cylindrical neck of 1.7 m length. In case of earthquake the largest stress will occur at the transition between neck and upper torospherical head, and thus this part is reinforced by an additional stiffening ring.

The inner vessel rests on 8 Torlon (or Vespel) pads which are located at the bottom between inner and outer vessel. The compensation for thermal shrinkage of the inner container, a maximum of 2 cm when cooled down from 300 K to 77(88) K, is provided by an double-walled stainless expansion joint in its neck. Three Torlon spacers within the neck and and three at the bottom keep the inner vessel centered.

A cylindrical skirt made from 12 mm thick stainless steel supports the outer vessel from the ground. The skirt exhibits 2(4) access doors and 8 circular ports for mounting photomultipliers of the muon veto system.

On a bolt circle of 4 m diameter, 24 M39 srews are used to attach the cryostat to the floor. At its neck, a metal ring of 1400 mm diameter carrying 16 M12 bolts will serve to establish a flexible yet gas-tight connection with the roof of the water tank.

The internal copper shield for the cylindrical shell will rest on two stainless steel support rings at the bottom of the shell which are spaced by 1 m; its fixation will use another steel ring at the top of the shell. The thickness of the copper shield has been determined by Monte Carlo simulations and depends of course on the radiopurity of the stainless steel material. For an activity of about 10 mBq(^{228}Th)/kg and liquid argon (LAr) filling, typically 40 tons of copper would be needed. With a liquid nitrogen filling (LN_2) the amount of copper would triple. The design allows for a total mass of 48000 kg copper lining.

The volume between both vessels will be pumped via a CF200 flange at the very top of the neck in order to maintain the insulation vacuum below 0.01 Pa. Two CF100 flanges will be used to connect safety and pressure relieve valves as well as manometers.

Two lifting eyes are provided at the top vessel head as well as a tracing eye at the skirt bottom ring. A cylinder introduced through the neck and attached at the top flange will serve as transportation lock that prevents any axial movement between inner and outer vessel in case of transportation in horizontal orientation.

Table 2 provides a compilation of the mechanical and thermal properties of various candidate materials for the support pads. While all materials qualify for cryogenic use, the polyamide-imide Torlon 4203 combines low thermal conductivity with very good mechanical strength.

Table 2: Candidate materials for support pads (values measured at 23°C).

Property	Vespel SP-1	Torlon 4203L	Torlon 4301
Density (g/cm^3)	1.43	1.42	1.45
Tensile strength (MPa)		192	103
Tensile modulus (MPa)		4900	6206
Shear/flexural strength (MPa)		241	113
Compressive strength (MPa)	137	221	152
Compressive modulus (MPa)	2400	4000	6500
Friction coefficient (dynamic, dry vs. steel)	0.29	0.35	0.2
Thermal expansion coefficient (10^{-4}/K)	0.30	0.31	0.25
Thermal conductivity (W/(m.K)	0.35	0.26	0.53

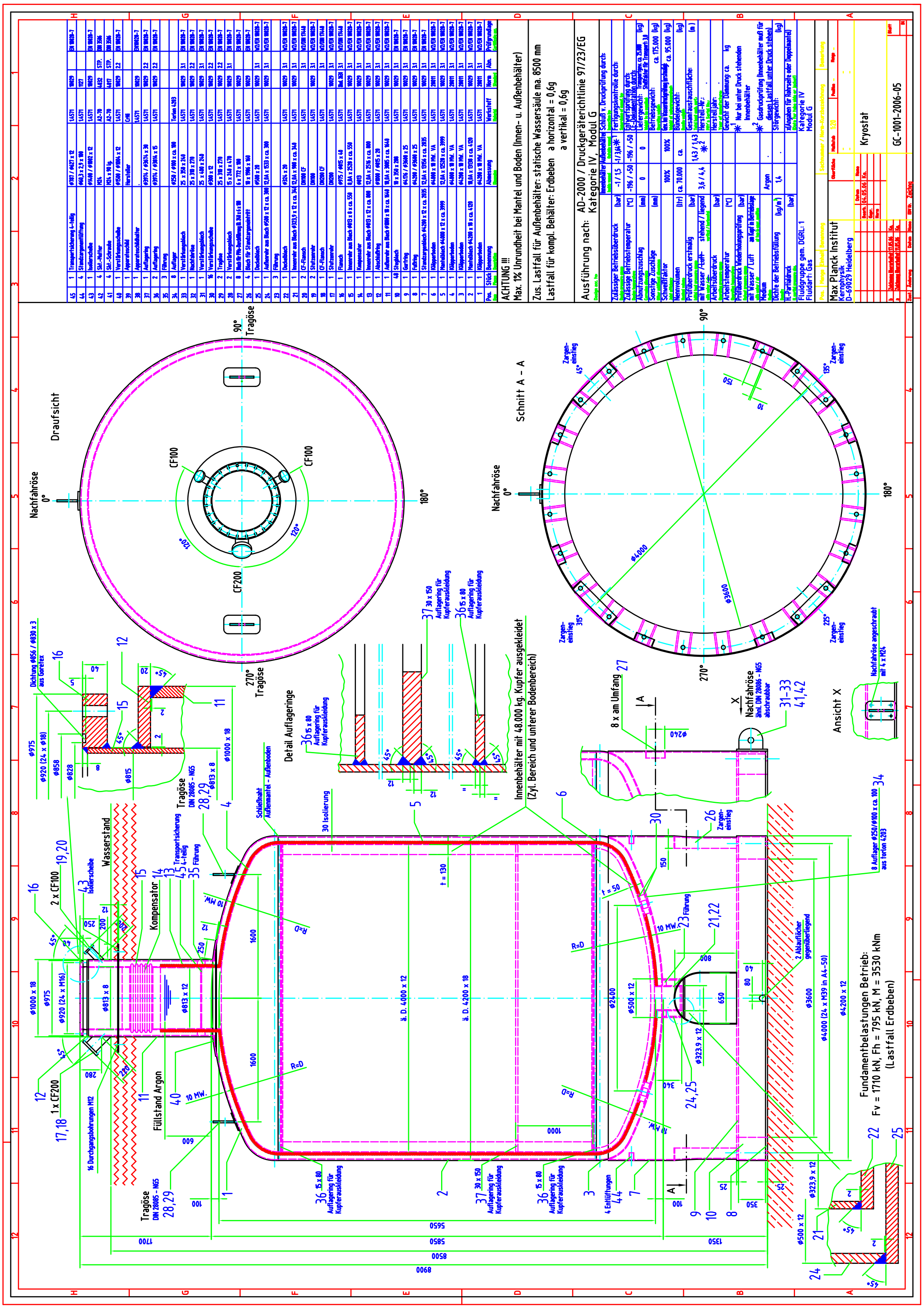


Figure 10: Technical drawing for the GERDA stainless steel cryostat.

Table 3: Characteristics of GERDA stainless steel cryostat

Materials and Radiopurity		
vessel	1.4571 equiv.	<10 mBq(^{228}Th)/kg
compensator	dto.	
multilayer insulation (MLI)	alum. polyester	< 2× steel activity
pads	Vespel or Torlon	<5 mBq(^{228}Th)/kg
Cu shield	OFRP copper	< 20 μBq(^{228}Th)/kg
Geometry		
overall dimensions $\O_{outer}\times$h	4200×8900	[mm×mm]
neck height	1700	[mm]
neck inner diameter $\O_i$	800	[mm]
top flange at neck	(Ø975×40)	[mm]
inner vessel volume	≈ 70	[m^3]
LAr fill level	6350	[mm]
Masses		
empty vessel	≈ 30,000	[kg]
max. load inner vessel		[kg]
LAr	≈ 98,000	[kg]
Cu shield	≤ 48,000	[kg]
total mass	≤ 176,000	[kg]
Pressures (w.r.t. atm. pressure)		
inner vessel operating pressure	< 0.5	[10^5 Pa]
inner vessel maximum pressure	1.5/-1.	[10^5 Pa]
outer vessel pressure	3.6/-1.8	[10^5 Pa]
pressure for LAr emptying	1.2	[10^5 Pa]
Loads		
Loads		
top of neck	1500	[kg]
top inner vessel head at r=1 m (e.g. hoist)	3000	[kg]
buoyancy outer vessel	≈ 700	[kN]
Superinsulation		
numbers of layers	20 - 40	
thermal loss	≤300	[W]
corresponding daily loss of LAr (0.2%)	140	[ℓ]
active cooling power	≈400	[W]
construction code	AD2000 HP DGRL 97/23 EG	
fraction of x-rayed welds	100%	
earthquake tolerance	h/v 0.6 g	

4.2 Multilayer Insulation

The multilayer insulation (MLI) will be attached in the space between both vessels using short spikes that are stud welded to the wall of the inner vessel. The sides of the support and centering pads must be covered by the MLI. The maximum thickness of the MLI will not exceed 20 mm including assembly and attachment provisions.

MLI or superinsulation consists in general of closely spaced shields of Mylar or Kapton covered with a thin reflective layer of aluminium, silver or gold. Stacks of typically 10 layers with integrated spacers, 'blankets', are tailored by industry for specific shapes and applications; depending on material, number of layers, and packaging density the thermal flux ranges from 0.55 to 1.5 W/m^2, see Table 4 for samples from a specific product line.

