Gerda

Progress Report to the LNGS Scientific Committee

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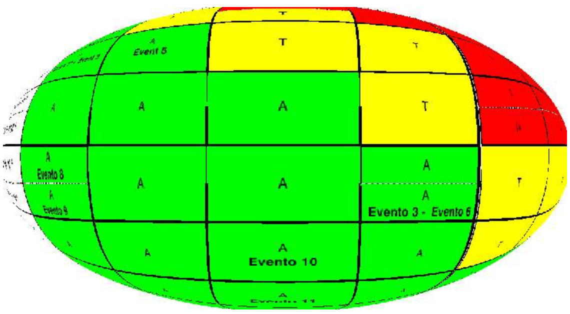

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1 Executive Summary

This report summarizes the accomplished progress of the GERDA collaboration since the last meeting of the LNGS Scientific Committee in October 2006. Relevant issues and recent achievements are highlighted below:

- **Safety review:** On January 15, representatives of the GERDA collaboration, NIER, LNGS and safety consultants participated in a concluding session at CERN. The outcome of the discussion was that the LNGS and the consultants are fully satisfied with the achieved results. The 'Executive Summary' of the risk analysis document concludes 'that the GERDA experiment ... is acceptably safe for assembly and operations'. In addition a detailed seismic analysis of the experimental setup had been charged to Ing. Pace. The outcome confirmed that the relative motion of water tank, cryostat and building are within the design specifications of the installation. All safety documentation has been submitted to the LNGS requesting the final approval of the experimental setup and its safety concept by the director of LNGS.

- **Cryostat:** The cryostat contract has been awarded to SIMIC S.p.A., Camerana, Italy and signed on November 11, 2007. In view of the shortage of stainless steel, all steel for construction had been ordered already by July 2006. Austenitic steel was identified with very low specific activities corresponding to 1 resp. 5 mBq(^{228}Th)/kg for walls and vessel heads. A delay in the delivery of the vessel heads together with weld joint imperfections in one of the heads, have created an overall shift of the cryostat construction by approximately four months with respect to the original production schedule provided by SIMIC.

- **Hall A infrastructure:** The experimental area in hall A has been overhauled by the commissioner and is now being prepared for the water tank construction. Locations for the cryogenic storage tanks have been identified and requests placed to the LNGS. The tender for the GERDA building has been published on March 12, 2007. Installations inside of the building like electricity, ventilation etc. will be part of a separate tender.

- **Clean room and lock:** The tendering process for the clean-room has been started. Parts of the lock have been built to simulate the movement of detector strings with mock up assemblies. Main hardware parts of the lock will be delivered in April.

- **Germanium detectors:** All enriched detectors which will be used in phase I have been dismounted from their cryostat and are currently processed at the manufacturer. Underground storage in between the processing steps assure that cosmogenic activation will be negligible. Contracts have been signed with PPM Pure Metals and the Institut für Kristallzüchtung in Berlin to investigate the purification of the enriched germanium material and crystal growing for phase II detectors.

- **Monte Carlo:** The GEANT4-framework MAGE, commonly developed and maintained together with the MAJORANA Monte Carlo group, has been used to further optimize the muon veto design including full Cherenkov photon tracking in the water tank. Validation of the MAGE code by comparison with experimental data has been further pursued. Energy spectra in response to radiation from a AmBe neutron source have been compared with MAGE simulations. Missing physics processes could be identified and included in the simulation code.

- **Material Screening:** Highlights are the HP-Ge measurements of stainless steel batches foreseen for the GERDA cryostat. The radium and thorium contamination of most batches turned out to be about one order of magnitude lower than those measured in previous years on many other steel samples. Samples with higher concentrations could be identified and replaced by material with higher purity. Based on this results, the mass of the internal copper liner could be reduced from the envisaged 40 tons to less than 16 tons. Measurements of the Kalrez gaskets, which will be used for the shutters, show a size dependent ^{222}Rn emanation between 10 and 150 μBq and thus qualify their use in the lock system.

- **Schedule:** The overall project schedule is driven by the delivery time of the cryostat to Hall A of LNGS. The schedule presented initially by SIMIC S.p.A. could not be maintained by the company, mainly because of the late arrival of the vessel heads. An updated production schedule has been provided by the company on April 2, 2007. The delivery time to LNGS is now scheduled for end of October 2007, corresponding to a delay of four months with respect the original production schedule. Subsequently, the water tank will be completed, the building and platform installed and the clean room and lock mounted. As the installation work proceeds sequentially, the completion of the experimental infrastructure is projected for the end of 2008.

- **Personnel:** The GERDA collaboration is organized in eleven task groups with distinct responsibilities. The available scientific and technical personnel is adequate to complete the tasks within the planned time. In total, 39 full time equivalent persons are working currently on the experiment.

2 Phase I detectors

Approximately 18 kg of enriched detectors, previously used in the Heidelberg-Moscow and IGEX experiments, are prepared for phase I of GERDA. The work proceeds in distinct work packages (WP), as described in the previous progress reports. WP1 concerns the installation and equipment of the underground detector laboratory for handling and testing of phase I detectors, now named GERDA DETECTOR LABORATORY (GDL). WP2 deals with the testing and characterizing HDM and IGEX prior to dismounting from their cryostats. WP3 includes the testing of bare prototype detector assembly in cryogenic liquid and WP4 the dismounting and processing of the enriched crystals. With the availability of 15 kg of non-enriched detectors, previously used in the Genius Test Facility, the scope of WP4 has been enlarged. The construction, operation and testing of the non-enriched, as well as the enriched crystals in the low-background test stand LARGE in the GDL is now coordinated within a newly defined work package WP5. R&D on liquid argon scintillation light detection and pulse shape studies are as well part of this work package.

2.1 Characterization of enriched diodes

The measurements with enriched detectors prior to their dismounting from their cryostats has been completed beginning last year. Recent analysis work related to WP2 concerned the determination of the lithium dead-layer of the enriched detectors RG-1 and RG-2 (IGEX). The IGEX detectors have been stored without cooling at the Canfranc laboratory for several years prior to their transportation to LNGS. An increase of the dead-layer due to lithium diffusion was expected. The analysis of the ^{133}Ba and ^{152}Eu source measurements showed a moderate increase of the dead layer by 150-200 μm for RG-1 and 450-500 μm for RG-2. Further WP2 related analysis concerned the determination of the active masses of the enriched crystals and comparison with earlier measurements in the Homestake mine.

2.2 Prototype tests

The 'Rn-free' detector test stand in the GDL has been further improved. This includes a new liquid argon level sensor system, an improved liquid argon re-rilling system, and an additional infrared shield mounted inside the cryostat. Procedures of detector mounting, handling and operations with a hermetically closed clean bench under nitrogen atmosphere were carried out successfully in order to simulate the handling of enriched diodes.

Operations and tests with the prototype detector assembly continued during the last six months. Though these tests were focused on technical aspects like the detector performance, electronic tests and crystal handling procedures, we could derive first physics results on the neutrinoless double electron capture (0νECEC) of ^{36}Ar. The limit for the radiative decay with the emission of a single photon is $T_{1/2}(0^+ \rightarrow g.s.) \geq 1.9 \cdot 10^{18}$ years (68% C.L.). It is the first limit for ^{36}Ar and comparable to recent results obtained in dedicated experiments investigating different isotopes. The experimental details and analysis are documented in an internal report [1] and a paper is under preparation for publication.

All detector parameter as energy resolution and leakage current were stable during standard operations since the beginning of September. In December 2006 integration tests with the IPA4 cold preamplifier were resumed and the results are reported in Sec. 4. After mounting of the preamplifier and cooling of the diode, an elevated leakage current was observed which further increased with time under continuous irradiation with a ^{60}Co gamma source. The source strength was 44 kBq and the counting rate in the detector 1.5 kHz. The origin of this effect is not yet understood. It should be noted that this observation is different to the high leakage current measured during August 2006. There, the current increased as a step-function as a consequence of improper detector handling. Similar step-like increases of the leakage current were reported from the Genius TF experiment.

The passivation layer of the diode was reprocessed at the manufacturer in Janurary and returned to LNGS within one week. Dedicated measurements are currently carried out to investigate the leakage current increase in response to strong gamma irradiation.

In total, 44 warming and cooling cycles have been carried out with the prototype detector assembly. The passivation layer of the crystal has been reprocessed twice, once in August 2006 and once in January 2007.

