GERDA

Technical Proposal

Version 0.1

The GERDA Collaboration

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Gerda
Technical Proposal V0.1

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Contents

1 Preface to Version 0.1

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 with liquid nitrogen (LN) or liquid argon (LAr). Because of its radiopurity the liquid does not contribute to the background 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.

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

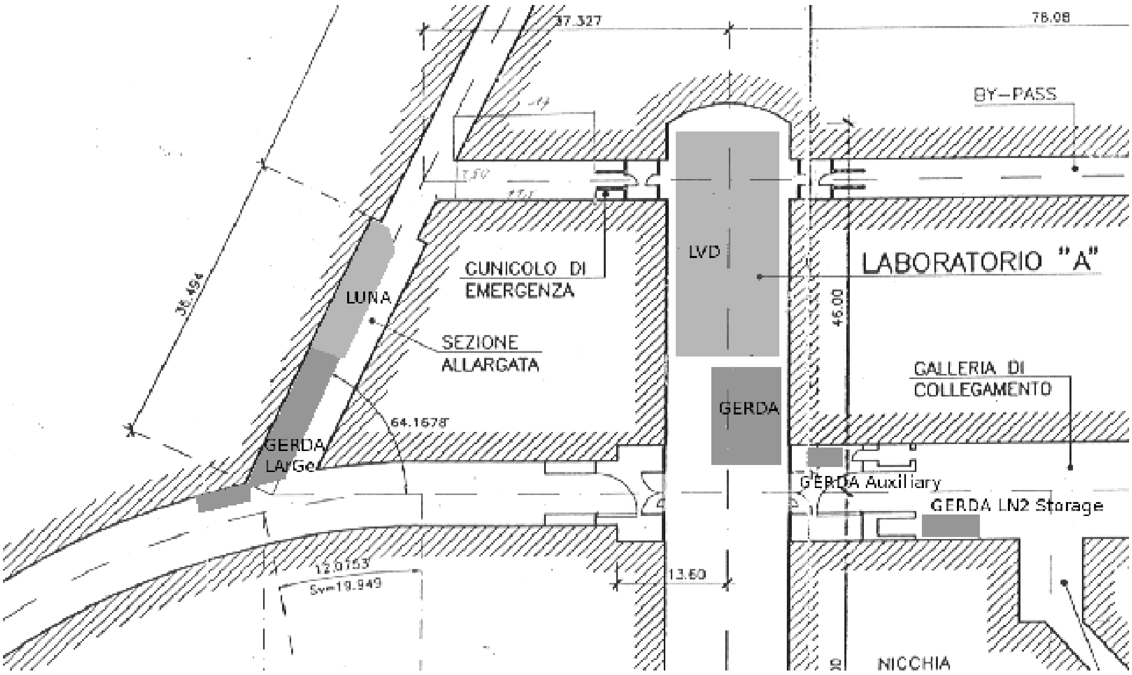

Figure 1: The sites of the GERDA experiment in the LNGS underground laboratory.

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 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.

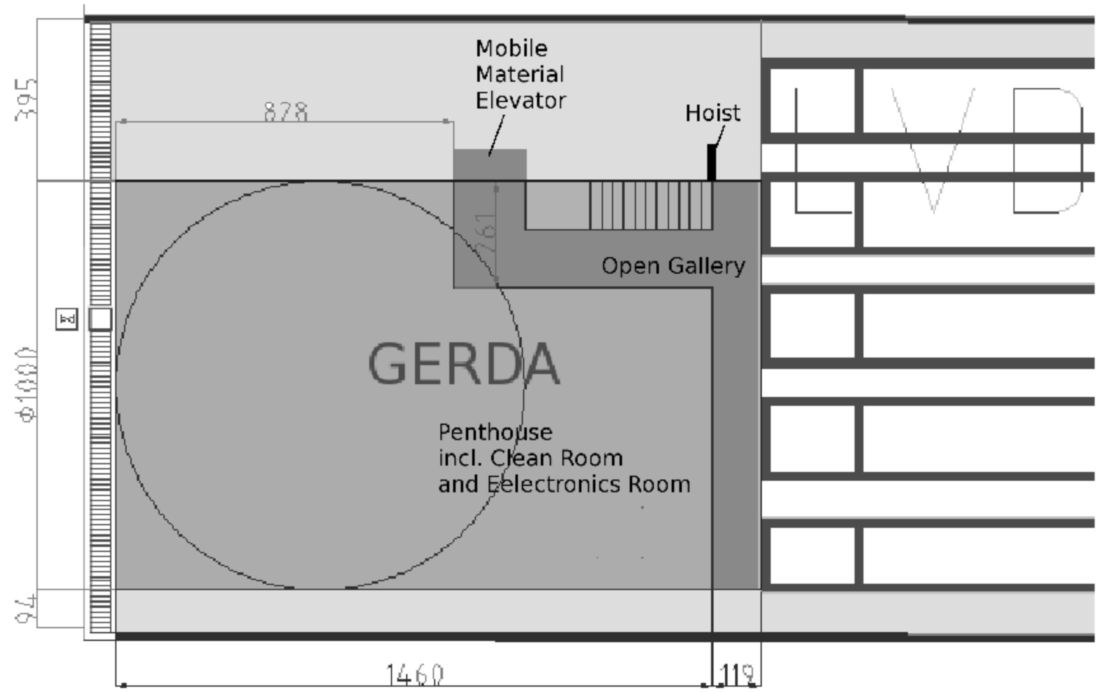

Figure 2: Layout of the Main Experimental Site of GERDA in Hall A (dimensions in cm).

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 5.

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. 18) 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.

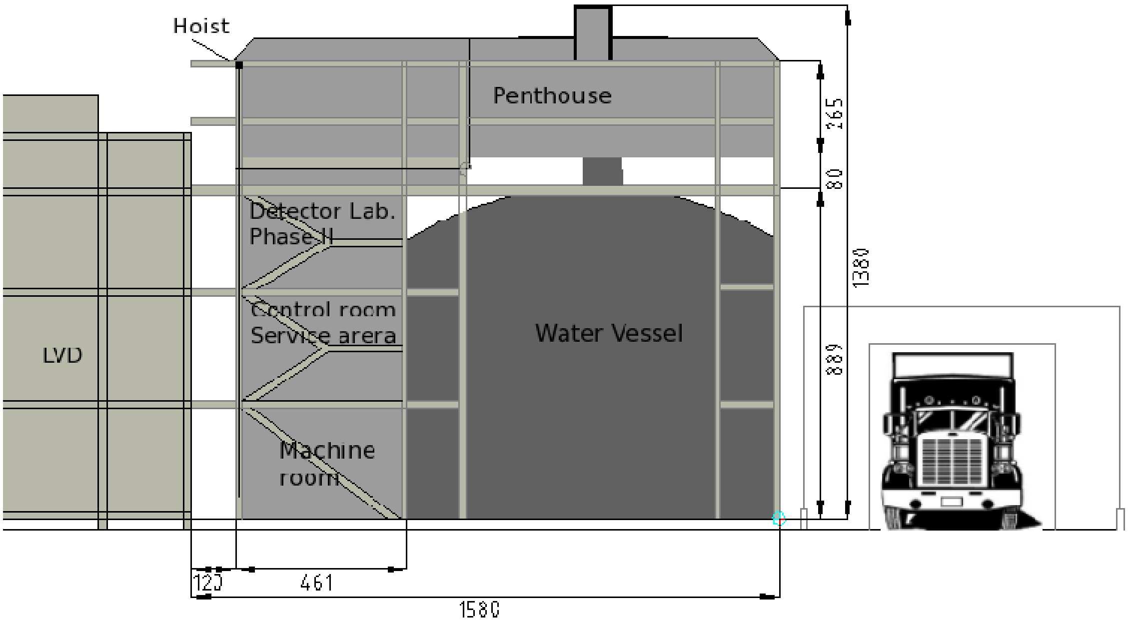

Figure 3: Lateral view of the GERDA experiment in Hall A (dimensions in cm).

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 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.

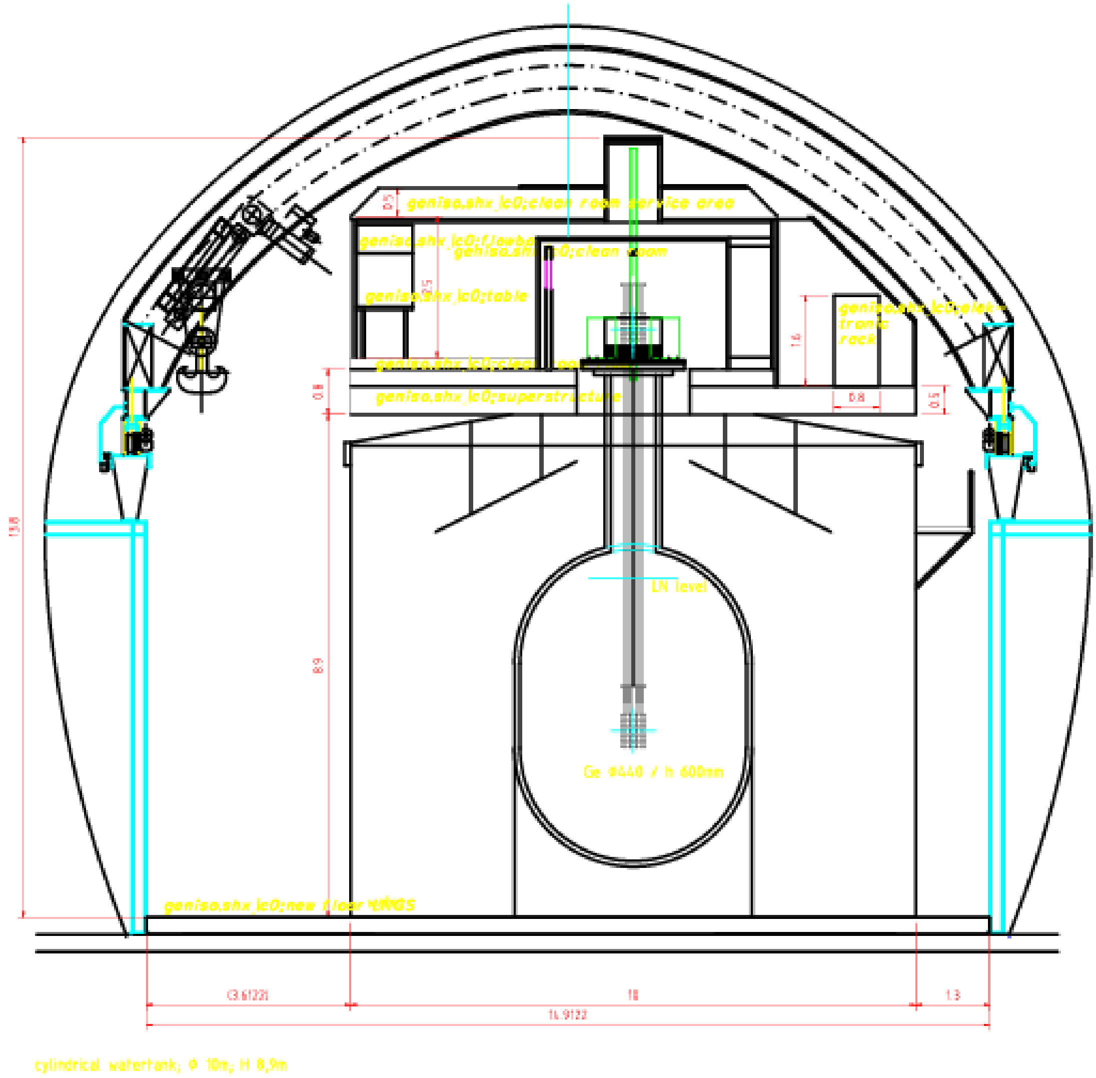

Figure 4: View of GERDA cross section from TIR tunnel. The shielding structure below the roof of the water tank might be not needed.