Table 4: Specifications of two commercial MLI thermal blankets for temperatures of 77 K and 300 K [AAe 05]. All products contain polyester foils or yarns.

Product	heat loss W / m^2	density g / m^2
Coolcat 1 crinkled		
one side aluminisation, venting at edges		
30 foil layers	1.0 - 1.5	234 - 276
40 foil layers	0.8 - 1.2	
50 foil layers	0.6 - 0.9	
Coolcat 2 NW spacered - porous structure		
double side aluminisation, perforated		
20 foil + 20 space layers	0.79	256 - 364 or 414 - 554
40 foil + 40 space layers	0.65	

To function as a high performance thermal insulation, MLI reqires high vacuum below 0.01 Pa. Fig. 11 shows the variation of heat flux with vacuum pressure for another commercial product consisting of 30 layers with 7.0 mm total thickness. Above 1 kPa the heat flux has increased by more than two orders of magnitude. Thus, the vacuum pressure will be monitored and maintained by periodical pumping.

To avoid degraded vacuum conditions between the foils of large area MLI blanket systems, the purely edge-pumped blankets of the past have been replaced recently by perforated blanket systems. These exhibit for example non-overlapping holes of typical 4 mm diameter and a pitch of 120×156 mm yielding 0.05 to 0.1% open area.

In case of polyester insulation suitable welding protection is required since this material is flammable. Polyester foil is known to fail in test 4.4.2 of EN 1797: flash in drop test under 50% LOX - 50% LN2 [AAe 05].

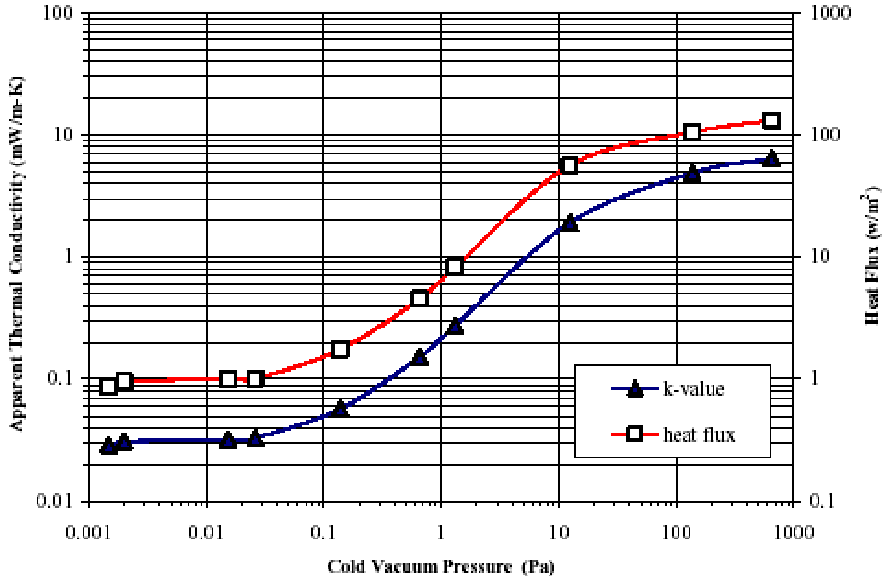


Figure 11: Variation of heat flux (right scale) and apparent thermal conductivity in a MLI blanket (30 layers, 7 mm total thickness) with cold vacuum pressure [Fes 02].

4.3 Thermal Performance

The heat flow $\dot{Q}$ through a material of cross section A and thickness t is given by

$$\dot{Q} = \lambda \cdot A \cdot \Delta T/t$$

where λ is the material's thermal conductivity and ΔT the temperature difference between its surfaces A. In the following ΔT is assumed to be (293-77) K = 216 K.

For a neck of 0.8 m diameter made out of 8(12) mm thick stainless steel (λ = 15 W/m·K) and a of 0.6 m length, A = 0.02(0.03) m^2, and hence $\dot{Q}$ = 81(121) W. With 20 W of the thin-walled (2× t=0.8 mm) compensator, the thermal loss through the neck totals about 14 W.

The heat flow through 8 pads (Ø250/Ø100×100 mm) made from Torlon (λ(Torlon4203) = 0.26 W/m·K) with an area of 0.041^2 m^2 each and 0.1 m height amounts to 185 W.

The thermal conductivity of a 20 layer superinsulation is about 0.0023 W/m^2K between 300 K and 77 K. Assuming a cryostat's surface area of 100 m^2 and a safety factor of 2, the heat flow amounts to 100 W (see also Table 4).

All thermal losses sum up to ≈300 W. With a total cryogenic mass of 97600 (56500) kg of LAr (LN2), the daily evaporation is 157 (127) kg LAr (LN2) i.e. in the order of 0.2%.

4.4 Material Radiopurity and Production

Table 5 provides a compilation of the specified radiopurity of the materials for the cryostat production together with results of screening measurements by the GERDA collaboration.

Table 5: Specified radiopurities of the materials for the cryostat production and the results of screening measurements using γ spectroscopy (G), mass spectroscopy (MS) or neutron activation (NAA). Units are mBq/kg.

Material	K-40	Co-60	Th-228(232)	Ra-226(228)	U-238(235)	Meth.
Steel [spec]			< 10			-
AISI 321(Cry)	< 4.2	4 ± 0.5	< 1.7	< 1.6 (< 1.0)	-	G
			0.5 & 0.9		-	MS
Tueb	< 2.7	16 ± 1	1.8 ± 0.4	1.6 ± 0.4	-	G
1.4429(Kat)	< 2.3	4	5	2.3	-	G
MLI [spec]			< 20			
alum. Teflon	≤ 16.2	≤ 1.7	≤ 6.3	$\leq 4.2(\leq 8.1)$		G
	64 ± 1		(1.1 ± 0.05)		1.46 ± 0.05	MS
NAC-2	81 ± 20		5.0 ± 3.4	23.0 ± 2.8		G
	87 ± 5		(7.2 ± 0.3)		23.4 ± 0.9	MS
Coolcat 2 NW	150 ± 30		2.3 ± 0.6	$1.1(1.8) \pm 0.5$	$\leq 59(1.8)$	G
	137 ± 4		(0.5 ± 0.02)		1.42 ± 0.09	MS
Pads [spec]			5			-
Torlon	≤ 0.93		≤ 41	≤ 37		NAA
Copper [spec]			< 0.02			-
NOSV(Lens)	≤ 0.088	≤ 0.01	≤ 0.012	≤ 0.016		G

While austenitic steel within our specification (10 mBq(Th-228)/kg) seems to be easily available, recent measurements indicate that material with an almost a factor of 10 lower radioactivity is on the market. In the few cases studied so far, the results from γ- and mass spectroscopy indicate that the secular equilibrium is not broken at the current sensitivity (see AISI 321 sample in Table 5). More tests of this hypothesis are under way; if positive, mass spectroscopy would be the desired fast method to preselect steel for the cryostat that has significantly lower radioactivity than originally specified. In turn, the amount of copper needed for shielding could be strongly reduced, and even operation scenarios with LN2 might be considered.

Several MLI types have been screened with regard to their suitability in a copper cryostat. They all fulfill the specifications for a cryostat built from stainless steel with an activity of 1 mBq(Th-228)/kg.

No measurement of sufficient sensitivity is yet available for the pad candidate materials Torlon and Vespel.

The required radiopurity of the copper has been verified for the copper grade NOSV which had been delivered by the Norddeutsche Affinerie AG to the MPI Heidelberg. The now available OFRP quality is expected to exhibit the same performance, at least.

To prevent contamination by additional radioactivity, the welding and assembly of the cryostat has to be done at clean conditions. The chosen welding electrodes should minimize the introduction of additional radioactive material. The final cleaning of the vessel has still to be defined and might include pickle and passivation of welds and surfaces as well as rinsing with de-ionized water.

4.5 Integration of Cryostat within GERDA

The cryostat will be mounted onto a vibration-isolated basement and will be completely de-coupled from the surrounding *Super-Structure*. Cryostat and electronics must be grounded in one place. If grounding via a suitable grounding bar in the floor of Hall A is not possible, the cryostat's mount must be also electrically isolated from the floor.