2.3 Detector processing

Following the successful processing of two enriched detectors in August and September 2006, the remaining enriched crystals (ANG2, ANG3, ANG4, ANG5, RG1, RG2) have been dismounted from their cryostats in November and moved to the HADES underground facility. In addition, six non-enriched crystals, previously used in the Genius Test Facility, have become available and have been transported to HADES for processing at the manufacturer. All enriched crystals, as well as four out of six non-enriched crystals have been machined and lithium drifted in the period of December '06 until February '07. Machining of the remaining two non-enriched crystals, boron implantation and passivation is scheduled to for next couple of months. All crystals will be tested at the manufacturer for leakage current and depletion voltage and subsequently transported back to LNGS. Cosmogenic activation is kept at a negligible level by storing the crystals underground. The crystals are moved above ground to the manufacturer for machining and processing in the morning and returned for underground storage at HADES in the evening.

2.4 Low-background test stand

Construction of the low-background detector test stand (LARGE) in the GDL is proceeding. As described in earlier reports, it consists of a cryostat of 1000 liter volume enclosed by a passive graded shield and instrumented for liquid scintillation light read out. All sheets for the cryostat construction have been produced during last autumn at CSN from high purity electrolytic copper. Stainless steel plates with < 1 mBq (^{228}Th)/kg specific activity for construction of the cryostat neck has been procured. The cryostat is currently under construction at Pützschler & Weiler and delivery is expected in May. Fig. 1 shows parts of the tanks, shield as well as the drawing of the full setup. The vacuum insulated cryogenic lines connecting the cryostat have been designed and ordered. The passive shield is in place at the Gdl and the lock design and construction is completed. Mounting and integration of the system is planned to start in summer.

Figure 1: From left to right: Inner and outer copper tanks of the cryostat, the partially mounted graded shielding and the overview drawing of the LArGe detector test stand in the Gerda Detector Laboratory (Gdl) at Lngs.

Laboratory work continued to study the achievable photo-electron yield from liquid argon scintillation. A stable wavelength shifting and specular reflecting system has been developed yielding 1240 ± 20 photo electrons per MeV. A new voltage divider has been designed which led to an improved energy resolution for the 20 kg liquid argon detector of 7.5% at 1 MeV, similar to a 3" NaI(Tl) detector. Further studies concerned the characteristic pulse shapes of the scintillation light in response to α, β, γ and neutron radiation and measurements of the visible alpha energies (i.e. alpha quenching). Papers summarizing the results of the background suppression by the simultaneous detection of the liquid argon scintillation light, the photo electron yield optimization and the pulse shape studies are in preparation.

3 Phase II detectors

3.1 Prototype tests

The successful test of the first 18–fold segmented n–type prototype produced by Canberra-France was described in the last progress report. Several papers describing the performance of this detector are in the publishing process. A second prototype 18–fold segmented detector is on order from Canberra, and we expect to operate the two detectors in a final phase II string setup by the end of this summer. A special test cryostat to facilitate this is under construction at the Max Planck Institute in Munich. This cryostat is a prototype of the test cryostat to be installed in the Gerda clean-room at the Lngs .

Other activities include the operation of detectors in various test facilities. As reported earlier, the n-type detector has been cooled down and warmed up 20 (3) times in liquid nitrogen (argon). The facilities to study the long term stability of segmented n-type detectors operated in liquid argon, to test the grounding schemes and to study the response of detectors to UV and IR light are under preparation.

3.2 Production of Phase II detectors

As reported at the last Scientific Committee meeting, the enriched Ge for the Phase II detectors has been procured and is in underground storage while we investigate purification and crystal growing options. Contracts have now been signed with PPM Pure Metals for tests of the purification procedures, and with the Institut für Kristallzüchtung (IKZ) in Berlin for crystal production.

Depleted Ge (<1 % ^{76}Ge) in the form of GeO_2 has been acquired from the Electrochemical Plant in Siberia (from the 'waste' of the enrichment procedure) for the purification tests. This material is expected to have the same purity as the enriched Ge acquired for phase II. Purification yields from this material should therefore be a good measure of what will be achieved with the enriched Ge. The use of isotopically shifted material will allow us to test for possible isotopic dilution during the purification procedure. The reduction of the depleted GeO_2 to Ge metal and the subsequent purification will be performed at the PPM plant starting at the end of April. The purification will proceed without any $GeCl_4$ chemistry, and will rely solely on polyzone refinement. The resistivity will be monitored along the resultant Ge ingot, and a large number of samples of the resulting material will be taken and analyzed via mass spectroscopy to ascertain the purity and the isotopic content. Results are expected by the end of June.

In parallel, a dedicated Czochralski crystal puller is being set up at the IKZ in Berlin for crystal pulling tests. Initially, 6N material will be used and a reliable and reproducible method for pulling single crystals of the desired dimensions (approximately 80 mm diameter and 70 mm length) will be established. Once a reliable procedure has been set up, higher purity material (8-9N) will be used as input and it will be determined if the crystal growing conditions at the IKZ are suitable for the production of the very high purity crystals needed for Ge detectors. The parameters of the crystal (dislocation density, impurity density, etc.) required for the production of a Ge detector have been defined in conjunction with Canberra. Once these conditions on the crystal properties are met, we will attempt to produce functioning detectors. These tests will all be performed with natural or depleted Ge, and first crystals should be produced within one year. If the IKZ is successful, then we plan to proceed and grow crystals with the enriched Ge. The funding for the development of the purification and crystal pulling procedures is in place. The funding for the crystal and detector production for the enriched material will need to be acquired once the procedures and costs are determined.

4 Front-end electronics

Since previous report the main activities of TG3 focused on

- testing of the IPA4 preamplifier connected to the prototype detector assembly;
- bench test of ASIC CMOS PZ mounted in a package suitable to be submerged in LAr and test of the support PCB;
- test of HV cables and connectors in the argon gas phase.

4.1 Test of IPA4 preamplifier connected to crystal

In December 2006 the IPA4 preamplifier mounted on its PCB, as shown in Fig. 2, has been tested for the second time connected at the prototype detector assembly in the GDL.

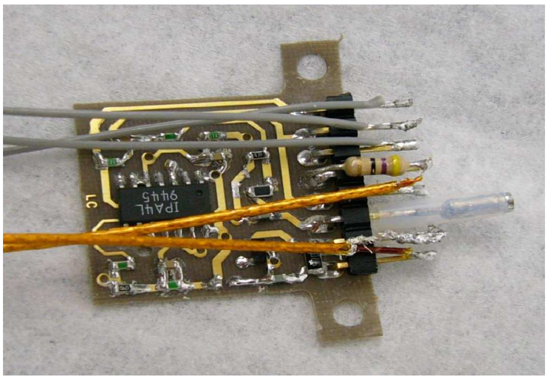

Figure 2: The IPA4 CSA mounted with cables to be connected to the prototype detector assembly.

Its performances, as previously measured and reported in [2], can be characterized by a 40 ns rise time and an equivalent noise charge of 110 electrons r.m.s. for $C_{Detector} = 27$ pF at $3-6\,\mu$s shaping time. The total mass of the device is 1.7 g including pins, of which the chip in its SOIC plastic case contribute only 0.13 g, the PCB plus components 0.57 g, the pins 0.45 g.

The integration tests were carried out in December 2006. The best resolution obtained was 4.1 keV (FWHM) at 1.332 MeV and 3.5 keV (FWHM) with a pulser for $3\,\mu$s shaping time. The intrinsic resolution of the charge sensitive preamplifier has been measured by replacing the crystal with capacitors, while keeping the mounting and cabling similar. The obtained resolution with $3\,\mu$s shaping time was ≤ 1 keV for 27 pF capacitor at the input, and 1.5 keV for a 100 pF capacitor. The extra line width measured can be attributed partially to the remaining environmental noise and to the enhanced crystal leakage current. The leakage current increased during the tests after the IPA4 mounting, most likely because of the continous irradiation with the 44 kBq ^{60}Co source (c.f. discussion in Sec. 2) and as a consequence, the energy resolution worsened and the peak positions shifted with time. Despite these problems, the IPA4 circuit and components showed a reliable performance during the integration tests. In total, the circuit was cooled down and warmed up about 20 times without problems.