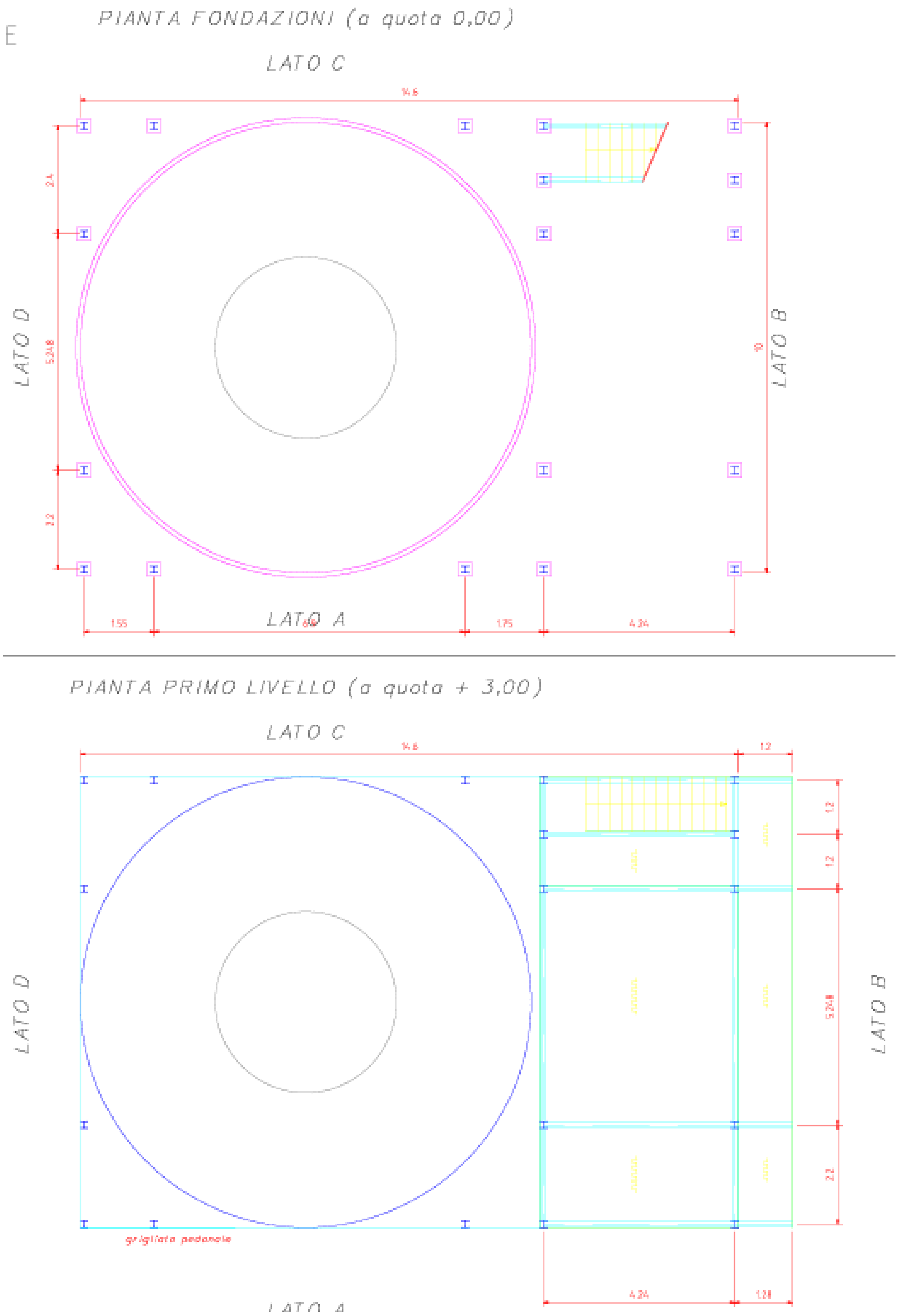

Figure 5: Plan of water vessel and laboratory building

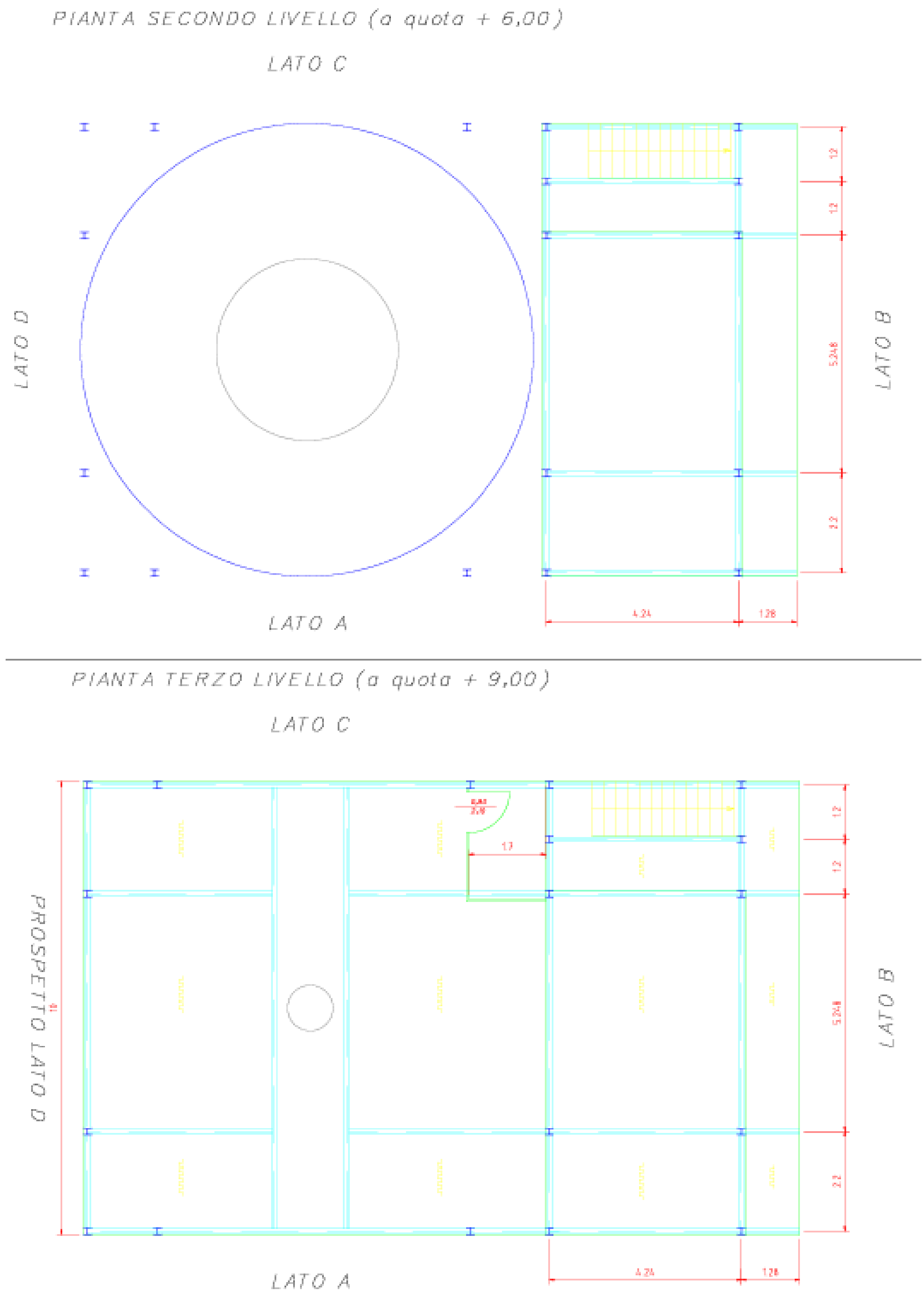

Figure 6: Plan of water vessel and laboratory building

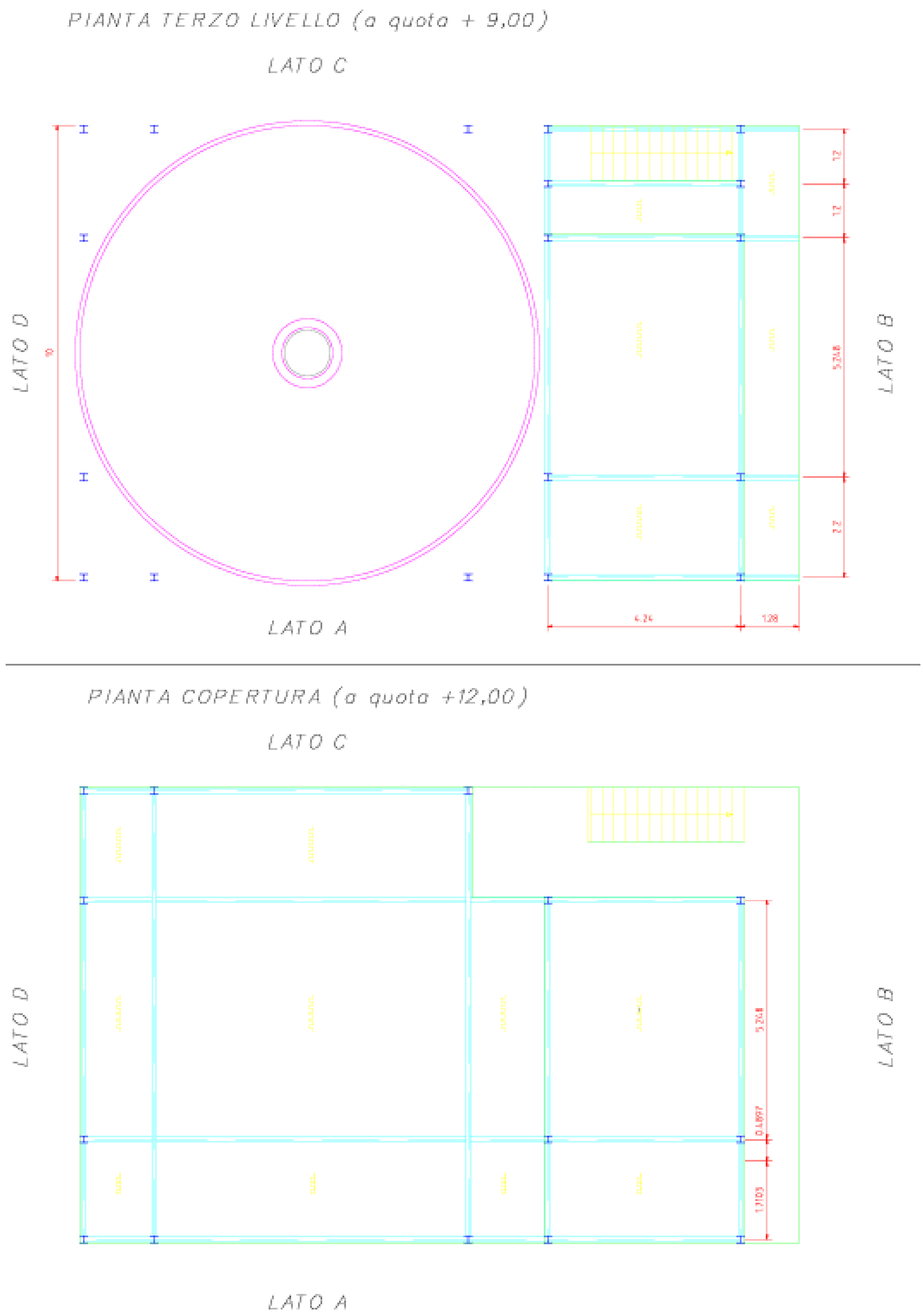

Figure 7: Plan of water vessel and laboratory building

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 a cross section is shown in Fig. 8, see also Figs. 4 to 7, and Fig. 9. The water tank consists of a cylinder

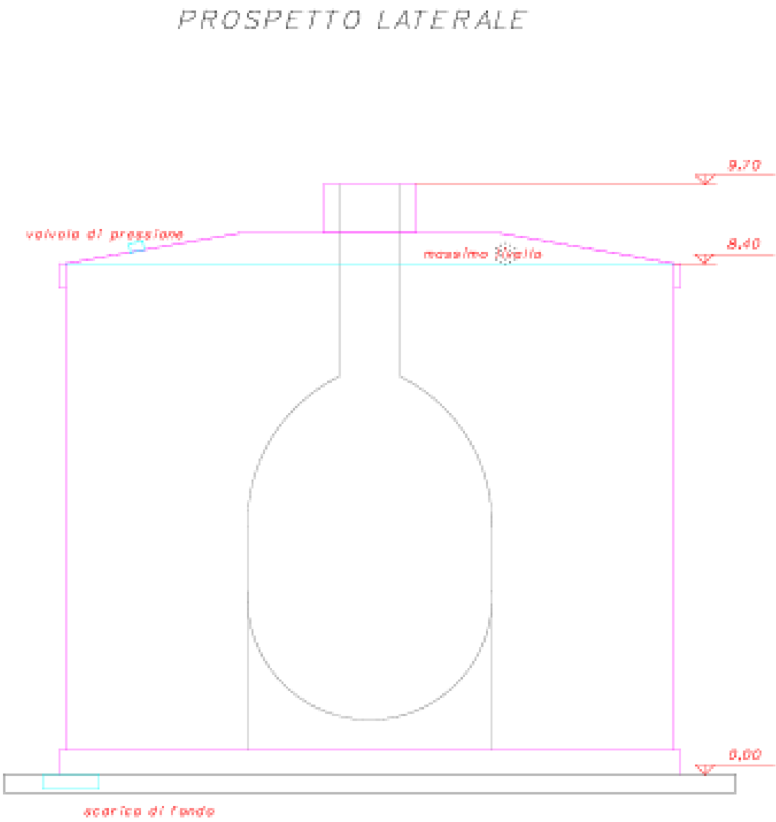

Figure 8: Cros section of watertank.

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 by a manhole of 5 m 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 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 and - depending of the final position of the cryostat within the water tank - also above the cryostat hanging there from the roof of the water tank. (see 'wings' in Fig. 9).

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

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:	$\approx$2 m
Angle between shell and roof:	$\approx 6^\circ$
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 DN 5000	with davit lateral at bottom
1 DN 1800	in roof for cryostat neck
6 DN 500	in roof for level, pressure and temperature sensors incl. spares
1 DN 300	for total drain compensation
2 DN 250	in roof for photomultiplier cables
1 DN 200	to drain tank completely in 20 h
2 DN 32	lateral for water recirculation
Weight of water tank (tons):	$<$20 tons
Weight of filled water tank:	650 tons
Operational over/underpressure:	$\pm$20-30 mbar
Safety device:	pressure/depressure $\pm$20-30 mbar
Water recirculation:	yes, 2-3 m^3/h
Water recirculation plant:	deionization, Radon stripping, particulate removal

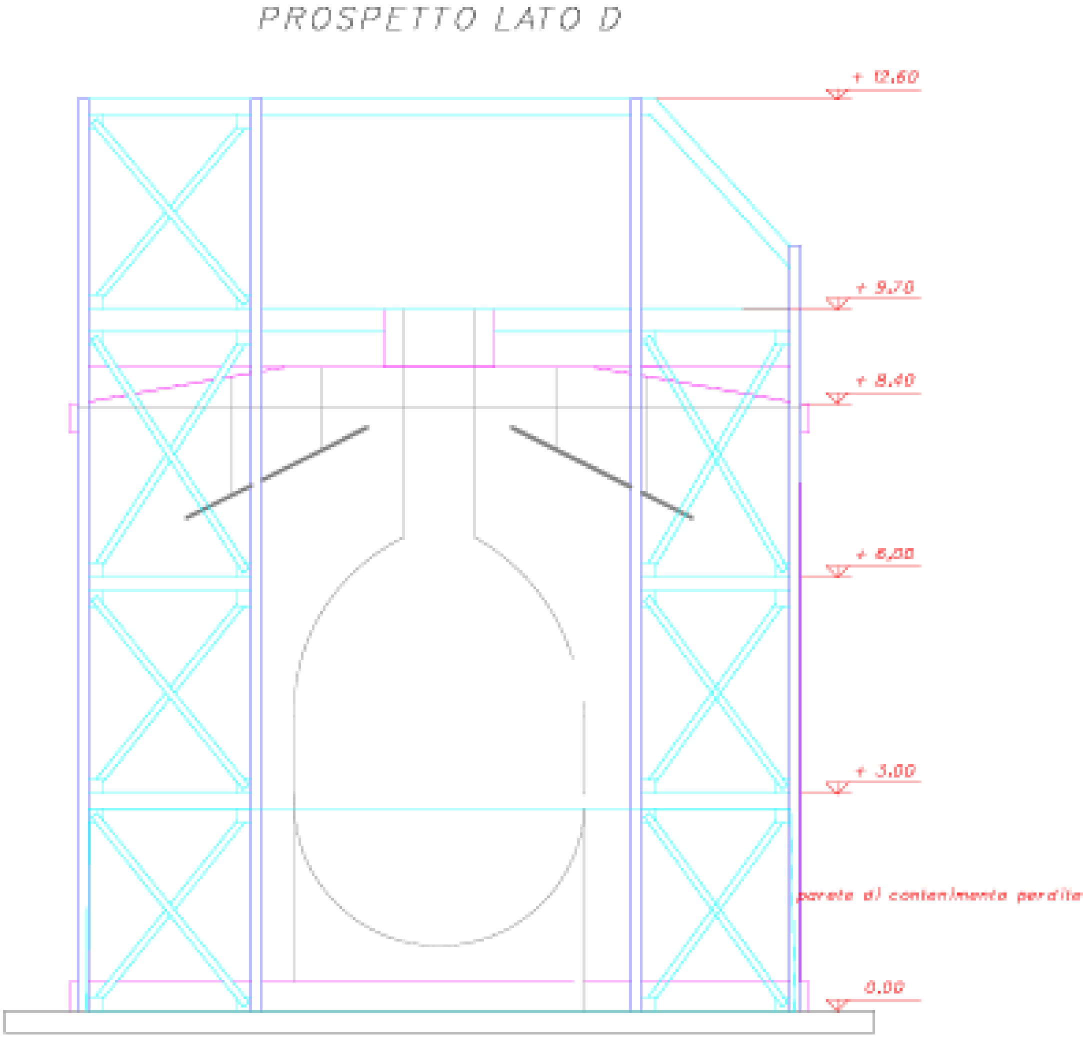

Figure 9: View from the TIR tunnel onto super-structure and water tank with cryostat. The shielding structure below the roof of the water tank might be not needed.

4 Cryostat

The GERDA cryostat serves as container for the liquid nitrogen (LN) or argon (LAr) 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.

4.1 Design Considerations and Specifications