The cryostat will be connected via a 80 cm long cylindrical interface of 80 cm diameter with the lock (see sections 2 and 6). This manifold is made from stainless steel and might

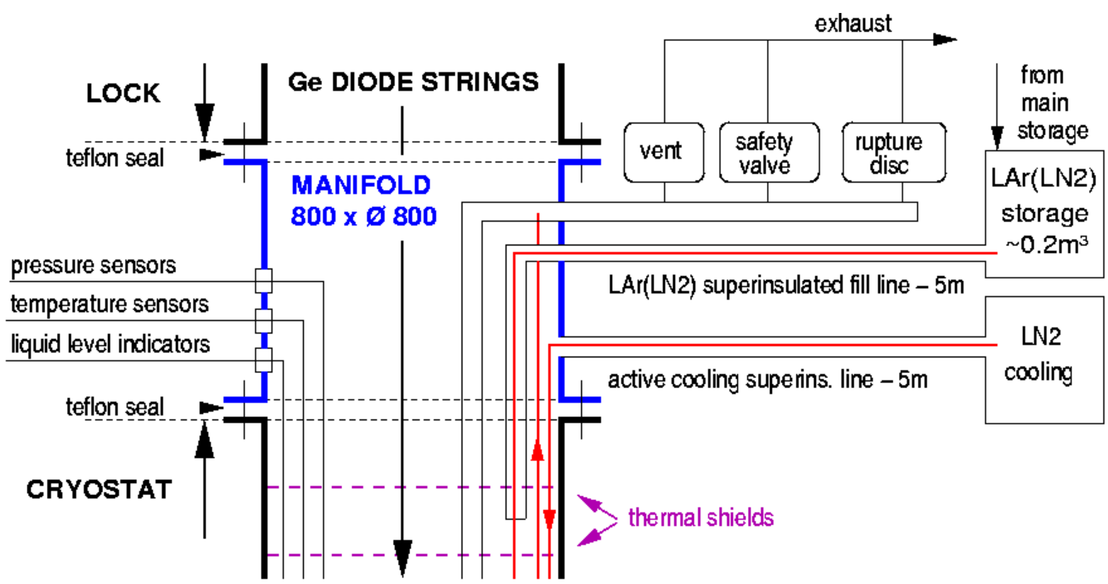


Figure 12: Schematic of the manifold through which indicated devices penetrate into the cold volume.

need thermal isolation. It contains the feed throughs for all devices that penetrate into the cold volume. The following tubings and feed throughs are foreseen (Fig. 12):

- superinsulated filling tube,
- gas exhaust tube,

- one superinsulated pipe for active cooling,
- feed throughs for all instrumentation,
- feed throughs for detector cables,
- several spare lines.

Detailed specifications will be presented in a future section.

While the manifold is rigidly connected with the cryostat and the lock, all other connections to the manifold have flexible parts for decoupling relative movements. Teflon seals will be used between cryostat, interface and lock, and metal seals else; all connections must pass a He leak test to verify Rn tightness.

Cryostat, manifold and lock must have also a low impedance electrical connection.

5 Cryogenic Infrastructure

5.1 Components

The cryogenic infrastructure includes

- One storage tank for liquid nitrogen (LN2) and one for liquid argon (LAr). These standard vessels will have a volume of 6 m^3 each and will be located in the TIR tunnel (see chapter 2). The cryoliquids will be supplied to the GERDA experiment by superisolated pipes.
- Cooling unit to avoid / reduce evaporation losses during operation. The losses are specified to be less than 0.2% of the cryostat volume per day. This corresponds to a heating of about 300 W.
- Equipment for filling and emptying the cryostat. Different options exist for draining the cryostat: overpressure in the gas volume, pumping, or evaporation using a heater.
- Pumping unit to generate and maintain the vacuum between the inner and outer walls of the containers including pressure sensors and safety devices. The vacuum pressure is the most-sensitive probe of leaks in the cryostat walls.
- Pressure control valve for the cryostat
- Heater for the evaporated LN2 and LAr gas to guarantee that the LNGS ventilation system is not charged with cold gas
- Redundant safety devices for the cryostat
- Redundant pressure and level sensors for the cryostat
- Radon cleaning unit for the removal of radon from the liquid argon. At the moment several options are under discussion: (i) a large unit like it is in operation for BOREXINO and the Genius Test Facility, (ii) a much smaller unit which would only clean the LAr for refilling, or (iii) no cleaning at all.
- Slow control of the entire cryogenic infrastructure by a redundant programmable programmable logic controller (PLC), e.g. a SIMATIC 7. Safety relevant information will also be made available to the LNGS general infrastructure control.

5.2 Operational Modes

Fig. 13 shows a sketch of the piping and instrumentation diagram (PID). It is largely based on a first layout made by Air Liquide. A radon cleaning unit is not shown. In the following paragraphs some basic functionality is explained.

Filling and emptying

The filling of the cryostat "B001" proceeds via the buffer "B200". This buffer of about 200 liters is filled from the storage in the TIR tunnel which operates at typically 5 bar. After the filling, the pressure in "B200" is reduced to the one of the cryostat with the pressure controlled valve "PCV221". The filling of the cryostat from the buffer via "FCV200" is therefore (almost) without flash losses and causes little microphonic noise. "B200" is elevated with respect to the cryostat (located at the penthouse level) and the LAr flows just by gravitational force. The initial filling can also proceed directly from the LAr storage via the valve "FCV203". The filling time is not crucial for GERDA.

The filling line inside the manifold and cryostat will be superinsulated up to the maximum fill level. Afterwards an simple pipe is used. During initial filling the LAr will flow to the bottom of the tank. Afterwards the refilled LAr will enter directly at the height of the filling level through holes in the pipe.

Before filling, the entire volume (cryostat, buffer, LN2 and LAr pipes, gas exhaust pipes, manifold, lock) has to be flushed with GN2 (hand valve "HV202") and/or evacuated. The latter option is not included in the current PID but considered a desirable design option to remove radioactive contaminations and moisture from the entire piping system. The inner cryostat container is designed to be evacuated even if the volume between the two walls is not evacuated.

No decision is made how to empty the cryostat. Since it is not anticipated to exchange the cryogenic liquid during the lifetime of the experiment the evaporation with a heater at the end of the operation or after a period of several years (if maintanance is needed) might be the simplest solution. As an example, the drainage will take 2 weeks with a 10 kW heater. A pipe for drainage by overpressure will be installed in the cryostat (not shown in the PID) in any case. No drainage of the cryoliquid is foreseen in case of an emergency. There exists no container at LNGS where to store the cryoliquid.

Level sensors

There are several low resolution level sensors inside the cryostat (temperature sensors "TE020" to "TE025") and one level sensor of higher resolution inside the neck to control the filling height (sensor "LT012" and level switch points "LSLL013" to "LSHH017") The sensors inside the cryostat are only used during filling and will be switched off during normal operation.

The sensor in the neck is used during normal operation to control the filling level. Its operation must not disturb the operation of the Germanium diodes.

Pressure control and safety devices

The pressure is regulated with the pressure control valve “PCV005” to the nominal overpressure. It is regulated by the pressure sensor “PT002”. In case large amounts of flash gas are present “HV001” might be opened. The heater “EH031” prevents the freezing of “PCV005”.

The safety valve “PSV008” opens at about 0.9 bar overpressure and the rupture disk “PSE009” triggers at about 1.3 bar overpressure. The design overpressure of the entire system is 1.5 bar overpressure. [1] The exact triggering points of the safety devices still have to be defined.

For the safety valve a rupture disk before the valve, e.g. at the cryostat side, might be used to avoid any radon contaminants from the vent line to leak into the system. This measure would protect the experiment even if the valve does not close perfectly.

The cross sections of the safety valve is dimensioned for the evaporation rate in case of loss of insulation vacuum. The exact geometry of the pipes from the cryostat to the safety valve and of the vent line will be taken into account in the calculation.

A leak in one of the cryostat walls will lead to a much larger evaporation rate and in such a scenario the rupture disk will open and protect the system against overpressure.

All safety relevant equipment is redudantly available. “HV006” switches between one set of rupture disk and safety valve and the second set and “HV004” between one pressure control valve and a second one. If the risk of clogging of the vent line is too large this could also be built redundantly, as shown in the figure.

Not shown is the heating of the exhaust gas. Here a solution similar to the one used by ICARUS is possible: the exhaust gas passes through a large container (3 tanks of 1 m diameter and 3.5 m height for ICARUS) filled with electrically heated steatite mineral pieces. Alternatively, our large water reservoir could be used as heat source, i.e. the pipe for the exhaust passes through the water tank.

Pumping unit

The volume between the two walls of the cryostat is evacuated with the “pumping unit”. This unit might run continously or on demand, depending on the vacuum pressure. A rupture disk “PSE012” protects this volume against overpressure in case the inner container leaks.

Precautions have to be taken to avoid damage to the MLI foil during transportation and during pump down and venting. A mesh in the vacuum line will protect the vacuum pumps from being damaged by fragments of the MLI.

Any leak in a cryostat wall will cause an increase in the vacuum pressure. The pressure monitoring is therefore the most sensitive method to detect any failures and to trigger an

[1] The pressure test of the cryostat will be performed according to AD 2000 at about 2.6 bar overpressure.

alarm.

Active cooling

To avoid contaminations with radon and to reduce microphonics due to boiling, the LAr in the cryostat is cooled with LN2. Ideally, no LAr refilling is needed during standard operation. The LN2 from the storage has a pressure of more than 5 bar and passes through the valve "PCV101" which acts as a pressure reducer. After the valve, the temperature of the LN2/GN2 mixture corresponds to the one of the LAr (or in case of LN2 filling to the one of LN2) and the vapor passes through the heat exchanger "E040" in the cryostat. Most of the volume of the current is gas and the liquid fraction will be transported by the gas stream such that no "local liquid pockets" form. The latter would evaporate and create some pressure waves in the cooling pipes. This cooling method should hence minimizes the risk of microphonic noise.