4.2 ASIC CMOS

The integrated circuit named PZ-0 [2, 3] is extremely light and compact; it has a surface occupancy on silicon of only $366 \times 275\ \mu m^2$ and it takes advantages of a newly designed single-ended line-driver to drive a cable loaded on $50\,\Omega$. In this version, the front-end FET as well as the feed-back components are discrete SMD components, while the first stage and line driver are fully integrated. Since the previous report, the task group has worked on a technology to mount the chip under vacuum in a proper ceramic carrier to prevent ice or water vapor condensation formation when the device is cooled down. Moreover, a dedicated printed circuit board (PCB) has been developed to install and contact the charge sensitive device mounted in its package (Fig. 3) at the junction box level. The mass of the ceramic carrier (type LCC20) is 0.35 g, while the mass of the PCB is 2.55 g; the mass of the silicon chip is totally negligible compared to the mass of the carrier and the PCB. Therefore the total mass of the working device for the full string is 2.9 g (cables excluded). The chip performances obtained at cryogenic temperatures at the test bench with capacitors at the input to simulate the detector are satisfying and can be summarized as follows: 15 ns rise time, equivalent noise charge of 110 electrons r.m.s. for $C_{Det} = 15$ pF at $10\,\mu$s shaping time. The second version of the chip, named PZ-1 (v1), uses a MOSFET integrated on the chip as input FET, while keeping the feedback components non-integrated. The chip contains a fully differential line driver to drive both coaxial cables and twisted pairs loaded on $50\,\Omega$, and a digital circuit externally driven for stability and rise time control. The surface occupancy on silicon is $\approx\ 2000 \times 2000\ \mu m^2$ including pads for wire bonding. The chip performances at cryogenic temperatures are: rise time 22 ns, equivalent noise charge of 190 electrons r.m.s. for $C_{Det} = 33$ pF at 12μs shaping time. The intrinsic noise of the device decreases to 150 electrons r.m.s. applying optimum digital filter and longer shaping time.

Test with the ASIC developed in Heidelberg have continued during the last months. The noise measured is typically a factor of 2 larger than anticipated and hence larger than what is acceptable for GERDA. By comparing the noise of two channels we conclude that the increase is due to common mode noise whose source has not been identified yet despite intensive investigations. Recently it was observed that modifications of the bias current settings can reduce the noise level. This might give us new insight into the source of the problem.

4.3 Cables and HV connectors

In the last semester several candidates for signal and HV cables have been tested. A solution has been found and tested also for the HV connectors that caused discharge problems in

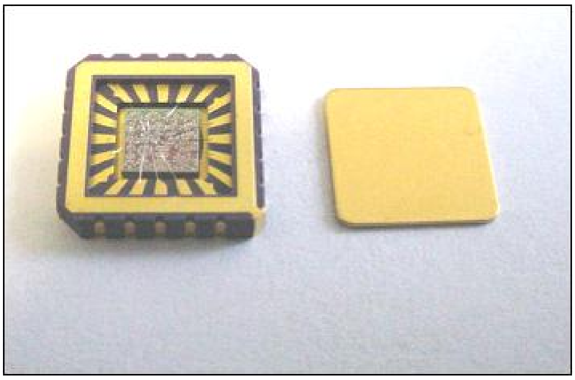

Figure 3: The PZ0 silicon chip CSA mounted in a LCC20 ceramic package.

the past. We were able to solve the problem by encapsulating the inner side of the HV contact exposed to gas Ar atmosphere with Stycast. For the final setup it is foreseen to adopt HV connectors mounted on CF flanges sealed with Stycast or epoxy on the inner side. These flanges exists, have been developed and patented by the INFN–PD electronics group in the framework of ICARUS project. The final choice of the signal cables strictly depends on the adopted circuit. The work to choose the HV cables is ongoing and at least two candidates have been identified. The low voltage cables needed to power the preamplifier have to be selected. In summary, the selection and qualification of the cables, in particular with respect to their radiopurity (c.f. discussion of PEN samples in Sec. 12) is an important aspect that needs further experimental work.

5 Cryogenic Vessel and Infrastructure

In response to the tender for the cryostat [4] quotes from six companies were received by the deadline of September 29. A small committee including two external experts evaluated the quotes, and the contract was awarded unanimously to SIMIC S.p.A., Camerana, Italy. By November 11, 2006, the contract for the fabrication of the cryostat was signed.

In view of the shortage of stainless steel on the world market, a major part, 27 tons, of the 1.4571 stainless steel for the cryostat had been ordered already in July by the MPI. The contract allowed to return material of too high radioactivity. All the stainless steel screening was performed with the gamma spectrometers of the LNGS or the MPI Heidelberg. While our envisaged limits were 5 resp. 10 mBq(^{232}Th)/kg for the cylindrical walls resp. the vessel heads, we were able to identify steel of significantly lower radioactivity so that our limits could be lowered to 1 resp. 5 mBq(^{232}Th)/kg. More than 15 steel batches have been screened, and a compilation of the results is given in Tab. 1 of Sec. 12.

The screened 1.4571 steel material for the cylindrical shells of the cryostat and some other parts has been delivered to SIMIC by January 2007. However, the delivery of the vesselheads is strongly delayed, and only three out of the four vesselheads are available by now (Fig. 4).

Figure 4: Three vesselheads for the GERDA cryostat at SIMIC (2007/03/19).

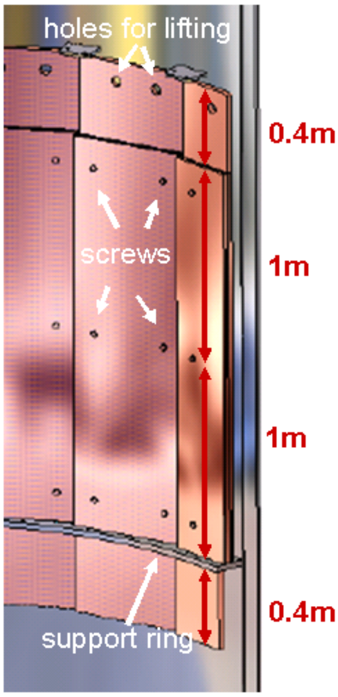

Figure 5: Layout of the Cu-shield

Four pairs of 5 x 2.5 m^2 stainless steel sheets for the fabrication of the vesselheads were delivered by November 8 to the manufacturer, ANTONIUS Vesselheads BV, Netherlands. The respective sheets of a pair were welded together in order to yield the sheet from which the 5 m diameter circular blank for a vesselhead could be cut. A total production time of seven weeks after material delivery was quoted. An explanation why the delivery was delayed until March 9 is difficult even considering the Christmas break and the fact that we delivered the material at November 9, i.e. 7 weeks later than planned. Unfortunately, the fourth vesselhead is still not available since the X-ray of the weld shows a number of weld joint imperfections, 'Bindefehler'. The repair and welding certification for -196 °C is still in progress. Thus, the fabrication of the cryostat is delayed by about four months.

Pads made from TORLON of low thermal conductivity will be used to support the inner vessel of the cryostat as well as to center it within the outer container. A sample of TORLON 4203 material has been now successfully tested at -196 °C for a load that is ten times larger than foreseen.

The unexpectedly low radioactivity of the 1.4571 stainless steel material for the cryostat allowed to reduce the amount of the internal copper shield from the envisaged 40 tons to less than 16 tons. Its thickness and profile have been determined by Monte Carlo calculations. The profile is symmetric w.r.t. the midplane, the thickness is 6 cm up to the height of 1 m, and continues from there with 3 cm thickness up to 1.4 m . The shield will be assembled from 20 overlapping segments (see Fig. 5) which will fit through the cryostat's neck. Each segment consists of three 3 cm thick and 61.5 cm wide copper plates of 0.4, 2.0 and 2.4 m length, respectively. The two longer plates are screwed together and will rest on a support ring within the cryostat; the short plate will be attached below. The orders for the the ultra-pure NOSV copper material as well as for its rolling have been placed in February, and the production is scheduled for week 15.

The cryogenic infrastructure has not yet been tendered. However, major progress has been achieved with respect to crucial issues: (i) a design of the active cooling system is now available, (ii) suppliers for cryogenic valves have been identified which can deliver radon tight devices, and (iii) specifications and dimensions for the exhaust gas heater have been determined. The preferred option for the exhaust gas heater is a tubing system of rectangular cross section which covers 100 m^2 of the external surface of the water tank. Studies are in progress in order to find out if such an implementation would imply an increase of the wall thickness of the water tank.