The size of the cryostat must allow to transport the complete vessel from its manufacturing plant to the LNGS underground laboratory by road. This constraint fixes its diameter to not much more than 4 m. Using high performance superinsulation as thermal shield which needs very little space, about 2 cm, the radius of the LN shield will amount to about 1.9 m which implies severe constraints for the radiopurity of the building materials. Thus, in order to achieve the desired background index of 10^{-3} cts/(keV·kg·y), only selected copper (or lead) is known to exhibit the required ^{228}Th activity of less than 25 μBq/kg. The cryostats minimum height amounts to 6-7 m, i.e. 4 m plus the space for the Ge-diode arrangement (0.5 m) plus the space for a neck (1.5 m) serving both as thermal impedance and port for insertion of the diodes. Up to 1 m additional height of cryogenic liquid will help to compensate the loss of shielding material due to the hole in the neck. The support of the cryostat will add at least 0.5 m in height to guarantee an efficient water shield against neutrons; however, a thicker water layer at bottom, up to 3 m like reaially, would be economic since else lead or copper shileds are needed for compensation.

The following list shows a summary of the general specifications:

- design and manufacture conforming to AD2000 Regelwerk [AD 2000] for pressure vessels, DGRL 97/23 EG, and other applicable codes,
- maximum outer radius of vessel system not more than 2.0 m,
- thickness of cryogenic liquid, LN or LAr, in radial direction at least 1.85 m,
- minimum height of cryogenic liquid in axial direction 5.2 m,
- operating pressure 49 kPa,
- use of low-radioactivity copper (25 μBq/kg ^{228}Th) as major construction material,
- other used construction materials to be shielded accordingly,
- use of metal gaskets,
- redundant instrumentation conforming to AD2000 and other applicable codes,
- loss of cryogenic liquid by evaporation less than 0.2% per day,
- earth quake resistance up to 0.6 g horizontal and vertical,
- operating in water vessel of 9 m height,
- operating temperature 20°C, lifetime >10 years.