After the heat exchanger the return flow separates. One fraction goes directly through "PCV106" to the vent line and a second part passes through a second heat exchanger "E041" in the neck and through "PCV104" to the vent line.

With the main cooler "E040" the LAr in the cryostat is kept subcooled and "E041" allows to regulate the vapor pressure in the neck. There will be at least two cooling shields in the neck to reduce the heat load due to thermal radiation from the worm manifold. These shields can also be cooled by the return gas.

Vent line

The vent line conducts the GERDA cryostat exhaust gas to the appropriate place of the LNGS ventilation system. As mentioned above, two independent lines can be implemented to reduce the risk of clogging.

The gas volume above the cryostat's filling level and of the pipes connecting the manifold with the safety valves will in total correspond to about 4% of the liquid volume. This gas volume serves as a buffer to avoid rapid pressure variations.

The vent line will contain a high level of radioactive radon. Its penetration into the cryostat must be avoided. Therefore a rupture disk in front of the safety valves and the backflow valves "NV033" and "NV222" might be added.

In addition, the vent line will be purged with the GN2 from our active cooling system. Note that the cooling circuit is not connected to the cryostat volume and a contamination of this part of the system does not disturb the experiment.

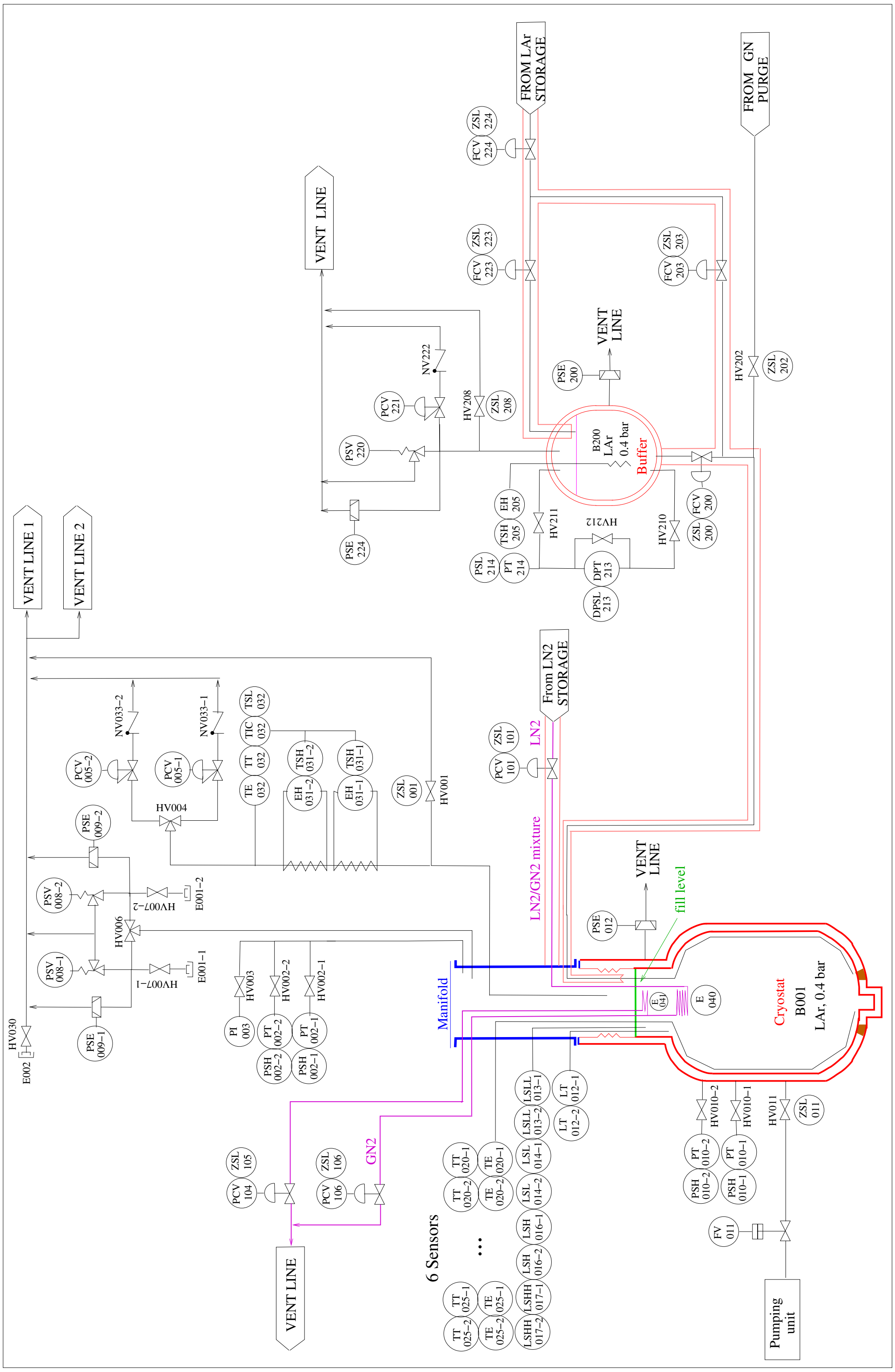


Figure 13: Piping and instrumentation drawing (PID) for the cryogenic infrastructure.

6 Penthouse

The penthouse is located on top of the experiment. It is the upper part of the super-structure also encompassing the platform above the water vessel and the laboratory building on the back-side of the experiment. The super-structure as a whole is decoupled from the water vessel.

Functionally the penthouse is separated into a clean- and an electronics-room. The clean-room houses the lock system which allows the insertion of detectors and calibration sources. The lock itself is mechanically supported by the platform, but mechanically damped. The electronics-room contains the needed racks and support systems. Also incorporated is a control area which allows commissioning and debugging.[2] The penthouse or parts of it will be shielded as a Faraday cage according to specifications expected from the electronics group. Fig. 14 shows the layout of the penthouse.

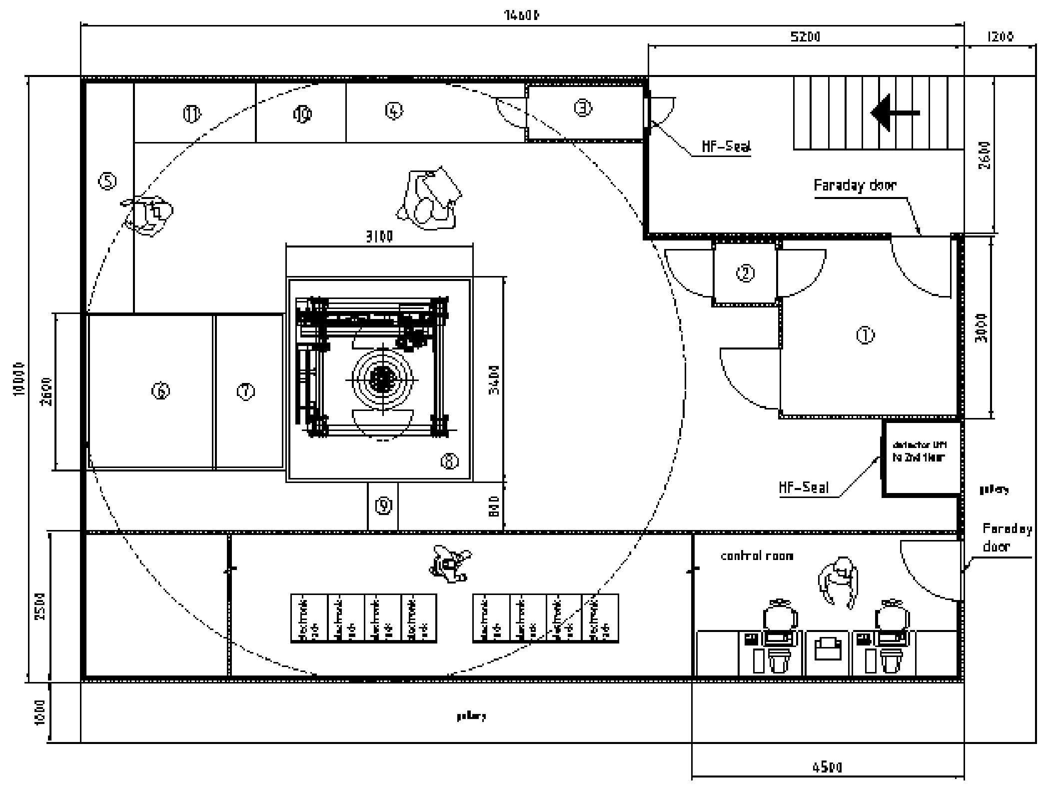


Figure 14: Layout of the penthouse [int.vers. 8] on top of the vessel with clean-room, lock system and the electronics-room. Numbered components are specified in subsection 6.3.

[2]This is not the control room for normal operation which is located on the first floor of the laboratory building.

The footprint of the penthouse is determined by the platform and the laboratory building. Due to requirements of the neighboring experiment [LVD] the penthouse has a cut-out. In this area a platform on top of the staircase services crane operation for heavy parts and access to the penthouse. The penthouse is surrounded by a gallery for access and safety purposes.

The overall floor load is specified to 1 t/m^2. Above the neck of the cryostat the inner lock incorporates a lead shield of approximately 2 t. The complete lock is estimated to weigh about 6 t. This load has to be supported by the platform.