The plan to use chevrons as a thermal shield in the neck has been abandonned in order to avoid potential mechanical problems in an area of most difficult access; instead the aperture of the neck will be reduced by thermal shields which at the same time will provide a cold surface for catching intruding radon. The cooling of the surface will be for free by using the exhaust gas of the active cooling system. Three independent methods for sensing the fill level in the cryostat's neck have been identified and are under test: a chain of Pt100 sensors, a magnetic swimmer moving along a network of magnetic Reed contacts, and a radar device. It is planned to implement two independent systems, at least. - The specifications for the cryogenic valves and the dimensions of the cryogenic tubing have been determined, and a general layout of the rather bulky cryogenic and exhaust gas system including the position of the large safety valves has been worked out in a joint effort with the task groups of water tank and superstructure.

The 'Preliminary Risc Analysis for Cryogenic and Water Tank System' performed by NIER Ingegneria, Bologna, has been concluded in February 2007 by updating the phase 1, 2 and 3 documents and by supplying an 'Excecutive Summary'. A meeting in Bologna on November 16 served to clarify a few open points. On January 15, representatives of the Gerda collaboration, NIER, Lngs and safety consultants participated in a concluding session at CERN declaring there to be fully satisfied with the achieved results. The 'Excecutive Summary' concludes that - taking into account all the considerations discussed and the recommendations provided - 'that the Gerda experiment, as for Water Tank and Cryostat System..., is acceptably safe for assembly and operations'. All documents prepared by NIER [5] can be accessed via the newly established 'Safety Documentation' webpage of Gerda. Here also all other safety relevant information for the Gerda experiment will be collected and archived as soon as it becomes available. A new 'Second Opinion' as well as a final statement on safety by the Lngs safety department is expected to be available for this session of the Scientific Committee.

6 Infrastructure on Top of the Tank

The upper infrastructural complex is sitting on the superstructure. Its main constituent is the clean-room which houses the lock-system for insertion of the detectors to the cryogenic volume. Fig. 6 shows a sketch of the lock system as it will be installed. Its main parts are the inner and the outer lock (the latter is not visible on the figure) as well as two cable tubes. The inner lock houses the rail system to position the detector strings in the array. The cable tubes contain the linear pulleys to lower individual detector strings to the cryogenic volume. The inner lock system can be decoupled from the cryogenic tank with a circular shutter. Rectangular shutters separate the inner from the outer lock and the outer lock from the clean-room. The lock system is supported by steel bars that rest on the superstructure.

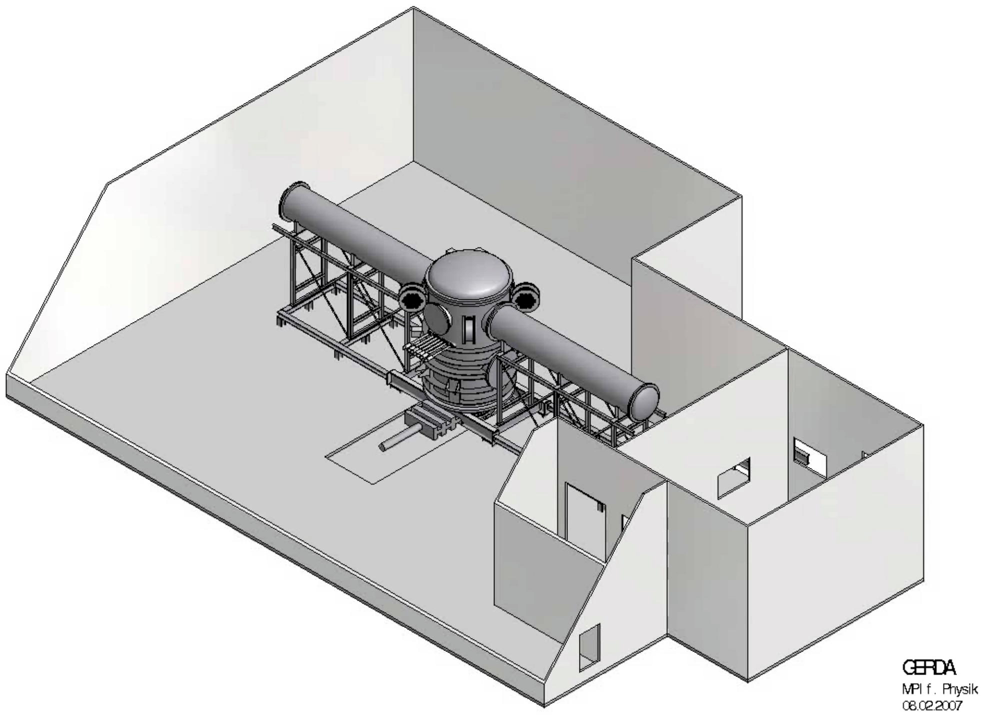

Figure 6: The lock system inside the clean-room.

6.1 Status of clean-room and lock

The tendering process for the clean-room has been started. Budget and time schedule permitting, the clean-room will be suitable for radon-reduced air (welded metal walls).

The operational parameters are defined and infrastructural requests to LNGS are stable, waiting for the confirmation of the clean room requirements from the bid-winning company.

Solutions for all technical issues regarding the lock and the internal loading system are available.

Parts of the lock infrastructure have been built and are currently being tested at the MPI für Physik in Munich. The first mock up of the linear pulley is shown in Fig. 7. It proves that the design is feasible. A complete mock up of the phase I string (Heidelberg Moscow and IGEX detectors) is currently being tested with the linear pulley system.

The internal transfer system to position the strings in the matrix is currently being assembled.

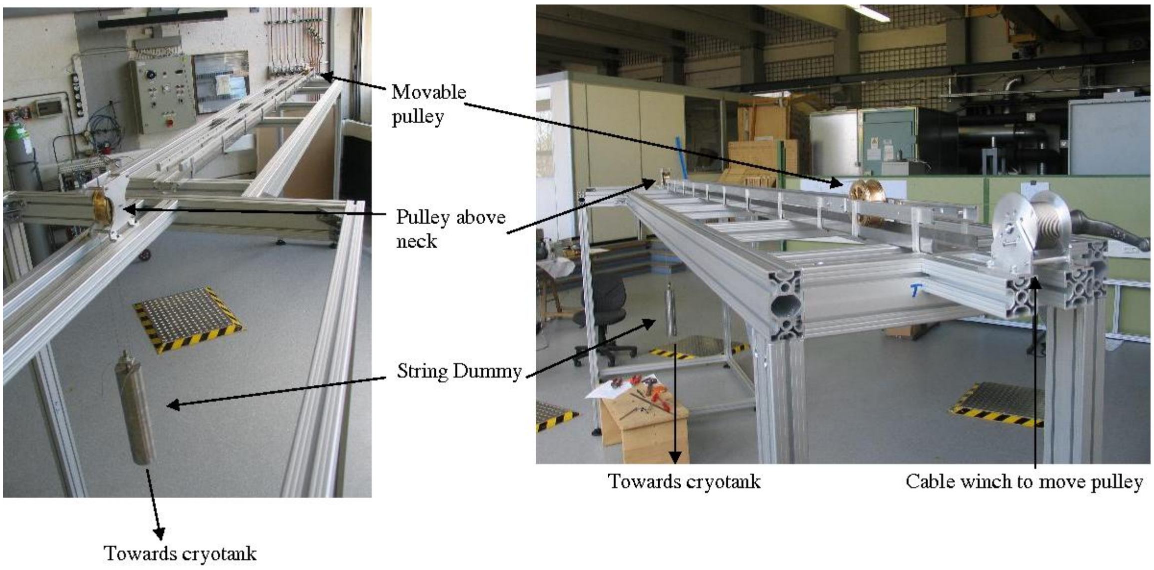

Figure 7: Mock up of one linear pulley segment. A movable pulley can be moved along the arm by a cable winch at the end of the arm. The steel cables holding the detector string are fed around the movable pulley. Thus the string is lowered or lifted if the movable pulley is moved along the arm.

The vacuum shutters of the lock system are ready for delivery in April 2007 after the screening of the KALREZ (R) o-ring seals at the MPI-Kernphysik in Heidelberg is completed.