In addition the cryostat will be equipped with a cooling system that allows to reduce the evaporation rate of the cryoliquid by use of a heat exchanger.

4.2 Engineering Description

Fig. 10 shows the cross section of the superinsulated cryostat designed in accordance to the German codes for cryogenic and pressure vessels using copper of the DIN type DHP R240 (formerly SF-Cu, material # CW024A, formerly 2.0090); the detailed production drawing is shown in Fig. 11. A summary of its characteristics is given in Table 2. The cryostat consists of two coaxial vessels which are built from hemispherical shells of inner radii of 1.89 m resp. 2.00 m and corresponding cylindrical centerpieces of about 1 m height. Both vessels have a coaxial cylindrical neck of 1.5 m length; a major part of it is made from stainless steel (1.4571) for achieving a high thermal impedance. The upper ends of the necks are connected to each other so that the inner vessel is suspended via its neck in the outer vessel without any further thermal contact. Additionally, the vessels are centered at bottom by a cylinder of about 30 cm diameter and 16.5 cm height and a corresponding socket that are welded to the inner and outer vessels, respectively. A cylindrical skirt made from 8 mm thick copper supports the outer vessel from the ground.

The volume between both vessels will be pumped via two about 2 m long pipes in order to maintain the insulation vacuum below 0.01 Pa. Four further flanges will be used to connect safety and pressure relieve valves as well as manometers.

The pressure vessel code requires a maximum thickness of the DHP R240 copper plates of 15 mm. This constraint implies that the earth quake tolerance of 0.6 g can be fulfilled for horizotal accelerations only; in vertical direction 0.5 g can be tolerated. The crticial part is the transition from neck to hemisphere, and thus the neck is reinforced by two stiffening rings which, however, degrade thermal insulation. Work is in progress to solve this problem by manufacturing the complete neck including an adaptor ring from stainless steel.

An alternative design is shown in Fig. 12, see also Table 2. The crucial difference with respect to the former design is that now the inner vessel rests on 12 glass-fiber reinforced plastic (GPR) pads which are located at bottom between inner and outer vessel. The compensation for thermal shrinkage of the inner container, a maximum of 36 mm when cooled down from 300 K to 77 K, is provided by a bellow in its neck. Three spacers within the neck and three spacer at bottom keep the inner vessel centered. Finite element analysis has proven it to meet all earth quake requirements despite of an increase in the height of the centerpiece to 2 m.

A final decision between both options will be made as soon as both design are finalized and more information about the GRP material and the copper-stainless steel weld are available.

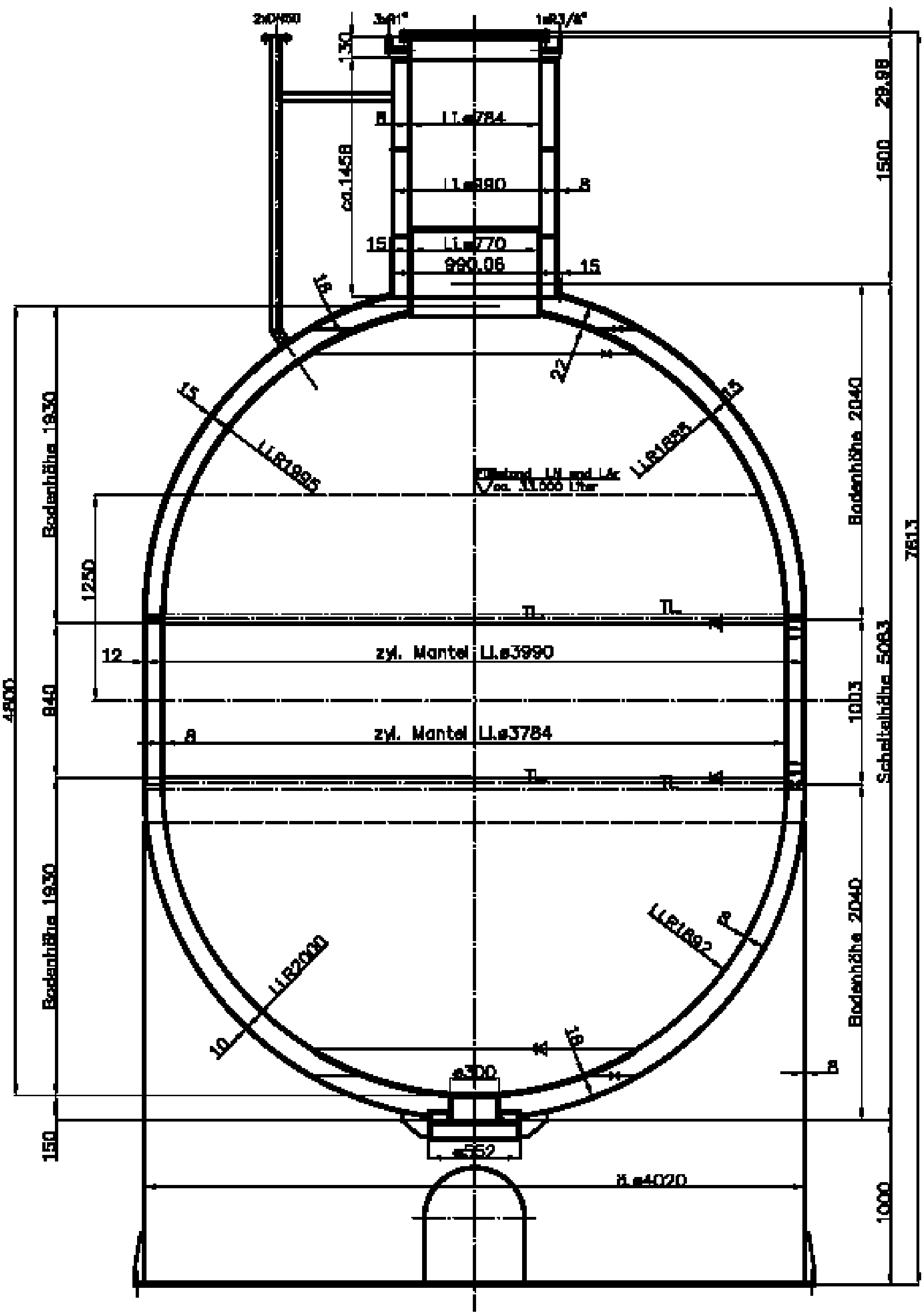

Figure 10: Preliminary design for a copper cryostat with the inner container hanging from the neck.

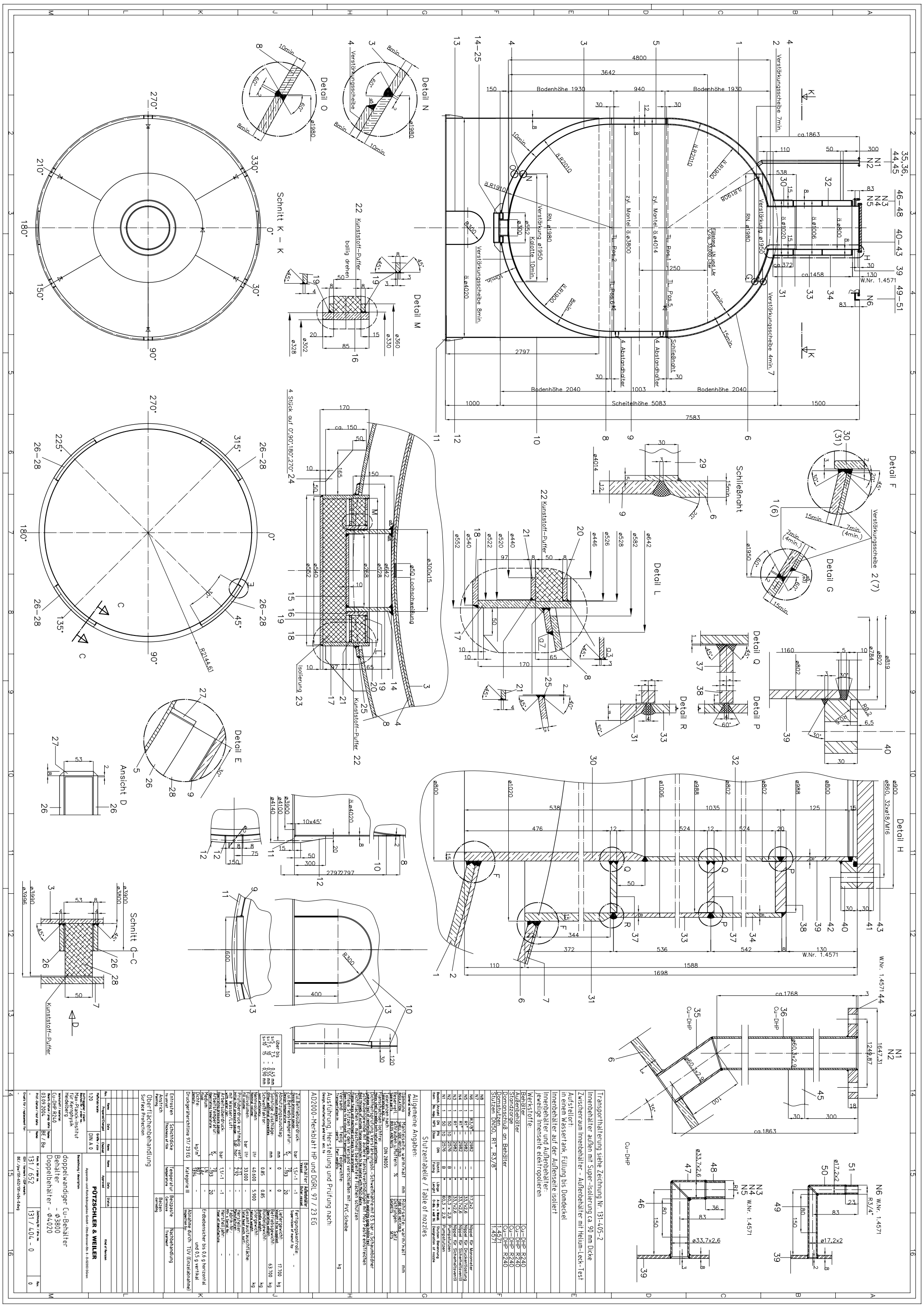

Figure 11: Production drawing for the preliminary version of a copper cryostat with the inner container hanging at neck.

Table 2: Preliminary technical data for two copper vessel options.