Fig. 4 shows a vertical cut through the experiment looking from the street. The current design tries to exploit the full height of hall A. This does not allow the crane to pass over the experiment. Probably, a special crane will have to bring up loads to the cut-out area.

The penthouse ceiling has a dome above the lock in order to facilitate vertical lift. The muon veto is partially placed on top of the dome, partially around it. It is assumed that most of the cryogenic support is installed on the left side (viewed from TIR) which is easier to access. The drawing shows two lines at 500 mm and 800 mm above the water tank. To the left of the lock all 800 mm are allocated to the cryogenics. On the right side a channel for cables running between the lock and the electronics room is foreseen between the 500 mm and 800 mm levels. The electronics-room is lowered to the 500 mm level. It should be noted that the maximum rack height will be 1600 mm.

The final space requirements of the platform and the internal allocations will have to be rediscussed when a design of the water-tank and the super-structure becomes available. The current space allocations allow a height of 8900 mm for the water tank. If additional space for the super-structure is needed, the height of the water tank will have to be reduced.

6.1 Clean-Room Functionality and Radon Reduction

The clean-room with its integrated lock system will provide the possibility to insert and withdraw detectors in a modular way while the vessel stays at cryogenic temperatures. The clean room will also be used for the final preparation of the detectors and their integration into the detector suspension system. The detectors are delivered either through a material lock located in the cut-out of the penthouse or through an internal lift from the detector lab on the second floor of the backside house.

Radon is a major concern for the experiment. The interior of the cryostat has to be basically "radon free". The inner lock is connected to the main gas volume of the cryostat. Therefore the partial pressure of Radon in the clean-room has to be reduced in order to suppress Radon creeping into the lock. The air of the clean-room will thus be filtered through a Radon reduction plant.

The second consideration is the attachment of Radon to aerosol particles which settle on the detectors. Radon decays into ^{210}Pb which is a dangerous source of background on surfaces of n-type detectors. The clean-room will be of class 10000 which is sufficient to suppress this problem when combined with Radon reduction.

For some of the handling the flow boxes can be provided with synthetic air to further reduce the danger of contamination of the detectors. For storage facilities a pure nitrogen atmosphere is foreseen.

Materials :
All wall and components will be constructed out of stainless steel. Any window needed will be acrylic. All materials will be cataloged and tested for radon emanation

Environmental Control :
Particle counters will be available to check the condition of clean-room and work-stations. In addition the oxygen content and humidity will be controlled.

6.2 Mechanical Decoupling

The super-structure is one mechanical unit. It is decoupled from the water tank.

The lock system is mechanically decoupled from the supporting platform. This is to keep the position of the detectors inside the vessel stable and reduce vibrations.

6.3 Clean-Room Components

The main components of the clean-room infrastructure can be located through their numbers in fig. 14. They are:

1. Personnel-lock
2. Air-shower
3. Material-lock
4. Container loading station
5. Detector Preparation Tables
6. Final assembly station
7. Outer lock
8. Inner lock
9. Cable bridge
10. Detector storage unit
11. Tool-cabinet

1,2: Personnel enter the clean-room through a classical personnel lock and an air-shower. In the lock private storage space will be available.

3: Materials, especially detectors, can enter the clean-room through a material-lock suitable for containers up to l=60 cm×d=50 cm×h=40 cm. The lock can be evacuated, heated [80 °C] and flushed with nitrogen.

4,5,6,7: All these stations will be laminar flow-boxes. When not in use they are closed and flushed with nitrogen. As a result, detectors which are under preparation do not have to be transferred if unpredicted breaks are necessary. All station specific tools are kept in holders within the station.

4: The material-lock opens towards the container loading station. A passive roller system is foreseen. Storage space for 4 containers will be provided under the work-bench.

5: This station will be used to prepare detectors and cables. All work that can be done before the integration of a detector into a package will be done here. Pressured clean air will be available.

6,7,8: These stations are connected via a rail system below the ceiling of the lock system. Detector packages are hung on movable hooks. Packages can be rotated. The windows between the stations are opened to allow the transfer from one station to the next. The maximal package height is 150 cm.

6: Lowered tables with integrated suction systems allow easy access to the hanging packages. Packages can be temporarily stored in the area close to the outer wall when the area is closed off. During the final assembly the detectors are integrated into so called strings and all cables are combined into easily pluggable units. Pressurized clean air or nitrogen will be available. While open the laminar flow consists of artificial air. During transfer to the outer lock both stations are filled with nitrogen.

7: The outer lock always contains an ultra-pure nitrogen atmosphere. While closed off against the inner lock and the final assembly station it can be evacuated, heated [50 °C] and flushed. After the last cleaning cycle the outer lock will be flooded with nitrogen from the boil-off of the vessel and the connection to the inner lock will be opened. A mechanical arm grabs the cables hanging inside the inner lock. After they are pulled into the outer lock they are connected with the help of a glove box integrated in the outer lock. The glove box is shuttered off during non operation and constantly flushed. After the cables are connected the package is transferred into the inner lock.

7,8: During normal operation part of the boil-off from the tank is transferred to the inner lock. Gas streams through a valve into the outer lock. The inner lock has the same pressure as the vessel, 1.2 bar. The outer lock has a pressure of ≈1.15 bar, which is intermediate between the inner lock and the clean-room. During transfers from the outer to the inner lock both volumes are kept under 1.2 bar.

8: The neck of the vessel opens into the inner lock. During insertion operations it is basically a part of the volume of the vessel. During normal operation the neck will be closed and only part of the boil-off will be lead into the lock.

A positioning and support plate for the suspension system will be placed inside the neck. It is placed above the rupture disk or safety valves for cryogenic emergencies. During normal operation the strings are hanging from this plate. If further MC calculations indicate the necessity of further neutron shielding a polyethylene plug will be lowered into the plug above the plate. A lead lid is incorporated at floor level. It is opened for insertion operations. Additional polyethylene can be placed above the lead.

Cables enter through a panel from the cable-tunnel, see 9. They are fixed to holders inside the lock.

The inner lock has a web-cam for constant surveillance.

9: A cable tunnel between the lock and electronics room will minimize cable lengths. It is integrated into the super-structure below the clean-room floor. Special feed-throughs bring the signals from the lock into the tunnel.

10: The detector storage unit allows the storage of detectors and other materials under radon reduced nitrogen atmosphere.

11: The tool cabinet holds all non station specific tools, especially the ones needed for mechanical operations steered from outside the lock system. This cabinet has normal clean-room atmosphere.

6.4 Electronics-Room Components

The systems to be supported are

- signal processing and DAQ
- fast control
- high voltage
- slow control and low voltage
- environmental monitoring
- mechanical support

The racks for signal processing [FADC] have to be temperature controlled.

6.5 Safety Considerations

Clean-Room: The oxygen content of the clean-room atmosphere will be constantly monitored. Oxygen masks will be provided for accidents.

As the direct view into the hall is obscured, video monitoring of the hall will be available in order to allow fast assessment of external dangers. The inner lock is video controlled to assess possible internal mechanical failures.

There are temperature and pressure sensors in all areas of the lock. There are mechanical safety valves to prevent over pressure in the lock system.

An internal alarm system as well as the connection to the LNGS general alarm systems inform about all safety relevant failures.

Escape routes follow the main staircase or the connection between the penthouse and hall galleries.

Lock: The lead cover of the neck which is incorporated in the inner lock can be retracted within 5 to 10 minutes. However, in case of a sudden build-up of pressure in the cryostat the lead cover suggests to have the blast disk below the inner lock. The positioning plate of the suspension system should also be located above the blast disk. Thus only the suspension cables will be below the blast disk.

During normal operation part of the boil off from the cryostat is used to flush the inner and outer lock. In case of a malfunction the pressure could build up inside the lock system. Safety valves will be incorporated in order to prevent dangerous conditions.

6.6 Summary of External Requirements

Electricity: During operation the electronics will consume most of the power. The strongest power consumption is expected to come from heating systems in the lock areas.

- 240V:
  - heating for inner/outer lock/material lock,
  - electronics racks,
  - computers etc.,
  - motors,
  - lighting [halogen],
  - flow boxes,
  - air conditioning clean-room/electronics room
- UPS:
  - oxygen monitoring of clean-room
  - video monitoring of out-side and lock area
  - pressure and temperature monitoring of the lock area
  - alarm system for penthouse [and laboratory building]
  - some parts of electronics
  - some parts of data acquisition system

Cooling Water: The electronics will be water cooled using a regulated closed water system. External cooling water will be used to cool the system.

Nitrogen: All gas supplies will come from bottles or boil off from the cryostat resp. storage tanks.

7 Safety Aspects

7.1 Cryostat-Water Vessel System

Figure 15 shows a schematic of the GERDA vessel system which is used to discuss some of its safety aspects. Its characteristic feature is a cryostat being completely immersed into a water tank. The cryostat contains either LAr or LN2; its volume is 70 m^3 which corresponds to about 59000 (49000) m^3 of Ar (N_2) gas (20°C). The water volume is about 630 m^3.