The complete lock system will be built up and extensively tested in Munich in 2007. The lock will be ready for delivery to LNGS in April 2008. As soon as the superstructure is finished, construction of the clean-room can start. A detailed time schedule for the clean room construction is not yet available. The lock can be only installed after the clean-room is finished. The installation, cleaning and testing of the lock including installation of the safety and PLC systems and including the establishing of clean room conditions will take approximately 160 working days.

7 Water tank

In the last semester the executive project of the water tank (WT) has been worked out. All the mechanical details for photomultiplier (PMT) connections, cabling, water loop piping, flanges etc have been defined. The steel has been optioned and the company is ready to start the installation. The mounting procedure has been defined too; the tank bottom plate will be installed first, then the cryostat will come, it will be erected and tested on-site. After mounting of the internal copper shield and final tests on the cryostat, the shell and the roof of the water tank will be constructed. Therefore the WT mounting schedule is strictly interconnected with the cryostat delivery and test program schedule. Currently, it is planned to build the tank bottom plate in July 2007 and then resume the work to complete the tank installation in January 2008. The delay in delivery of the cryostat, the variation of the mounting procedure compared to what has been tendered, the anticipated long stop of the construction work on site and the increase of price of the stainless steel (a factor 2-3 from the moment the offer was formulated) has caused an increase of the total cost of the water tank, that will be shared among the collaboration, with a major contribution from the INFN groups responsible for this part of the experimental setup.

8 Muon veto

The GERDA muon veto consists of two parts: Plastic scintillator panels on top of the clean room, and a water Cerenkov detector inside the water tank. The muon veto system is designed to reduce muon induced backgrounds to values below 10^{-4} cts/(keV·kg·y).

8.1 The plastic veto

The plastic scintillator sheets of dimension $200\times50\times3$ cm^3 have been delivered. At present the first panels are being assembled by attaching the wave-length shifters and the photo-multipliers.

For wrapping new materials are investigated, in particular the cover should be able to absorb impact of hard materials as the panels will be mounted on the roof of the clean room.

The first 10 panels are expected at LNGS by late summer and will be used for tests at the GDL.

8.2 The Cerenkov veto

From the Monte Carlo simulations the number of photomultiplier (PMT) was fixed to 66 as well as their distribution: the ‘pillbox‘, the volume below the cryostat will house 6 PMTs, while 4 rings of 10 PMTs will be mounted on the wall of the water tank and the remaining 20 PMTs are located on the floor of the water tank (see Fig. 10 in Sec. 11). All the material for encapsulating the PMTs into stainless steel containers has been procured.

A major change with respect to the Borexino design is the omission of the very expensive watertight cable connector (Jupiter). At this moment long term tests of shrinking-hose seals are performed as they are considered as replacement. The voltage divider has been modified for a better linearity of the ET9350KB up to about 60 photoelectrons. First prototypes have been produced and tested successfully.

The number of chimneys has been reduced to one for cost reasons and space. Mounting procedures for the PMT installation at the LNGS site are being developed. So far measures and positions seem to be consistent without needs. VM2000 reflector foils are foreseen to cover most of the surfaces inside the water tank for improved light collection and wavelength shifting. This foil can only be obtained with glue on one side from the company 3M. Tests are being performed to understand if this glue is water-resistant and can stay on the foils.

The procedure of assembling is being tested to gain experience for mass production planned at the end of this year. These capsules undergo also longterm tests for water-tightness and pressure tests. Furthermore, the signals from the PMTs are investigated for noise, late- and after-pulses, and the sensitivity to magnetic fields. A small reflection has been found which we try to eradicate.

At the same time the flash ADC modules for data acquisition are being tested. They are the same type as the ones used for the germanium diodes. This choice will simplify the use and exchange of modules and alleviate the programming.

9 Gerda infrastructure at LNGS

The executive project for the Gerda Building at the GERDA main site in hall A has been completed in 2006. In summary, the structure consists of a three story building erected between the water tank and the LVD experiment. The top level of the building, located 9.70 m above ground level, extents over the water tank and is designed to host the clean room and the lock system for the insertion of the germanium crystals in the liquid argon. The project does not contain any plants (electricity, ventilation, etc.), which will be placed in the context of a different contract to be defined in 2007. The tender for the building has been published on March 12, 2007.

In addition to the risk analysis required by the Lngs, the Gerda collaboration charged Ing. Pace, LAquila, to perform a detailed seismic analysis of the GERDA experimental setup. In particular, the relative motions of cryogenic tank, water tank, building and lock were investigated in case of a seismic event, with an excitation frequency spectrum specified by the Lngs. The outcome of this study confirmed the correctness of the structural design of the various building blocks, and that the relative motions are within the design specifications of the setup. The final version of this report is now available and a copy has been handed to the LNGS SPP on February 27, 2007.

The overhauling of the experimental area in hall A by the commissioner has been completed and the place is now being prepared for the installation of the cryostat and the water tank. In particular, the anchorage points required for the fixation of the cryostat could not be placed in the context of the commissioner's work as their postions could not be finalized. A template has been produced which serves to match the anchorage points in the concrete floor with the cryostat.

Prepartion work of the floor will be done prior to the construction of the base plate of the water tank. These activities depend on constructional details of the water tank and will be worked out by the company in charge of the water tank.

The location for the cryogenic storage tanks which are required for the GERDA Detector Laboratory (GDL) has been assigned in November 21, 2006. Requests for placement of cryogenic storage tanks for the GERDA main site including tubing inter-connections have been placed on March 9, 2007. The GERDA collaboration is expecting feedback from LNGS in due time.

The detailed running of cryogenic tubing, cables, etc. is under design. In particular, the area below the clean room, platform and the 2nd floor laboratory which will house part of the cryogenic infrastructures and muon electronics (CryMu Lab) is being worked out.

10 Data acquisition

The DAQ system envisioned for Phase I consists of NIM modules which house 14-bit Flash ADCs running at 100 MHz and PCI cards in a PC which store the digitized data. This system was described in detail in the previous progress report.

During the last months the firmware for the PCI card was updated to increase the effective time duration of the recorded signals. Formerly, 2048 samples corresponding to a trace length of 20 μs could be stored in memory. This limits the shaping time of the moving window deconvolution (MWD) algorithm to 9 μs. In the modified firmware 4 consecutive 14-bit FADC values are summed and stored in 16-bit memory. Now 1024 sums (40 ns timing, total length 40 μs) and 512 original values (10 ns timing, total length 5 μs) containing the rising edge of the pulse are stored. With the latter information the rise time can be reconstructed and a pulse shape analysis performed. With the increased pulse length the shaping time can be doubled which is expected to reduce the serial noise by typically 10-20 %.

A complete system with 8 channels has been operated for several weeks at the GDL. The previous planned production of additional 16 channels by the end of last year is delayed but not critical for GERDA.

The phase II DAQ system is based on SIS3301 FADCs. These modules will be used for the Germanium diode readout and for the muon veto. In total 30 - 40 cards with 8 channels each will be needed. The design of the entire trigger scheme including the incorporation of the muon veto has started. VME cards containing a XILINX Spartan2E FPGA will be used for this task. This card was built for the HESS experiment and exists already. Work on the firmware has commenced.

11 Monte Carlo background studies

The main activities undertaken by the task group in charge of the Monte Carlo simulations during the last six months are:

- simulation of the test stands presently built at the MPI in Munich. It encompasses: (1) comparison of simulations with experimental data to validate the MaGe code; (2) acquisition of data for future simulations of pulse shapes from Ge detectors and for the development of algorithms for pulse shape analysis;

- simulation of the Cherenkov light emitted in the water buffer for the optimization of the muon veto;

- maintenance, debugging and improvement of the Geant4-based Monte Carlo framework MaGe [6], with the addition of new functionalities for improved flexibility, in collaboration with the MajoranaMonte Carlo group.