Design	option 1	option 2	
Materials			
vessel bodies	Cu-DHP R240	dto	
radiopurity ^{232}Th	<30 μBq/kg	dto	
radiopurity ^{238}U		dto	
neck	all stainless steel	copper + ss bellow	
pads	none	GRP	
Geometry			
overall dimensions $\varnothing_o \times$h	4034×7613	4000×9100	[mm^2]
outer vessel $\varnothing_o \times$h	4020×5083	4000×6000	[mm^2]
inner vessel $\varnothing_i \times$h	3784×4600		[mm^2]
neck height	1500	1600	[mm]
neck inner diameter	800	dto	[mm]
inner vessel volume incl. neck	(41)	(52)	[m^3]
volume for liquid gas	(33)		[m^3]
Masses			
empty vessel	17,7		[10^{3}kg]
LN fill	26,6		[10^{3}kg]
LAr fill	46,0		[10^{3}kg]
Pb shield			[10^{3}kg]
total max. mass	63,7		[10^{3}kg]
Pressures			
inner vessel operating overpressure	0.5	dto	[10^5 Pa]
inner vessel maximum pressure	2.5/-1	dto	[10^5 Pa]
pressure for LN / LAr emptying			[10^5 Pa]
outer vessel overpressure	-2	dto	[10^5 Pa]
Superinsulation			
number of superlayers	10 - 30	dto	
nominal insulation vacuum	10^{-2}	dto	[Pa]
leakage rate	10^{-5}	dto	[m^{3}Pa/s]
thermal loss (calc./upper limit)	/		[W]
corresponding daily loss of LN			[ℓ]
Safety			
construction code	AD 2000 HP	dto	
	DGRL 97/23 EG	dto	
earth quake tolerance	h/v : 0.6/0.5 g	0.6 g	

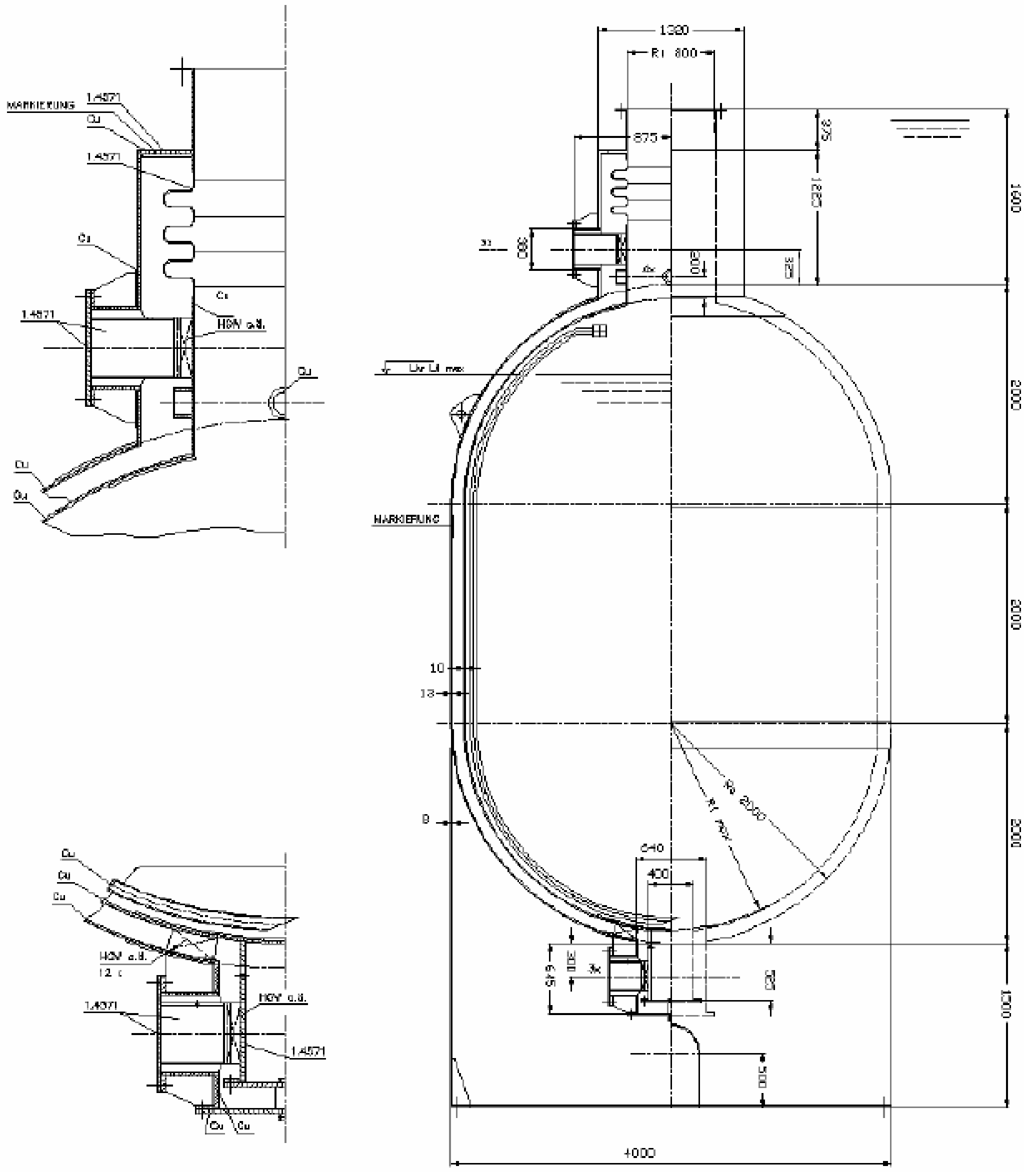

Figure 12: Preliminary design for a copper cryostat with the inner container resting on epoxy pads.

4.3 Backup Solution

Until the feasibility of a copper cryostat is clearly established work continues on an alternative solution i.e. a stainless steel cryostat that carries a Cu or Pb shield in the cold volume (see also section 6.2.3 of the Proposal). Fig. 13 shows the most recent design with a highly optimized graded internal copper shield. The dimensions of the vessel are now very much compatible with those of the copper cryostat and the weight of the shield is largely reduced compared to the version shown in the Proposal.

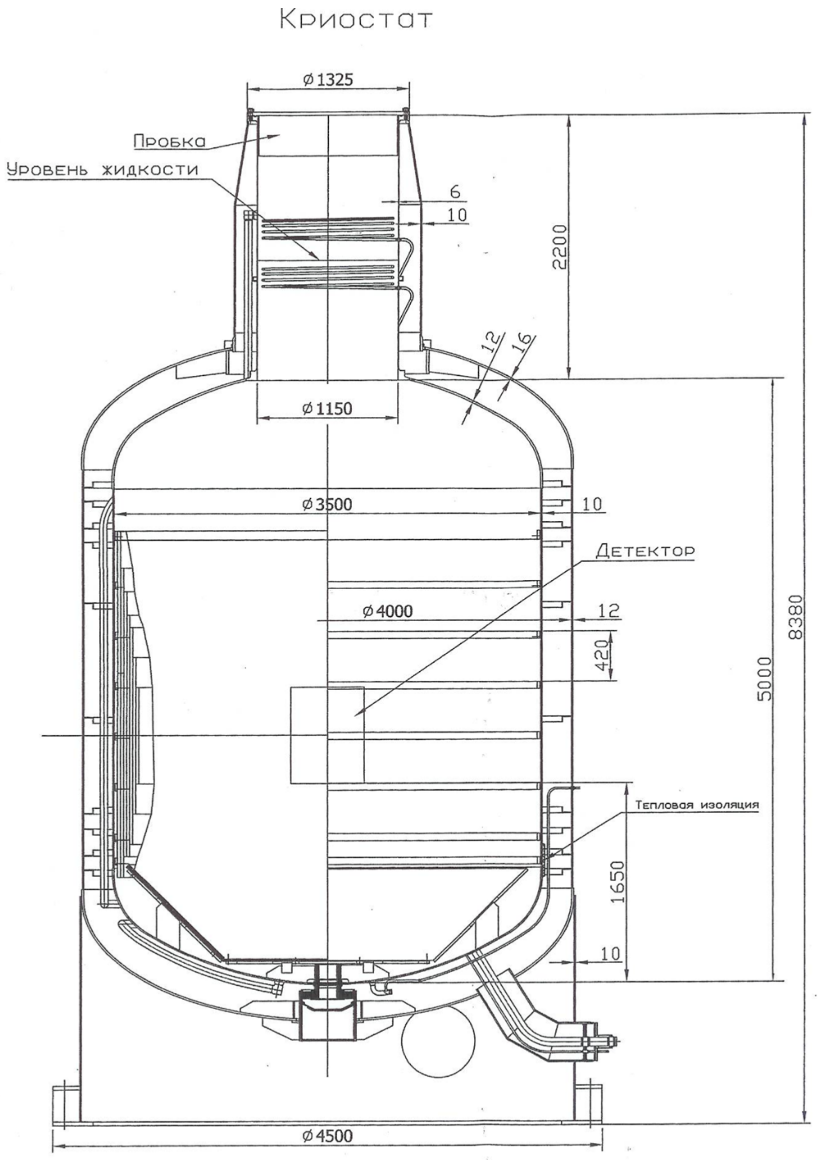

Figure 13: Preliminary design for a stainless steel cryostat with internal copper shield.

4.4 Multilayer Insulation

The multilayer insulation (MLI) will be attached in the space between both vessels to the wall of the inner vessel. If the inner vessel is resting on GRP pads, the MLI has to extend over the sides of these pads. The maximum thickness of the MLI will not exceed 20 mm including assembly and attachment provisions.

MLI or superinsulation consists 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 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 3 for one specific product line.

Table 3: Specifications of several 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 spacered - mesh		
double side aluminisation, perforated		
10 foil + 10 space layers	1.0 - 1.5	128 - 182 or 207 - 277
20 foil + 20 space layers	0.8 - 0.9	
30 foil + 30 space layers	0.7 - 0.7	
40 foil + 40 space layers	0.55 - 0.6	
Coolcat 2NW 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. 14 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.

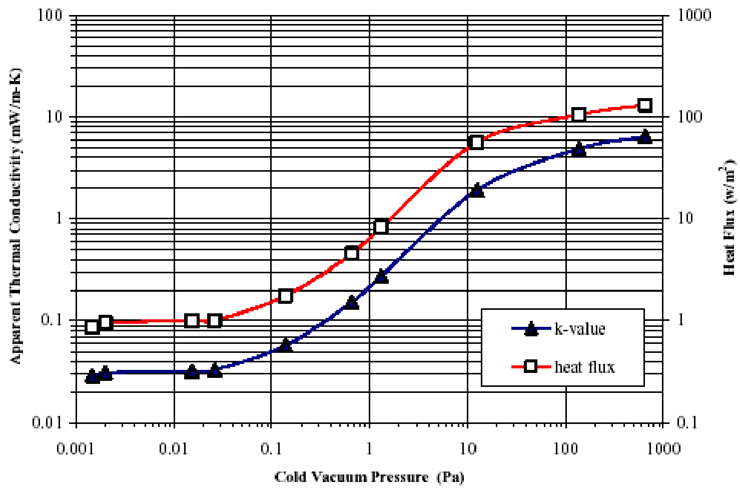

Figure 14: Variation of heat flux (right scale) and apparent thermal conductivity in a MLI blanket (30 layers, 7 mm total thickness) with cold vacuum pressure [Fes 02].