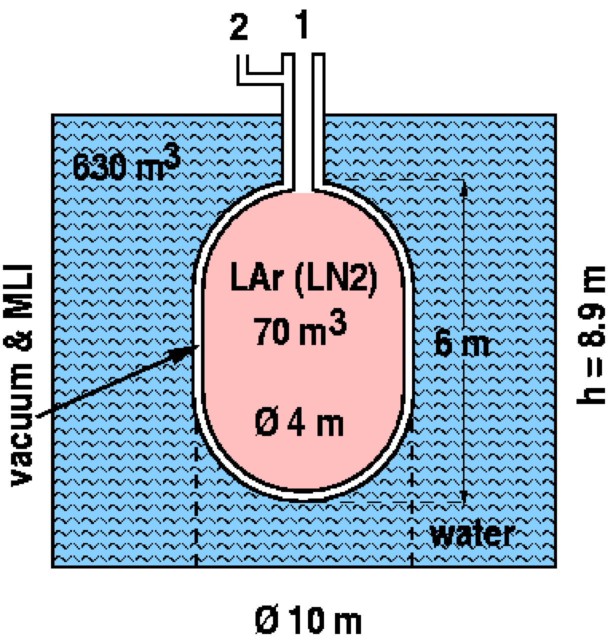


Figure 15: Vessel dimensions assumed for discussion of safety aspects. (1) indicates the neck of the vessel, (2) the tube through which the space between inner and outer container is pumped. Within this space the multilayer insulation (MLI) is mounted.

The operation of this cryostat poses a potential risk to the people working in the LNGS underground area and to the users of the car tunnel. Although argon and nitrogen by themselves are not poisonous, the risk of suffocation in case of a large concentration in the air is evident. Especially the operation of the cryostat in a watertank which represents a huge heat source needs special attention.

The purpose of this section is not to do a risk assessment of the experiment as a whole or the cryostat in particular. Hence there will be no discussion of probabilities for failure modes of the cryostat. Instead the actions are summarized which are taken to minimize the risk and evaporation rates are estimated that might occur in case of catastrophic failures, i.e. the failure of one of the cryostat walls.

GERDA is trying to minimize failures of the cryostat and hence the risk of its operation by the following design measures

- Design and production of the cryostat according to the European pressure vessel code even though it is operated at an overpressure below the limit above which this code applies (0.5 bar).

- Safety margin for the operation by a design pressure of 1.5 bar; this implies increased wall thicknesses.

- No port below the filling levels of cryoliquid and water has been implemeted. Usually, cryostats have ports e.g. at the bottom for emptying or for measuring the hydrostatic pressure. Such ports are known [Bar 85] to increase the risk of loss of the cryoliquid in case of failure.

- Minimization of local stresses in the design. The entire cryostat is rotational symmetric with the exception of the support pads and the centering pads. At these places the wall thicknesses are enlarged to lower the absolute stress value.

- Support of the inner vessel by pads at the bottom. Typically the inner cryostat container is hung at the neck. The support of the weight at the bottom reduces these stress peaks especially for loads due to earthquakes.

- Both the cryostat's inner and outer wall are made out of high ductile stainless steel.

- High production standard and 100% X-raying of the welds.

- Tolerance to earthquakes of up to 0.6 g horzontally and vertically, i.e. above the requirements of Eurocode 3. The cryostat is designed to withstand these loads undamaged.

The operation of the cryostat in water has not only the disadvantage of the large surrounding heat reservoir but offers also advantages: the buyoancy reduces the mechanical load and the water dampens earthquake loads. This enlarges the safety margin of the design. The increased load on the outer wall of the cryostat due to the hydrostatic pressure is taken into account by the enlarged wall thickness.

In case of any failure it is not feasible to empty the cryostat on a time scales of less than one day. There exists no thermally insulated reservoir which could hold such a volume underground, and so the cryoliquid would have be taken by tanker-cars. It is feasible, however, to empty the water tank. The water by itself is clean and can be discharged into the emergency pit (350 cm^3) and the TIR tube within less than 3 hours. This process would be triggered by loss of the vacuum or overpressure between inner and outer vessel without identified cause.

7.2 Estimate of Evaporation Rates in Case of Failures

The cryostat consists of two inpendent vessels. The space between both containers is evacuated and - for improved thermal insulation - equipped with a multilayer superinsulation. Possible failures caused of the cryostat are

- loss of insulation vacuum,
- leak in outer vessel,
- leak in inner vessel,
- leaks in both vessels.

Loss of vacuum for superinsulation: The loss of the insulation vacuum will cause a degradation of the thermal insulation of the cryostat. Fig. 11 shows this degradation for a special case to be about two orders of magnitude, while the compilation in Fig. 16 indicates even larger factors of up to 10^3. For a most conservative estimate, a superinsulation with

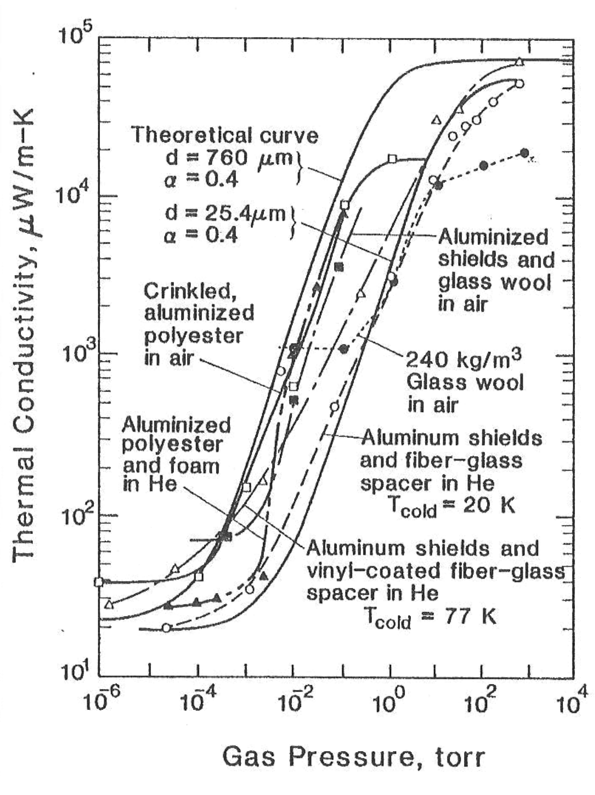


Figure 16: Thermal conductivity of superinsulation in dependence of gas pressure [Tim 89].

a heat flux of 1 W/m^2 between 77 and 300 K is assumed to be degraded by a factor of 1000 due to the loss of the insulation vacuum. With the cryostat's surface of 100 m^2 and

97(56) tons of LAr (LN2) (evaporation enthalpy: 162(199) kJ/kg) it will take about 44(31) hours until all LAr (LN2) has been evaporated. The resulting gas flow (20°C) of about 1340(1550) m^3 per hour is small compared to the present total LNGS ventilation rate of 40,000 m^3/h - which soon will be increased considerably.

Leakage of outer vessel: A leak in the outer vessel will destroy the insulation vacuum and enable the surrounding water to enter the space between inner and outer vessel. Water with its very high specific heat capacity of 4.19 kJ/(kgK) represents an efficient heater for the cryogenic liquid; a drop of less than 6° C in the temperature of the 660 m^3 stored water is enough to supply all the heat needed to evaporate the 70 m^3 of LAr(LN2) contained in the cryostat.

An estimate of the resulting gas flow is difficult lacking detailed knowledge of the involved heat transfer. The heat transfer in an unsteady state involving phase changes has been studied by many authors (see refs. in [Van 63, Fas 70], and also [Tso 83, Bro 01] more recently) but the application of the reported results to a specific case is not straightforward, and the agreement with theoretical predictions is often poor. Ad hoc studies at the MPI Heidelberg considered cylindrical metal cans (Ø15 and 30 cm) filled with 2 resp. 20 ℓ of LN2. After sudden immersion into a water bath of room temperature, the evaporation was measured as function of time. Strong convection in the water and strong boiling were observed as well as the formation of an ice layer. From these measurements, preliminary values for the heat transfer coefficients of about 22(7) kW/m^2 before(after) ice formation have been deduced. Inspection of the boiling curve of LN2 (see fig 17) reveals that the former value agrees with the expectation in the regime of film boiling, $\Delta T > 100\ K$.

Adopting for the moment a value of 22 kW/(m^2), the initial Ar (N2) gas flow will be 29,300(34,000) m^3 per hour which might be tolerable after the upgrade of the ventilation system provided that sufficient gas heating capacity is available. In this - worst case - scenario all LAr(LN2) would be evaporated after less than 2(1.4) hours. However, the presence of the many foils of the superinsulation and of the ice layer would definitely diminish the heat transfer so that the evaporation process will last significantly longer.

Leakage of inner vessel: A leak in the inner vessel will destroy the insulation vacuum and enable the cryoliquid to enter the space between inner and outer vessel. The LAr(LN2) will be efficiently heated by the water surrounding the outer vessel with consequences similiar to those discussed above. The maximum gas flow might be, in fact, smaller since the overpressure might inhibit further flow of the cryoliquid. However, other than in case of a leak in the outer shell, the prevailing amount of the gas cannot escape through the cryostat's neck but must be drained off through the pumping pipe(s). Thus the volume of the insulation vacuum must be equipped with overpressure safety valves of the same type as used for the actual cryostat.