11.1 Test-stand data and pulse-shape simulations

The prototype n-type 18-fold segmented Ge detector has been irradiated with γ-ray sources in order to validate the Monte Carlo simulation and to estimate the background rejection factor achievable by segment anti-coincidence [8]. In particular, the suppression of Compton-scattered events in the $Q_{\beta\beta}$-region of ^{76}Ge (2039 keV) coming from ^{60}Co and ^{228}Th sources was measured to be 14.2 ± 2.1 and 1.68 ± 0.02, respectively. The data to Monte Carlo comparison shows a substantial agreement with deviations on the level of 5-10% [8]. The Monte Carlo evaluation of the background rejection by segment anti-coincidence achievable in the full 21-crystal Phase II array is presented in Ref. [9].
The 18-fold segmented Ge detector in Munich has also been irradiated with an AmBe source, to study the response of Ge detectors to fast and thermal neutrons and to compare experimental data with simulations. The experimental AmBe spectrum is shown in in the energy range between 50 and 3000 keV in Fig. 8, superimposed with the corresponding MaGe-based simulation (summed with the background). The agreement of the simulation with the experimental data is in general very satisfactory. A few discrepancies have been identified in width, intensity or position of specific γ-lines. The origin of the discrepancies has been traced back to the treatment of neutron inelastic interactions of Geant4, mostly related to the management of nuclear isomeric states (e.g. ^{71m}Ge and ^{75m}Ge). Based on this, the Monte Carlo simulation is being corrected in order to improve the agreement with experimental benchmark data.

In the near future, a n-type prototype detector will be removed from its cryostat and immersed directly in cryogenic liquid. Measurements with several γ-ray sources (^{60}Co, ^{228}Th and ^{152}Eu) will be performed and compared with simulation results in order to further validate the Monte Carlo code.

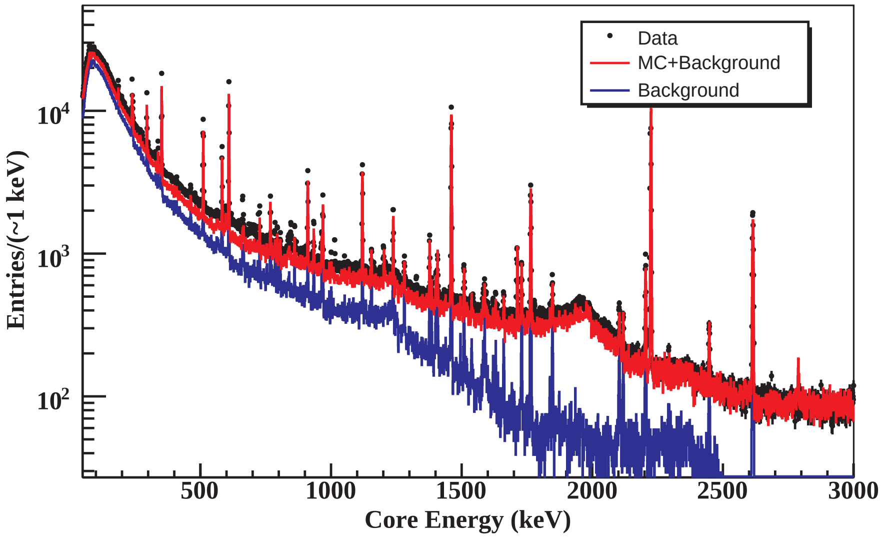

Figure 8: Energy spectrum from the core of the 18-fold segmented Ge detector irradiated by an AmBe neutron source contained in a paraffin collimator. The spectrum is superimposed with the corresponding MaGe-based simulation, summed with the background.

Pulse shape analysis methods were developed and their potential power to distinguish events induced by multiply scattered photons from events induced by electrons has been estimated with the help of the Monte Carlo. Figure 9 shows an indicator (R_{90}) of the spatial distribution of energy deposited inside a single germanium detector for different simulated processes (signal and background); R_{90} represent the radius within which 90% of the total energy deposited is contained. Single-site and multi-site events are defined by requiring $R_{90} < 2$ mm and $R_{90} \geq 2$ mm, respectively.

11.2 Optimization of the Cherenkov muon veto

While the estimation of the muon-induced background had been performed in the past and published in Ref. [7], work continued to optimize the muon veto performances and to define number and position of the photomultipliers. Simulations were run in which the Cherenkov light is produced, propagated and detected in the muon veto. To save CPU-power, muon events having energy deposition close to $Q_{\beta\beta}$ in the Ge crystals were pre-selected and then tracked again with the Cherenkov light. A database of such events has been built, corresponding to about 23 years of equivalent GERDA run-time.

After simulations with different photomultiplier distributions, the final placement has been selected. The location of photomultipliers is sketched in Fig. 10. There are four rings on the wall of the water tank, each with 10 PMTs, two rings on the bottom (the outer with 12 PMTs and the inner one with 8) and six PMTs in the pillbox below the crystals. Monte Carlo simulations run in this configuration indicate that the efficiency for the rejection of

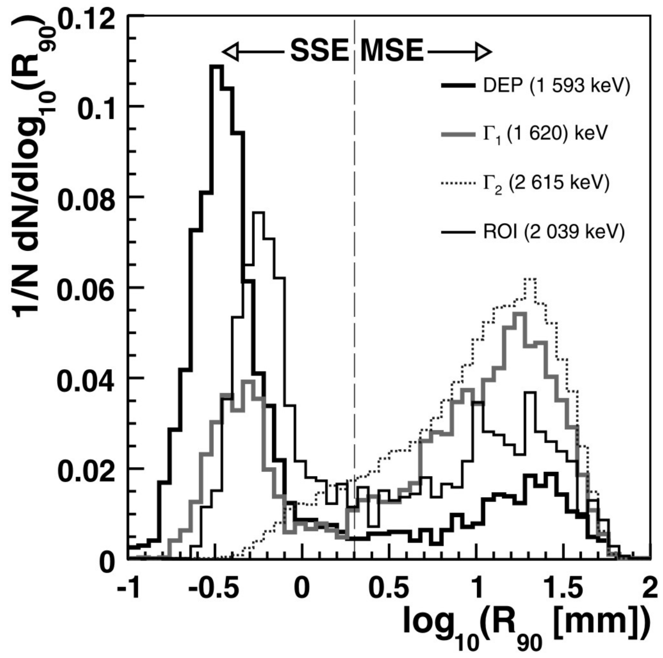

Figure 9: Distribution of the radius R_{90} within which 90% of the total energy deposited is contained for different events, namely: double-escape peak (DEP) from ^{208}Tl (1593 keV), single γ-ray of 1620-keV energy, single γ-ray of 2615-keV energy (^{208}Tl), Compton continuum from ^{208}Tl in the region of interest (ROI) at 2039 keV. The dashed vertical line is the conventional separation between single-site events (SSE) and multiple-site events (MSE).

muon-induced events having energy deposition close to $Q_{\beta\beta}$ in the Ge crystals is at least 98%.

11.3 Development of MaGe

In the last months new functionalities were included in the MaGe framework in order to improve its flexibility and usability. Since most of the simulation parameters (geometry, output, physics processes, materials) can be customized via ASCII-based macros, simulations can be easily run also by users who are not involved in the code development. A closer relationship was established with the material screening task group (TG–11). The geometries of the three Ge spectrometers available at MPIK-Heidelberg have been included in MaGe. Additional experimental data will be hence available to validate the code and improve its physics performances.

Besides ordinary maintenance and debugging, specific work is presently ongoing, in close connection with the Majorana Monte Carlo group, to improve the precision and the reliability of MaGe-based simulation, especially concerning neutron and muon interactions. Furthermore, common discussion started to define dedicate interfaces between MaGe and

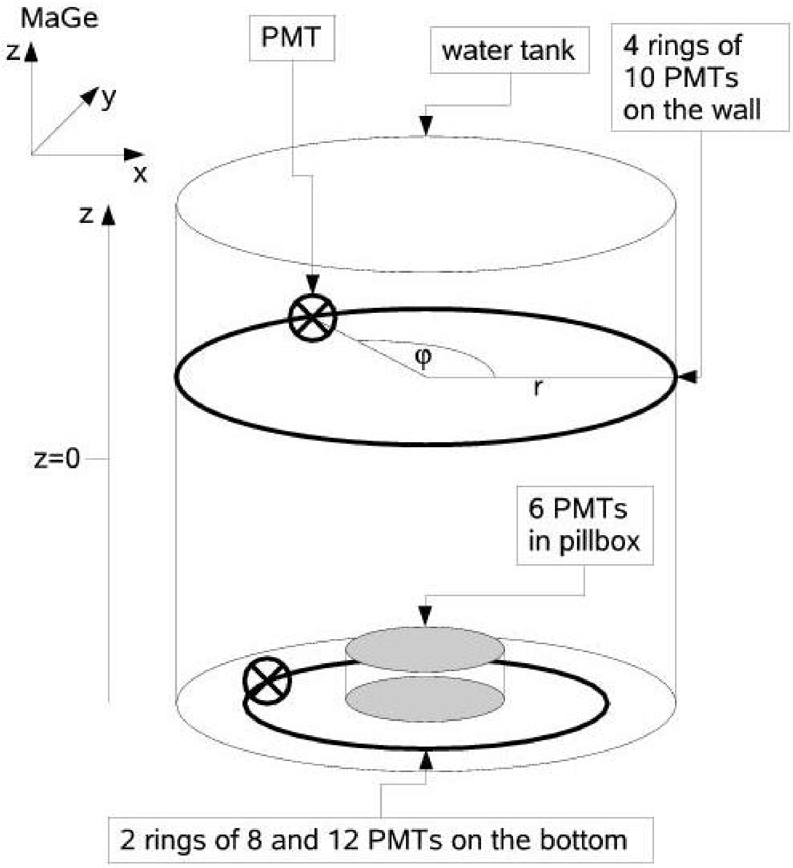

Figure 10: Proposed placement of the phomultipliers in the water tank. In total, 66 PMTs are deployed in the water tank (40 in the lateral surface, 20 on the bottom and 6 in the pillbox).

pulse-shape simulation codes, as well as between MaGe and analysis softwares.