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% LN [AAe 05].

4.5 Materials and Production

The required radiopurity of the copper has been verified so far for the copper grade NOSV only which had been delivered by the Norddeutsche Affinerie AG to the MPI Heidelberg. The required DHP copper grade is a phosphorus-deoxidized product; it can be produced from the NOSV grade by being alloyed with 0.015 to 0.040 (mass)% of phosphorus. Technically, a phosphorus-copper granulate with 10 (mass)% of P is added in the electrically heated melting furnace to the NOSV material. Thus the radiopurity of the resulting DHP copper can be deduced most easily from the radiopurity of the phosphorus-copper granulate. A preliminary value of its ^{228}Th activity is (10$\pm$2) mBq/kg; hence the addition of 3 g P-Cu granulate to 1 kg of NOSV grade copper will increase its radioactivity by 35 μBq/kg which is a factor of 1.5 higher than specified. Work is in progress to reduce the ^{228}Th content of the granulate.

The radiopurity of one type of thermal insulation, NAC-2 cryo-laminated superinsulation foil with bonded space material according to HERA/DESY specifications, has been measured to be less than 50 mBq/kg (upper limit). Assuming 20 layers of a density of 24.2 g/m^2, this would increase the radioactivity budget by less than 140 μBq/kg. Thus, a more sensitive measurement is needed.

The radioactive contribution from all other construction materials, stainless steel and GRP pads, is known to be much higher; typical values are 10 mBq/kg and the amount of material used locally is in the order of kg at least. Thus shielding of these materials is needed, and the designs of the cryostat account for that by including additional loads of 1000 kg at the transition neck-hemisphere and at the bottom of the inner vessel, respectively.

To prevent contamination by additional radioactivity, the welding and assembly of the cryostat has to be done at clean room conditions. Also in this context, electron beam welding is the optimum welding technique being carried out in vacuo and needing neither welding electrodes nor additives. A welding facility with a sufficiently large vacuum chamber of $6\times7\times14\mathrm{m}^3$ has become available recently [Pro 04]. First electron beam welding tests are in progress including the weldment of two pressed spherical segments from DHP copper as well as material tests for joints of DHP copper and stainless steel.

4.6 Thermal Performance

The heat flow $\dot{\mathrm{Q}}$ 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 6 mm thick stainless steel (λ = 15 W/m·K) and a of 1.5 m length, A = 0.0151 m^2, and hence $\dot{\mathrm{Q}}$ = 33 W.

The heat flow through 12 pads of glass fiber re-enforced plastic (λ(GRP) = 0.3 W/m·K) of 0.05^2 m^2 area and 0.1 m thickness amounts to 19.4 W.

The thermal conductivity of a 20 layer superinsulation is about 0.0023 $\mathrm{W/m^2K}$ between 300 K and 77 K. Assuming a cryostat's surface area of 74 m^2 and a safety factor of 2, the heat flow amounts to 74 W (see also Table 3).

Table 4 summarizes the thermal losses discussed above as well as the corresponding daily evaporation rates for nitrogen; for Ar the evaporation rate is a factor of 1.23 larger. With a total cryogenic mass of 39000 (67000) kg of LN (LAr) the daily evaporation rate is for each option well below 0.2%.

Table 4: Thermal losses

Cryostat part	W	kg($\mathrm{N_2}$)/d	kg(Ar)/d
Neck	33	14.3	
Bellow	10?	4.3	
GRP pads	19	8.2	
Superinsulation	74	32.0	
Sum(inner vessel hanging)	107	46.4	57.1
Sum(inner vessel on pads)	103	44.7	55.0

4.7 Integration of Cryostat within GERDA

The cryostat will be mounted onto a vibration-isolated basement and will be completely decoupled from the surrounding *Super-Structure*. If the cryostat cannot be grounded via a suitable grounding bar in (the floor of) Hall A, its 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 5). This manifold is made from stainless steel and needs to be thermally isolated. It contains the feed throughs for all devices that penetrate into the cold volume. At present, the following tubings and feed throughs are foreseen (see Fig. 15).

- superinsulated filling tube
- gas exhaust tube
- superinsulated pipes for active cooling
- feed throughs for all instrumentation outlined below
- feed throughs for detector cables
- several spare lines

Detailed specifications will be presented in a future section.

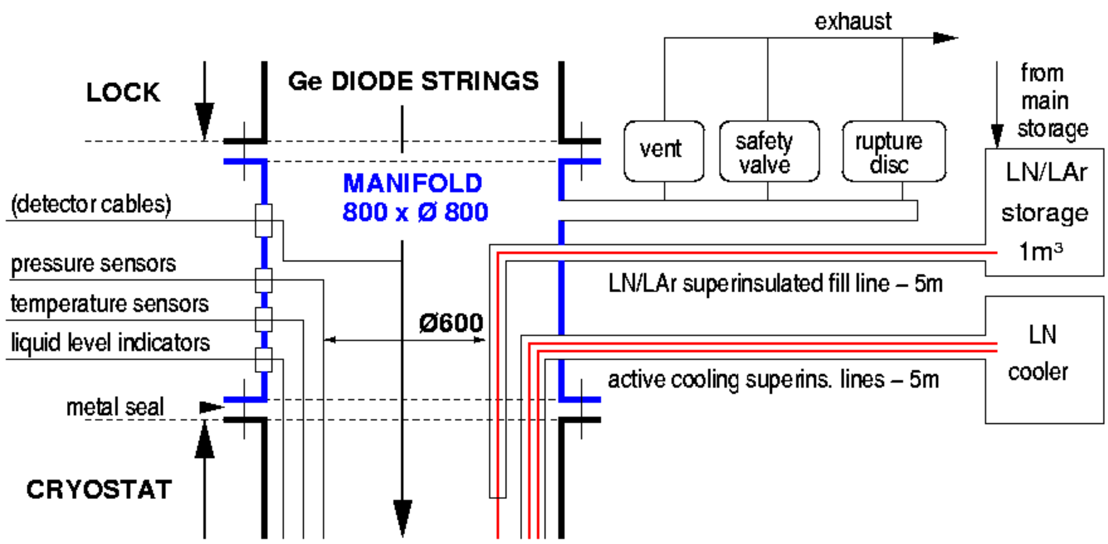

Figure 15: Schematic of the manifold through which indicated devices penetrate into the cold volume.

The connections between cryostat, interface and lock exhibit metal-gaskets and must pass a He leak test.

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

4.8 Instrumentation and Auxiliary Equipment

The instrumentation and auxiliary equipment allows to monitor and control the status of the cryostat such that a reliable and safe operation is guaranteed. Devices that are crucial for safety will be redunantly implemented.

The instrumentation for monitoring and controlling the cold volume includes (Fig. 15)

- level indicator of cryoliquid (hydrostatic and/or capacitive device)
- level indicator for cryoliquid (high resolution)
- manometers ($2\times$)
- pressure control valve
- overpressure safety valve and rupture disk
- underpressure safety valve and rupture disk
- thermometers (several)
- slow control system

The evaporated cryoliquid is pressure-less substituted by liquid stored in a small superisolated container of about 1 m^3 that is located close to the top of the cryostat's neck. This container, in turn, is refilled via a pressurized line from the big storage tanks in the TIR tunnel.

The instrumentation and infrastructure for controlling and maintaining the insulation vacuum includes

- manometers ($2\times$)
- mass spectrometer for identifying type of leak
- overpressure safety valve and rupture disk
- roughing and venting valve
- diaphragmas for roughing and venting
- slow control system

The insulation vacuum is served by one or two turbopumps which are located close to the top of the neck. The roughing pump(s) could be installed in the machine room of the laboratory building. Pump-down and venting must be done in a well controlled way so that the MLI is not damaged. For that purpose, the conductance of the line for roughing resp. venting will be controlled by diaphragms of appropriate size. In normal operation, the turbopumps will be shut off and the valves between pumps and cryostat flanges will be closed.

4.9 Cryogenic Infrastructure

The cryogenic infrastructure includes

- One storage tank for liquid nitrogen (LN) and one for liquid argon (LAr). The latter will be needed for the operation of the cryostat with argon. These standard vessels will have a volume of 4 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.

- An active cooling unit to avoid / reduce evaporation losses during operation. About 0.2% of the cryostat volume will evaporate per day. This corresponds to a heating of about 200 W.

  Just below the fill level in the cryostat a heat exchanger (copper tubes) will be installed and liquid nitrogen with lower temperature at sub-atmospheric pressure will circulate inside. Part of the equipment to provide the coolant will be installed on the gallery of the 3^{rd} floor.

- Equipment for initial filling and emptying of the vessel. Different options exist for draining of the vessel: overpressure in the gas volume, pumping of the liquid, or evaporation with a heater. Since it is not anticipated to exchange the cryogenic liquid during the lifetime of the experiment - except if nitrogen is exchanged by argon - the last option might be a viable one. As an example, the drainage will take 2-3 weeks with a 5 kW heater. In case overpressure is used, about 2 bar (absolute) is needed and hence the vessel will be classified as a pressure vessel according to European rules.

- A radon cleaning unit for the removal of radon from the liquid nitrogen/argon. This unit may only be needed during the first filling of the tank. A final decision can only be made once all parameters of the active cooling are known. Such a unit is already in operation for BOREXINO and the Genius Test Facility. It would also be placed at the ground floor of the laboratory building.

The overall space required for the equipment at the ground floor of the laboratory building is estimated to be about 20 m^2. The electrical power for pumps and control units is expected to be 5-10 kW.

A final design for the cryogenic infrastructure is not yet available but the basic features are known and two competing options are available. Both include drawings for the layout of the infrastructure together with a description of the operation. Some iterations are needed needed to come to a final design.

Fig. 16 shows the conceptual design by *CryogenMash*. The coolant for the heat exchanger (item 8) is liquid nitrogen taken out of a storage tank operated at an absolute pressure of 2 bar. The nitrogen is expanded through a nozzle. The resulting liquid/gas mixture will boil in the heat exchanger and the gas is then pumped by a vacuum pump (item 6). The pressure (temperature) of the cryostat is measured by the manometer P1 (temperature transmitter T1) and it is controlled by the flow through the pump (valve

VE2) and by the valve VE3. The fill level is measured by the hydrostatic pressure of the fluid (gauges L1 and L2). All lines with liquid nitrogen are routed from the cryostat to the ground floor of the laboratory building through one vacuum insulated pipe of DN 300. In the schematic, several pipes are inside the insulation vacuum of the cryostat and the inlet/outlet is at the bottom of the tank. For safety considerations, this solution will not be chosen, and we will avoid any openings in the vessel below its fill level. Instead, there will be one copper pipe inside the cryostat volume which can be used as inlet and for the hydrostatic pressure measurement. The passive safety valves S1/S2 open in case the pressure regulation fails. The insulation vacuum of the cryostat is pumped by a cryogenic getter pump (item 5). A heater (item 4) of 15 kW is able to evaporate some nitrogen and the resulting gas can be used to overpressure the vessel and hence to empty it through the valve V3.