Leakage of inner and outer vessel: A simultaneous leak in both vessels could lead to a mixture of cryoliquid and water which in certain cases might lead to explosion-like

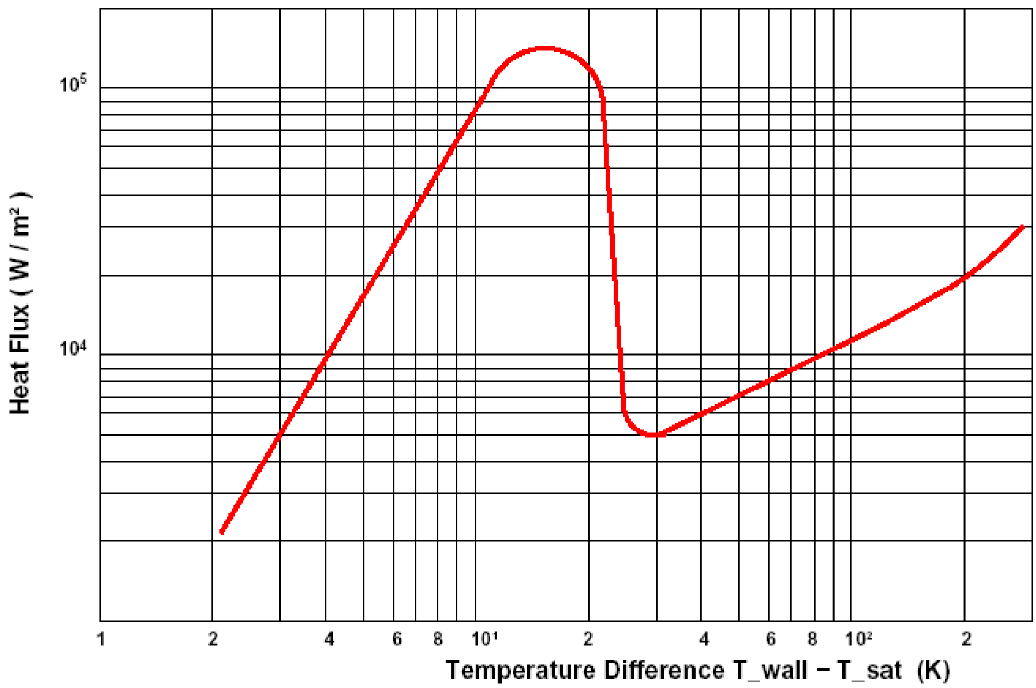


Figure 17: Pool boiling heat transfer characteristics of LN_2 at atmospheric pressure (from [Van 63]).

evaporation [Arc 04, Tso 83]. Equipment of the water vessel with an adequate overpressure safety valve will provide tolerance for tiny leaks. The simultaneous occurence of larger leaks in or the rupture of both vessels is not credible in view of all the design and construction measures discussed above - disregarding the scenario in which a heavy load would fall from the overhead crane onto the cryostat, a scenario that can be excluded by blocking out the crane from the area above GERDA experiment.

Sample Estimates for Safety Valves: According to the ASME Code it is recommended to use two safety devices to prevent buildup of pressure in the inner vessel: (i) a spring-loaded safety valve set at approximately 1.1 times the working pressure, and (ii) a safety head or rupture disk set to burst at approximately 1.2 times the working pressure [Bar 85]. The size of the safety valve is determined by the ASME Code by

$$A = \dot{m} \cdot \frac{(R \cdot T/M)^{1/2}}{C \cdot K \cdot p_{max}} \quad \text{with} \quad C = [\gamma \cdot (2/(\gamma+1))^{\frac{\gamma+1}{\gamma-1}}]^{1/2}$$

where A is the discharge area of valve, $\dot{m}$ the maximum gas flow rate through valve, R the universal gas constant (8314 J/K·kmol), T the absolute temperature of the gas at the inlet to the valve, M the molecular weight of gas, K the discharge coefficient, p_{max} 1.1 times the set gauge pressure plus the atmospheric pressure, and $\gamma = C_p/C_V$ (1.4 for N_2). Assuming

T=273 K, K = 1 and a set pressure of 1.5 bar absolute, Table 6 shows the required size

Table 6: Size of safety valves with a K = 1 discharge coefficient for indicated mass flow rates of nitrogen at T=273 K; the set gauge pressure is 1.5 bar absolute. The mass flow per hour in percent refers to a initial total cryogenic mass of $4{\cdot}10^4$ kg. Sizes have been calculated according the ASME VIII (1^{st} value) and AD2000 A2 (2^{nd} value) prescriptions using the software Si-Tech 2.2 [B&R 05]. For a more realistic discharge coefficient of K = 0.7, the quoted values have to be increased by 20%.

mass flow rate		valve diameter
kg/s	%/h	mm
0.78	7	49.3 / 51.4
3.7	33	107.0 / 111.5

for several mass flow rates. The first line refers to the case of loss of insulation vacuum, the second line to an event in which the outer shell is broken such that the space between inner and outer vessel is immediately filled with water.

7.3 Corrosion

The operation of a stainless steel cryostat in de-ionized water contained in a stainless steel vessel should not be affected by corrosion.

7.4 Summary

To reduce risk, the design of the Gerda cryostat exhibits big safety margins, and its production will obey high quality standards. The evaluation of failure scenarios due to the loss of insulation vacuum or the damage of one of the two cryostat's walls has shown that even worst-case evaporation rates can still be digested by the Lngs ventilation system. Further mitigation of risk will be guaranteed by the installed Lngs safety system which includes oxygen monitors, alarm signals and the supply of oxygen masks.

Any leakage of one of the cryostat's wall will be identified most sensitively by an increase of the insulation vacuum; in such a case the water surrounding the cryostat can be drained within less than 3 hours. Thus the only credible cause for the occurence of a simultaneous leak in both cryostat walls would be provided by a heavy load falling from the hall crane onto the cryostat - a scenario which can be excluded with certainty by excluding the crane from the area above the Gerda experiment.

8 Gerda Assembly at Lngs

As outlined in chapter 2, the Gerda experiment will consist of a cryostat immersed into a water tank, and a superstructure including laboratory building and platform with a penthouse overlapping the water tank. The various components of Gerda are envisaged to be build in the following sequence:

1. water tank and cryostat, interleaved
2. super-structure including vent lines
3. mount of cryostat's copper lining and manifold
4. laboratory building,
5. penthouse,
6. lock.

A detailed plan for the complete assembly procedure is still missing, and present efforts focus at detailing the various phases of construction.

The fabrication steps of the water tank are known, and in one scenario the cryostat could be inserted in the tank as soon as the roof and one ring of the water tank's wall have been welded together:

- build the water tank's bottom plate,
- build the conical roof leaving a hole of 4.5 m in its center,
- lift up the roof,
- weld the first sheet-metal plate of shell to the roof,
- insert the inner cryostat through the 4.5 m hole in the roof into the water tank,
- do basic cryostat tests
- complete the construction of the water tank by repeated welding and lifting,
- solder last part of the roof,
- X-ray test all solderings,
- clean soldering (decappaggio and passivazione),
- clean water tank with ultraclean water.

After the superstructure has been erected around the water tank, part of the heavier components of the cryogenic infrastructure like vent lines will be attached to the beams of the superstructure. In addition, a temporary platform on top of the superstructure will provide access to the cryostat for mounting the internal copper lining. Thereafter, the manifold including auxiliary cryogenic equipment will be installed.

The installation of the penthouse can start as soon as the steel construction of the laboratory building has been finished.

The installation of the lock and its connection to the manifold completes the assembly of the major GERDA mechanical hardware. It is planned to test this assembly procedure before at Munich using the original lock, manifold and a protoype cryostat neck.

9 The LArGe-facility

The LArGe-facility of Gerda is located in the former Lens barrack underground in the interferometer tunnel adjacent to Luna–II. The structure of the barrack, the air handling system, as well as the Lens shielding system are currently being modified for their future use in the Gerda project.

The purpose of the LArGe-facility is to provide underground laboratory space, shielded against radiation from cosmic rays, to minimize the production of cosmogenic radioisotopes of the enriched germanium diodes and of the detector support structure. It also provides the utilities for R&D on a novel background reduction technique using the anti-coincidence signal provided by the scintillation light of liquid argon as veto in the search for neutrinoless double beta decay.

To meet these objectives, the barrack is currently being modified and new laboratory infrastructures are under preparation. The start-up of the LArGe–facility is on the 'critical path' for the Gerda experiment, because the existing enriched diodes are required to be modified and tested *timely* for Phase-I of the experiment.