12 Material screening

12.1 γ ray screening

Screening of construction materials for GERDA in the low-level laboratories of MPIK Heidelberg, IRMM Geel, INR Baksan and LNGS Assergi has been continued in the period under review. Most important in this context have been the measurements of samples (between 40 - 75 kg each) from stainless steel batches foreseen for the GERDA cryostat. Table 1 summarizes the results. The radium and thorium contamination of most batches turned out to be about one order of magnitude lower than those measured in previous years on many other steel samples.

No.	**Charge**	**Specific activity [mBq/kg]**				
		^{228}**Th**	^{228}**Ra**	^{226}**Ra**	^{40}**K**	^{60}**Co**
1 D	#5991	5.1 ± 1.0	< 2.9	2.9 ± 1.0	< 3.9	6.5 ± 0.5
2 D	#494257	< 1.9	< 3.4	< 2.0	< 4.5	14.2 ± 0.6
2 G	#494257	< 0.27	< 1.1	< 0.35	< 1.1	13.0 ± 0.6
3 D	#493553	1.1 ± 0.4	< 3.3	< 0.84	< 3.3	15.1 ± 0.5
4 D	#493554	< 2.6	< 4.5	< 2.2	< 6.2	14.4 ± 1.0
5 D	#492217	< 1.1	< 2.6	< 1.2	< 2.8	11.6 ± 0.5
6 D	#495895	< 0.8	< 1.4	< 0.6	< 1.7	16.7 ± 0.4
7 G	#495243	< 0.20	< 2.6	< 1.3	< 2.8	45.5 ± 2.1
8 G	#494257	< 0.11	< 0.86	< 0.24	< 0.93	14.0 ± 0.1
9 G	#506015	< 0.41	< 1.0	< 0.74	< 1.1	13.8 ± 0.7
10 D	#496895	< 1.0	< 4.1	< 1.3	< 6.8	17.1 ± 0.7
11 G	#254533	1.5 ± 0.2	1.0 ± 0.5	1.0 ± 0.6	< 0.81	18.3 ± 0.7
12 G	#255455	5.1 ± 0.5	< 3.0	< 1.3	< 1.7	20.0 ± 1.0

Table 1: γ ray screening results for stainless steel batches foreseen for the GERDA cryostat construction.

Samples No. 1 through 5 are from the charges to be used for the top and bottom parts of the cryostat, samples No. 6 through 11 are from the charges foreseen for the cylindrical part. The letter "D" denotes measurements performed with the DARIO detector at MPIK Heidelberg, "G" indicates measurements with the GeMPI detector at LNGS. Sample No. 2 has for comparison been measured with both, the DARIO and GeMPI detectors. Sample No. 12 was originally foreseen for the cylindrical part of the cryostat. Because the measured ^{228}Th activity exceeded slightly the required limit (5 mBq/kg for the cylindrical parts of the cryostat) needed for a background index of 10^{-4} cts/(keV·kg·y), this charge has been rejected and replaced by sample No. 6.

ICPMS (Inductively Coupled Plasma Mass Spectrometry) measurements on PEN (Polyethylene Naphthalate) samples described in our last report gave values below 1 mBq/kg for

^{238}U and ^{232}Th, compatible with the required purity for the cables close to the Ge crystals. In order to check whether these low numbers hold also for the relevant daughter nuclides a γ ray screening measurement on a 4.4 kg sample (different batch) has been performed with the GeMpi detector. Unfortunately, this PEN batch revealed activities about three orders of magnitude higher ((242 $\pm$ 3) mBq/kg for ^{226}Ra, (135 $\pm$ 3) mBq/kg for ^{228}Th).

As mentioned in our last report, the increased demand for quick γ ray screening measurements for Gerda led to the set-up of several new germanium detectors. The first one at the Low-Level Laboratory of the Mpik Heidelberg (Corrado) is running. The construction of the second one, the GeMpi III spectrometer at Lngs has been completed two months ago. However, the first background measurements revealed the presence of a ^{207}Bi contamination somewhere in the detector set-up. Tests in order to identify the location of this contamination are currently under way. It is probably necessary to partially disassemble the set-up again. This would postpone the completion of the detector by several months. Finally, two more Ge detectors (Ge-8, a low-energy detector and a sandwich detector) have been installed at the Hades underground laboratory operated by Irmm Geel.

12.2 ICPMS measurements

Six of the stainless steel samples for the cryostat have been measured for their ^{238}U and ^{232}Th content by ICPMS at the Analytic Certification Testing Center of the Russian Academy of Science in Moscow. Only upper limits for both elements have been obtained which in all cases except one are consistent with the γ spectrometric measurements. Of special interest is sample #5991 (first line in Table 1). While the ICPMS upper limit for ^{232}Th (<4.8 mBq/kg) is in marginal agreement with the ^{228}Th activity measured by γ ray spectroscopy (5.1 $\pm$ 1.0 mBq/kg), the upper limit for the intermediate nuclide ^{228}Ra (<2.9 mBq/kg) indicates its (at least partial) removal in the steel production process.

In order to check whether the high ^{226}Ra and ^{228}Th activities measured in the PEN batch described above are due to an extreme deviation from radioactive equilibrium, the Lngs chemistry group performed ICPMS measurements on PEN samples from the same 4.4 kg batch. The resulting activities are (160 $\pm$ 50) mBq/kg for ^{238}U and (100 $\pm$ 30) mBq/kg for ^{232}Th, respectively. This essentially confirms the high γ ray screening values, therefore the search for a suitable cable material is ongoing.

12.3 ^{222}Rn emanation measurements

The studies on ^{222}Rn emanation have been continued. Currently several Kalrez gaskets for different systems to be located in the air lock are under investigation. The rates obtained so far vary from 10 μBq up to 150 μBq per gasket, depending on their sizes. These numbers are well below the total allowed ^{222}Rn emanation rate from all materials inside the Gerda cryostat (10 mBq).

The specific emanation rate from Murdtfeld sliding plastic strips was found to be (1.0 $\pm$ 0.1) mBq/m^2. The emanation test of a cryogenic valve from the WEKA company gave

(62 ± 14) μBq. In the near future tests of high voltage and signal cables, high voltage feed-throughs and cryo valves are planned.

12.4 ^{222}Rn in argon

A measurement on the radon concentration in argon of purity 5.0 stored in a 5 m^3 tank at LNGS resulted in an upper limit of 20 μBq/m^3 (STP). This is the lowest radon concentration measured so far in argon. Further investigations on the purity of argon from different suppliers and on the purification are under way.

12.5 Radon monitoring

The radon chamber (active volume ∼700 l) intended to monitor the ^{222}Rn concentration in the air of the GERDA detector setup at LNGS is currently tested at MPIK. It is based on the electrostatic collection of the ionized ^{222}Rn daughter atoms onto a Si PIN diode where the α decays of ^{214}Po and ^{218}Po are measured. It works well up to a high voltage of 35 kV (design high voltage 50 kV). Above 35 kV the signal background increases due to light emission from dust particles and to high voltage discharges. Efforts to reduce this background are under way. These include cleaning of the inner detector surfaces, modifications of the insulator set-up and application of the double amplifier technique. The latter is capable to discriminate signals produced by high voltage discharges from Rn events.