An alternative design for the refilling and cooling of the cryostat by *Sommer Labortechnik* is shown in Fig. 17. The liquid nitrogen from a high pressure storage tank is expanded to a smaller tank of $\simeq 1\ \mathrm{m}^3$ volume (left tank in figure) with an absolute pressure of 0.6 bar in the gas phase. The underpressure is maintained by a turbo blower. The liquid nitrogen temperature is therefore cooled to about 73 K, and it will be used as a coolant for the heat exchanger inside the vessel. The advantage of this solution is that no boiling occurs in the cryostat and thus microphonic noise is avoided during operation. In addition, the cooled nitrogen can be used for refilling. The 1.4 bar absolute pressure inside the cryostat is maintained and controlled by a commercial system (right tank in figure).

The control system for the electromagnetic valves and measurement devices will be a Programmable Logic Control (PLC). One possible solution is the *DeltaV* system of Emmerson Inc. since it is already used by experiments like BOREXINO and expertise exists at LNGS. The PLC and the safety control devices should be connected to an uninterruptable power supply.

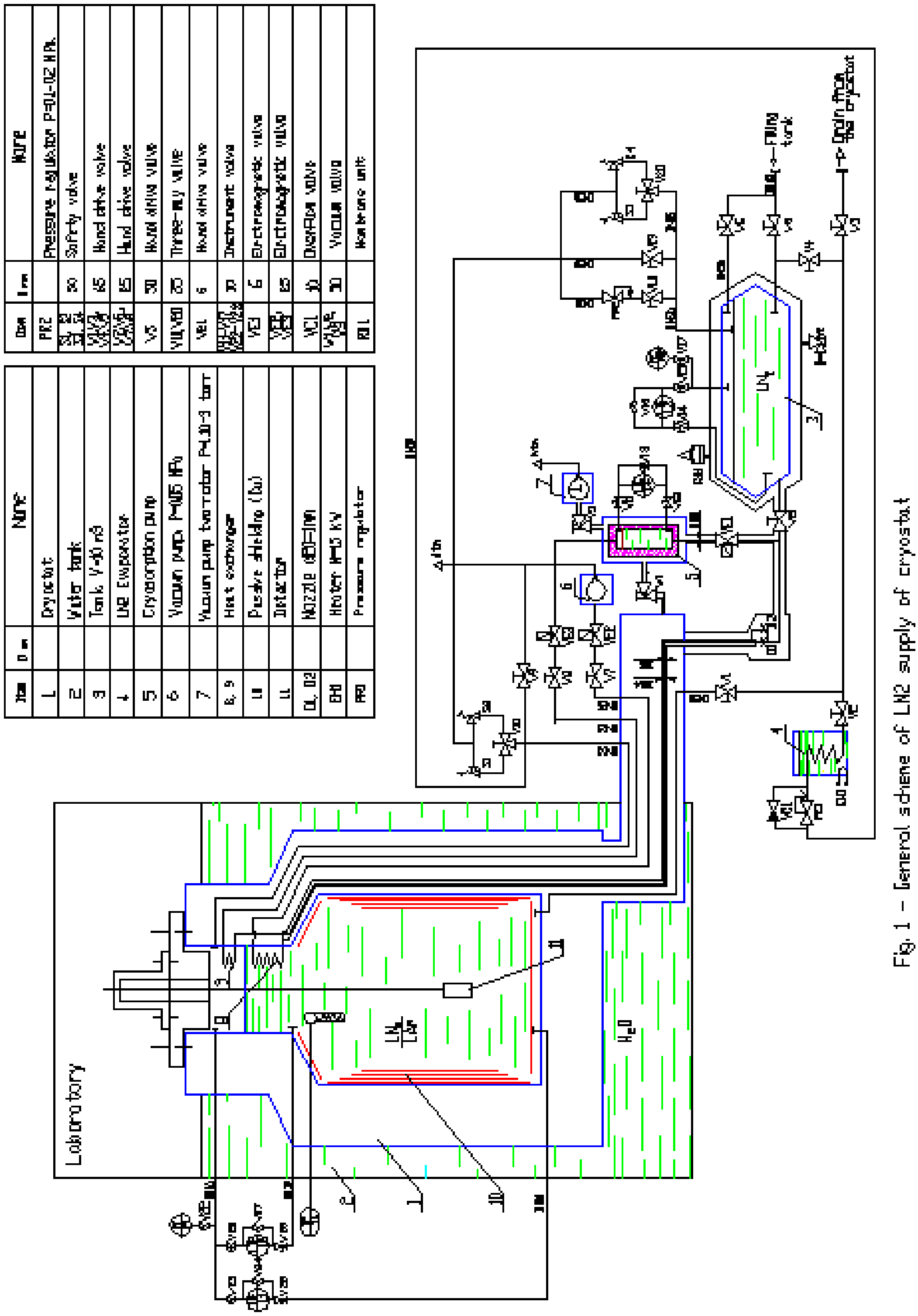

Figure 16: Schematic of the cryogenic infrastructure according to a design by *Cryogenmash*.

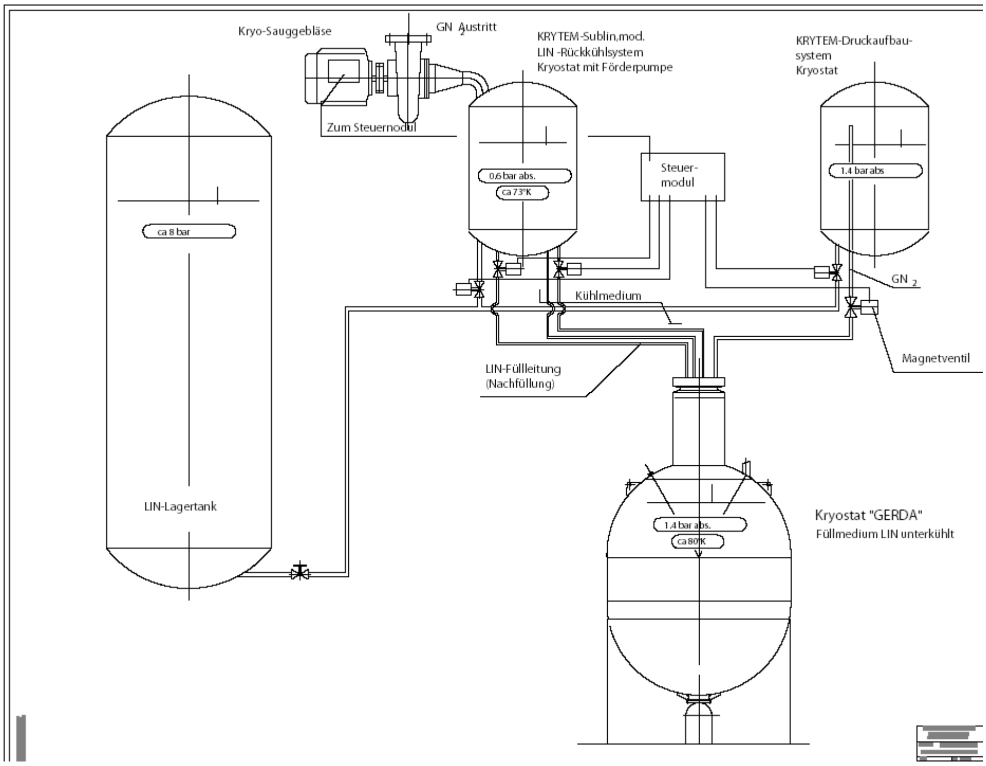

Figure 17: Schematic of the refilling and cooling system according to a design by *Sommer Labortechnik*.

5 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.[1] The penthouse or parts of it will be shielded as a Faraday cage according to specifications expected from the electronics group. Fig. 18 shows the layout of the penthouse.

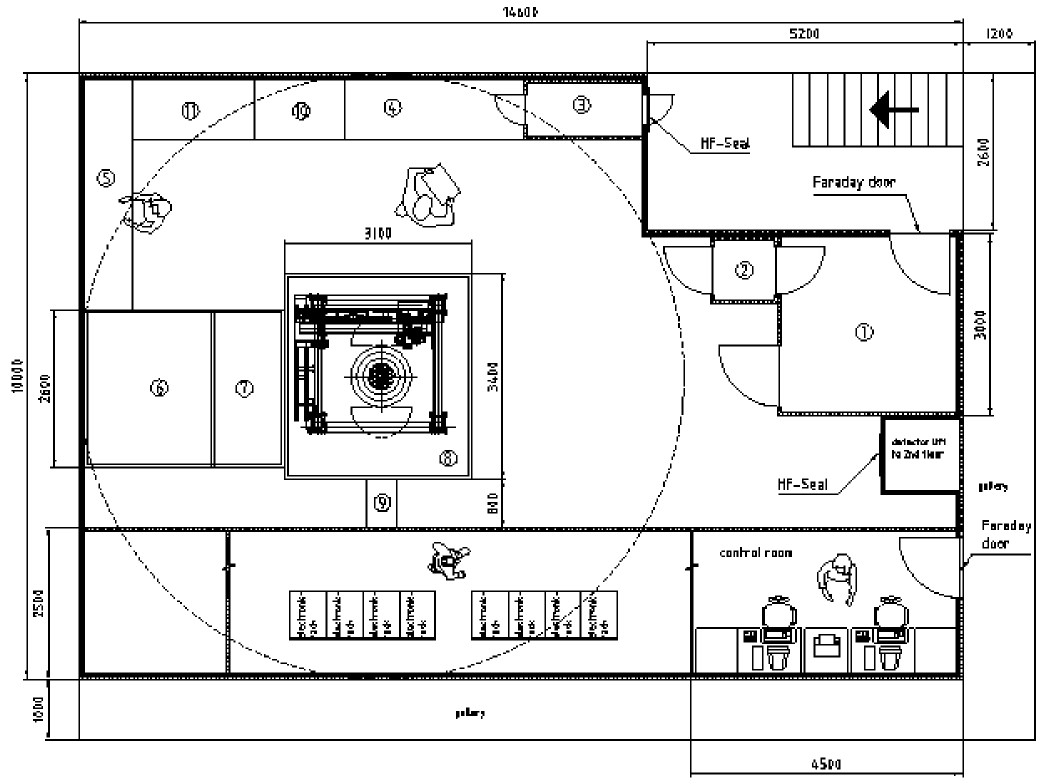

Figure 18: Layout of the penthouse [int.vers. 8] on top of the vessel with clean-room, lock system and the electronics-room. Numbered components are specified in subsection 5.3.