9.1 LArGe infrastructures

Figure 9.1 displays the floor plan and dimensions of the LArGe–facility. The barrack will be operated as a clean room with access through a personnel lock from the TIR tunnel. Fresh air enters the barrack through a ventilation system with temperature and humidity control. The air inventory (approx. 300 m^3) of the barrack is exchanged about once per hour. It is constantly circulated and dust particles are removed by hepa-filters. High purity working zones of class $<$ 100 will be achieved in dedicated clean benches (4,5 in Figure 9.1) and by mobile hepa-filters. Chemical treatment of detector materials as e.g. surface etching is carried out in a fume hood (1) equipped with activated charcoal filters retaining vapors. An evaporation system to produce thin metal layers for electrical contacts will be installed (not shown in figure). Final detector cleaning, refurbishment of electrical contacts and mounting in their support structure will be carried out in a radon-free clean bench (5). A detector test device (6) is connected to this clean bench. It serves to test the detector performance after their refurbishment without exposing them to ambient air. The device consists of a moderately shielded (liquid nitrogen (argon) dewar which is equipped with a detector insertion system. Filling of the cryogenic liquids and blanketing are carried out with the gas and cryogenic liquid distribution system (10). The LArGe device (12) for studying the background levels of the refurbished detectors will be installed in the northern part of the barrack. Further general infrastructures as washstand with deionized water system (2), mounting tables (3), storage shelfs (8), data acquisition system (7,13) will be installed. Technical details of the infrastructure are given below.

1. Fume hood with ventilation unit and activated charcoal filter. Exhaust air from filter can be vented either to the outside of the barrack or into the barrack (circulation

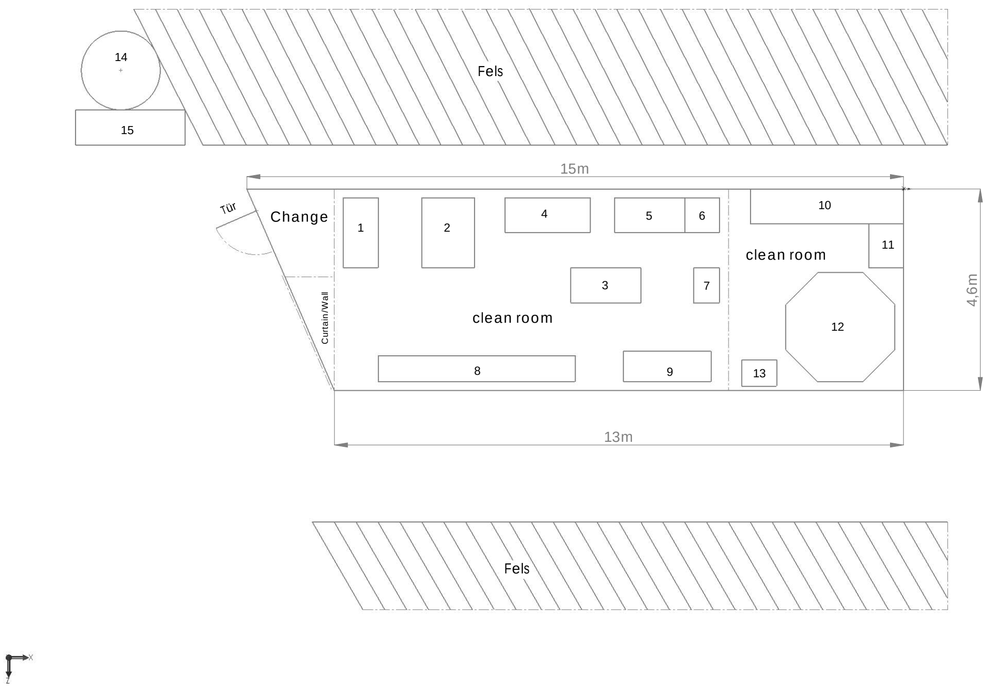


Figure 18: Floor plan of the LArGe barrack. Explanations cf. text.

mode). L x W x H: 1800 mm, 2500 mm, 850 mm. Air flow 0–800m^3/hour; 380 V, max. 16 A.

2. Washstand and water purification system for the production of deionized water (Millipore system and/or quartz distillation).

3. Mounting table stainless steel (movable),

4. Clean bench, vertical air stream (class 100, Airstream AVC-6A1), LxWxH: 1950 x 750 x (1250+860) mm, 1930 m^3/h, 230 V, 2.5 A, $<$ 62 dBA.

5. Rn-reduced clean bench operated under nitrogen atmosphere in circulation mode, Optional, operational in exhaust mode as fume hood. LxWxH: 1600 x 800 x 3000 mm, 380 V.

6. Nitrogen/argon dewar connected to 5. Volume: 70 liters, max. operational over pressure: 1.5 bar; height: 1100 mm, diameter: 550 mm (plus wheels).

7. Data acquisition system for 6.

8. Storage shelfs for laboratory material and enriched detectors with dewars (Igex, HdM detectors prior to refurbishment).

9. Desk workspace with PC.

10. Liquid/gaseous nitrogen/argon handling system for (re-)filling, emptying and gas blanket for supply for 6 and 12.

11. Access ladder to top of 12.

12. LArGe system

13. LArGe data acquisition (14 bit SIS flash ADC, controlled by Intel PC operated under Linux) and slow control.

14. Liquid argon storage approx. 6 m^3

15. Purification system for water, oxygen and radon removal from liquid argon.

9.2 The LArGe system

A vacuum insulated copper dewar of 900/1000 mm inner/outer diameter and 2050 mm height is housed in a graded shielding system of 200 mm PE, 230 mm steel, 100 mm low-activity lead and 150 mm electrolytic copper. A gas-tight lock mounted on top of the shield serves as the access port for detector insertion. The system is hermetically gas tight and kept under a overpressure of argon atmosphere of approximately 10 mbar to avoid radon contaminations.

Filling and emptying of the cryogenic liquid inventory (1000 liter of liquefied argon) occurs via a dedicated liquid/gas handling system. Necessary safety related instrumentations as well as burst disks and ventilation tubes are integrated into the system. Liquid argon for initial filling and re-filling during operations is stored in a storage dewar (6 m^3) external to the barrack. Adjacent to the liquid argon storage is a liquid argon purification system based on the LTA technique (low temperature adsorption on high purity charcoal) developed for Borexino. Optional, an oxygen removal cartridge (Oxysorb) is inserted upstream from the LTA to prevent emanated radon to reach the LArGe dewar.

A detailed description of the LArGe system is given in a separate report.

9.3 Time schedule

The modification of the barrack structure – ie the removal of walls, the refurbishment of the floor and coating with epoxy resin, enlargement of northern barrack part, modification of the air ventilation and hepa system has been completed last year. The laboratory infrastructures is completed and Work with detectors in a clean environment has started. Completion of the installation of the full LArGe system is targeted for 2006.

Appendix A

Table 7: Physical properties of nitrogen and argon

Property	Argon	Nitrogen	Unit
Boiling point at 101.3 kPa (1 bar)	-185.5	-195.8	°C
	87.28	77.36	K
Density of liquid at boiling point	1394	807	kg/m^3
Specific heat c_p at boiling point	1.14	2.05	kJ/kg·K
Thermal conductivity λ at boiling point	123	140	mW/m·K
Dielectric constant ϵ_r at boiling point	1.52	1.43	
Latent heat of evaporation	161.9	199.3	kJ/kg
Amount of gas (20°C, 0.1 MPa) produced by 1 m^3 of liquid	841	693	m^3
Density at 20°C compared to density of air	1.4	1.0	
Ratio of enthalpy of vapor at 20°C and latent heat of evaporation	0.7	1.14	

References

[AD 2000] AD 2000-Regelwerk, Verband der Technischen Überwachungsvereine e.V., Essen, 2004, Karl Heymanns Verlag KG, Köln.

[AAe 05] Austrian Aerospace, datasheet 2005.

[Arc 04] U. Archakositt, S. Nilsuwankosit, and T. Sumitra, J. Nucl. Sci. Tech.**41** (2004) 432-439.

[Bar 85] R.F. Barron, Cryogenic Systems, Oxford University Press, 1985, ISBN 0-19-503567-4.

[B&R 05] Bopp & Reuther Sicherheits- und Regelarmaturen GmbH, Mannheim, http://www.sr.boppureuther.com.

[Bro 01] L. Brown, S. Carothers, M. Monyok, and Z. Smith, 'Incorporating Phase Changes with Unsteady State Heat Transfer - S01', http://rothfus.cheme.cmu.edu/tlab/ussht/projects/index.htm.

[Fas 70] Kryotechnik, W.G. Fastowski, J.W. Petrowski, A.E. Rowinski, Akademie-Verlag, Berlin 1970.

[Fes 02] J. Fesmire, S. Augustynowicz, C. Darve, 'Performance characterization of perforated multilayer insulation blankets' ICEC 19, Grenoble, July 2002, http://tdserver1.fnal.gov/nicol/lhc_irq_cryostat/ch_darve/public/publication.htm.

[Ger 04] GERDA, 'The GERmanium Detector Array for the search of neutrinoless double beta decay in Ge-76 at LNGS', The GERDA Collaboration, Proposal to LNGS P38/04, September 2004.

[Tim 89] K.D. Timmerhaus and Th.M. Flynn, Cryogenic Process Engineering, Plenum Press, 1989, ISBN 0-306-43283-8.

[Tso 83] C.P. Tso and J.H. Strauss, J. Phys. D: Appl. Phys. **16** (1983) 943-953.

[Van 63] Cryogenic Engineering, R. W. Vance, John Wiley & Sons, Inc., New York, London