[1]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.

5.1 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.

5.2 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.

5.3 Clean-Room Components

The main components of the clean-room infrastructure can be located through their numbers in fig. 18. 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.

5.4 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.

5.5 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.

5.6 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.

6 Safety Aspects

6.1 Cryostat-Water Vessel System

Figure 19 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 LN or LAr; its volume is 46 m^3 which corresponds to 32000 (39000) m^3 of N_2 (Ar) gas. The water volume is 660 m^3. Safety-relevant events might be due to the leakage of either the cryostat or the water vessel.

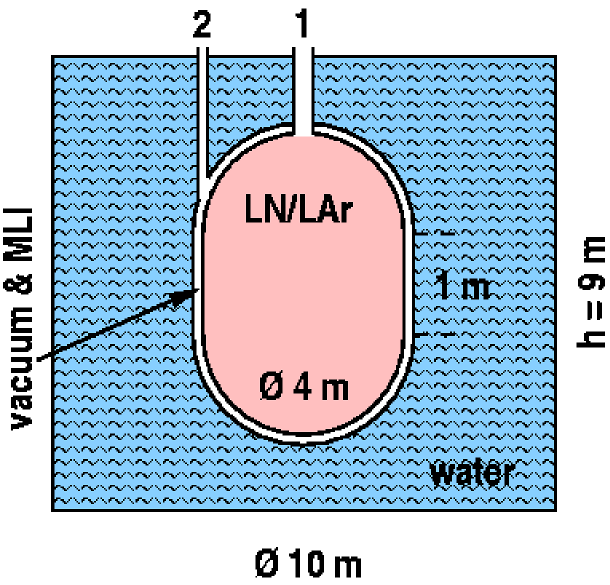

Figure 19: Vessel dimensions assumed for discussion of safety aspects. (1) indicates the neck of the vessel, (2) the tube through which the space between inner and outer container is pumped. Within this space the multilayer insulation (MLI) is mounted.

6.1.1 Leakage of Water Vessel

While the water contained in the GERDA vessel is purified and, hence, cannot pollute the Gran Sasso natural water, the sheer amount of water released through a major leak could represent a problem for nearby installations. Only 350 m^3 can be retained in the emergency pit. Thus, it might be recommendable to either build an appropriate water retaining bassin around GERDA and/or to install a pipe for draining the water to the outside.

6.1.2 Leakage of Cryostat

The cryostat consists of two vessels which are connected at the neck. The space between both containers is evacuated and - for improved thermal insulation - equipped with a multilayer superinsulation. Possible failures caused by 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. 14 shows this degradation for a special case to be about two orders of magnitude, while the compilation in Fig. 20 indicates even larger factors of up to 10^3. For a most conservative estimate, a superinsulation with

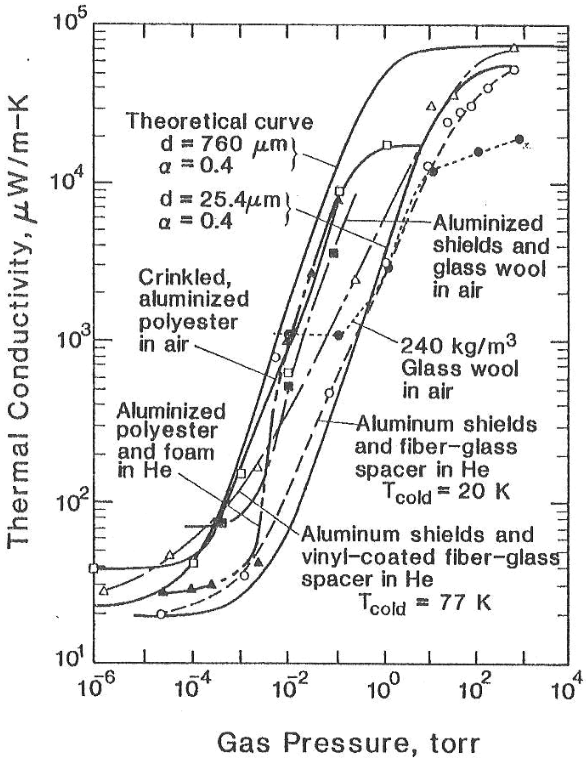

Figure 20: Thermal conductivity of superinsulation in dependence of gas pressure [Tim 89].

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 63 m^2 and 37 tons of LN (evaporation enthalpy: 199.3 kJ/kg) it will take about 32.5 hours until all LN has been evaporated. The resulting gas flow of 985 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. For LAr the corresponding gas flow is slightly lower (see Appendix A).

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 LN; a drop of less than 4°C in the temperature of the 660 m^3 stored water is enough to supply all the heat needed to evaporate the 46 m^3 of LN 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 putting a 1.5 in diameter copper cylinder at 70°C into a bath of LN and measuring its change of temperature with time. As long as a bubble layer (boiling) was present, the heat transfer coefficient was found to be (170 ± 10) W/(m^2K) (values between 600 to 900 W/(m^2K) were found for the case that a copper cylinder of 80 K was immersed into water of 70°C) [Bro 01]. While all these values are known to vary with radius ($\propto$1/r) and length of the rod, a complete understanding is still pending and agreement with theoretical predictions is poor. In another approach, studies at the MPI Heidelberg considered a metal can filled with LN (15 cm diameter, 15 cm height) which was suddenly immersed into a water bath. Very strong convection in the water and very strong boiling were observed as well as the formation of an about 1 cm thick ice layer after about 3'. It took 3'20" until about half of the LN amount was evaporated, and 6'40" for the second half. From these measurements preliminary values for the heat transfer coefficients of about 55[47] W/(m^2K) before[after] ice formation have been deduced. Adopting for the moment a value of 100 W/(m^2K), the initial gas flow will be 22,000 m^3 per hour which might be tolerable after the upgrade of the ventilation system. In this scenario all LN would be evaporated after less than 3 hours. However, the presence of the many foils of the superinsulation will definitely diminish the heat transfer.

Leakage of inner vessel: A leak in the inner vessel will destroy the insulation vacuum and enable LN to enter the space between inner and outer container. The LN 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, somewhat smaller than in above scenario due to the isolating effect of the huge number of gas bubbles which will be generated in the space between inner and outer vessel. 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 draine 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: Leaks in both the inner and outer vessel can lead to a mixture of LN and water which in certain cases [Arc 04] may lead to explosion-like evaporation of nitrogen. Thus the water vessel needs to be equipped with a adequate overpressure safety device.

If leaks develop simultaneously in both shells of the cryostat it is highly desirable to empty the water vessel such that the cryostat is no longer in contact with water. Estimates show that this could be done in less than 10 minutes using pipes of still acceptable diameter.

6.1.3 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 5 shows the required size

Table 5: 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.

6.1.4 Corrosion

The operation of a copper cryostat in de-ionized water contained in a steel or stainless steel vessel has the potential hazard of serious corrosion effects. A study of this topic is im progress at the University of Milano.

7 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,
2. super-structure,
3. laboratory building,
4. penthouse.

A detailed plan for the complete assembly procedure is still missing, and present efforts focus at which step the cryostat can be installed.

The various 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 two rings 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,
- weld the first sheet-metal plate of shell to the roof,
- lift up the roof,
- weld the second sheet-metal plate of the shell at the first one,
- insert the inner cryostat through the 4.5 m hole in the roof into the water tank,
- 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.

While this procedure is viable, it contradicts the schedule outlined in the Proposal. There, it had been assumed that the water tank will be finished before the estimated delivery of the cryostat in January 2005 - the laboratory building was not yet explicitly mentioned.

In an alternative scenario, the cryostat would be placed into the water tank after step 3, i.e. after the completion of water tank, super-structure, laboratory building, and parts of the penthouse. This would help to avoid potentially large delays - the delivery date of the highly non-standard cryostat is not yet ensured - and to minimize hardware modifications if the cryostat, after its installation, would have to be removed from the water tank for repair. This scenario would require an adequate flange in the water tank through which the cryostat could be inserted in either vertical, horizontal or inclined position as well as adequate lifting tools to move the cryostat within the water tank into its final position.

8 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.

8.1 LArGe infrastructures

Figure 8.1 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 8.1) 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

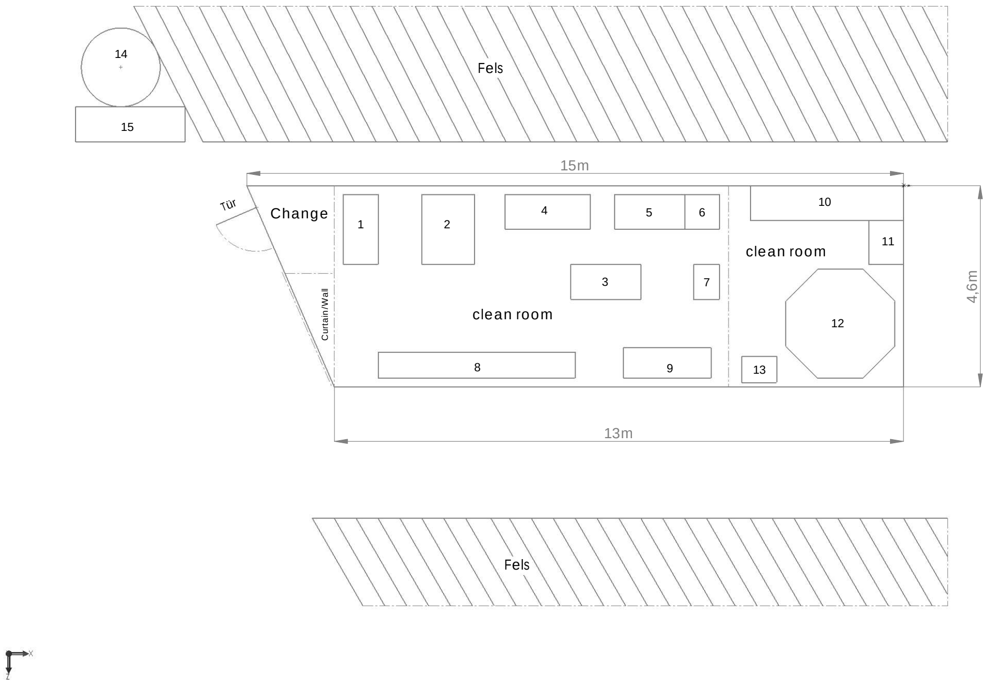

Figure 21: Floor plan of the LArGe barrack. Explanations cf. text.

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.

8.2 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.

8.3 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 – started in February 2005 and will be completed early April. Installation of the graded shielding and the laboratory infrastructures is scheduled for April and early May. Work with detectors in a clean environment will commence in May. Completion of the installation of the full LArGe system is targeted for summer 2005.

Appendix A

Table 6: 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	

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