13 Personnel and management structure

The GERDA collaboration counts currently about 80 members. The project is broken down into eleven task groups (TG's) with distinct responsibilities. The task group leaders form the GERDA project management group and convene once per week in a telephone conference. The management team consisting of spokesperson, co-spokesperson, technical coordinator and chair of the institutional board are as well TG leaders, thus follow closely the progress of the different sub-project. The full collaboration convenes three times per year in a general meeting. Ad hoc meetings and reviews on specific topics complement the exchange of information and are part of the process to prepare and take decisions.

The scientific and technical personnel available to the various TG's is adequate to assure that the tasks can be accomplished timely. In total, there are about 37 full time equivalents (FTE's) assigned to the project. A detailed break down of the TG structure and the available personnel is given in Tab. 2.

A new group from the University of Zürich plans to join the project in the near future providing about two additional FTE's.

TG-1 Modification and test of existing Ge diodes	5.7	S. Schoenert
TG-2 Design and production of new Ge diodes	3.0	A. Caldwell
TG-3 Diode readout and signal processing	2.8 (3.8)	C. Cattadori
TG-4 Cryogenic vessel & infrastructures	2.0	K.T. Knoepfle
TG-5 Infrastructure on top of vessel	5.0	B. Majorovits
TG-6 Water tank system	1.3 (2.3)	A. Bettini
TG-7 Muon veto system	2.8	P. Grabmayr / V. Egorov
TG-8 Infrastructure & logistics for Gerda	2.0	M. Junker
TG-9 DAQ Electronics & software	1.5	B. Schwingenheuer
TG-10 Simulation and background studies	4.5	L. Pandola
TG-11 Material screening	8.0	W. Hampel / H. Simgen

Table 2: List of the task groups (TG's), the available personnel (in full time equivalent, FTE), and the responsible task group leader. FTE numbers in brackets correspond to new contracts assigned. In total, about 39 FTE's are currently working on the experiment.

14 Schedule and budget

Contracts have been signed with external companies for the construction for the water tank, the cryostat and for parts of the lock system. The tender for the Gerda building has been published in March and the tender for the clean room is under final preparation. A design for the cryogenic infrastructure is available. The contract for reprocessing phase I detectors and the non-enriched Genius TF detectors have been awarded to the manufacturer and the work is close to completion. R&D contracts for the purification of germanium oxide and phase II crystal pulling have been signed. First versions of the DAQ electronics for phase I and phase II are available and are under test. Front-end solutions for phase I are available and first ASIC chips required for phase II are under test. Monte Carlo simulations have been developed and are used for design optimizations.

Given the nested design of the Gerda experiment, the overall project schedule is driven by the delivery time of the cryostat to Hall A of Lngs. The schedule presented initially by the company producing the cryostat, SIMIC S.p.A., could not be maintained, mainly because of the late arrival of the vessel heads. An updated production schedule has been provided by the company on April 2, 2007. The delivery time to Lngs is now scheduled for end of October 2007, corresponding to a delay of four months with respect to the original production schedule. This delay can not be recovered, since the other parts of the detector infrastructure can only be installed after the arrival of the cryostat in Hall A of Lngs.

The sequence and allocated time for the installation work is displayed in Figs. 11 and 12. After installation of the water tank bottom plate, the cryostat is erected. Then the water tank construction can be completed. Thereafter, the Gerda building will be mounted and the clean room and lock installed. According to our current analysis, all hardware components should be in place at the end of 2008. Additional three months are allocated for final cleaning, testing and detector commissioning.

Phase I detector processing is scheduled to be completed by the end of May 2007. Background measurements of phase I detector assemblies will commence in autumn 2007. First, non-enriched detectors will be used in the Gdl-LArGe setup. If a background index of 10^{-2} cts/(keV·kg·y) or below can be achieved, background measurements with enriched detectors will be carried until the Gerda setup becomes operational.

The schedule for phase II detectors assumes the successful R&D of the germanium oxide purification at PPM and of the crystal pulling at the IKZ. The uncertainties on this schedule are therefore still large.

The overall capital investment for Gerda corresponds to 14 MEuro, including the enriched material and production costs for phase II detectors as well as natural reference detectors. The available budget does currently lack the funds for the phase II crystal production and detector fabrication, as well as the natural phase II reference detectors. Other budget shortfalls are related to the increase of the water tank costs. The collaboration is active to close the open funding gaps. A more detailed break down of the budget and costs will be given during the Lngs scientific committee meeting.

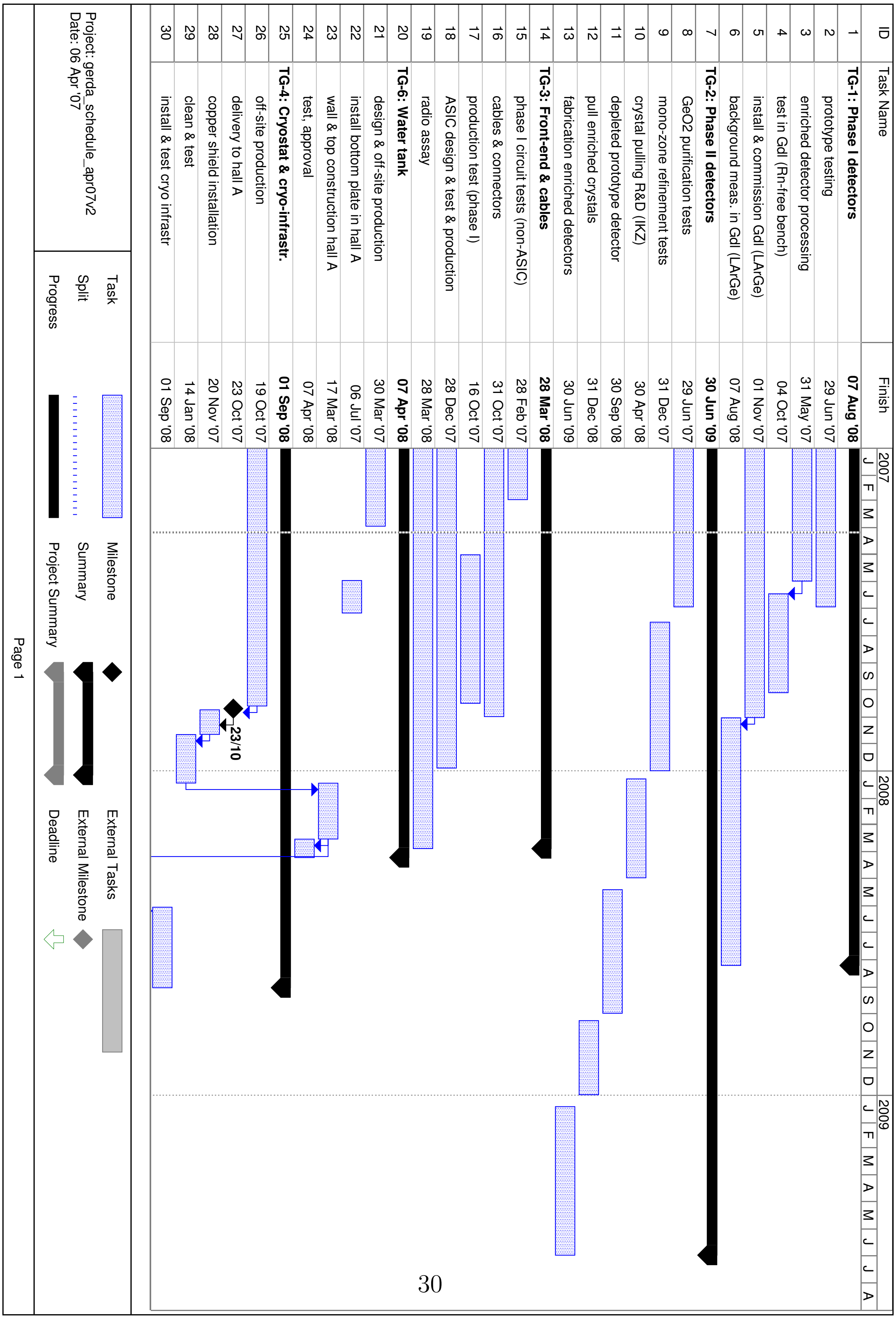

Figure 11: GERDA project schedule overview.

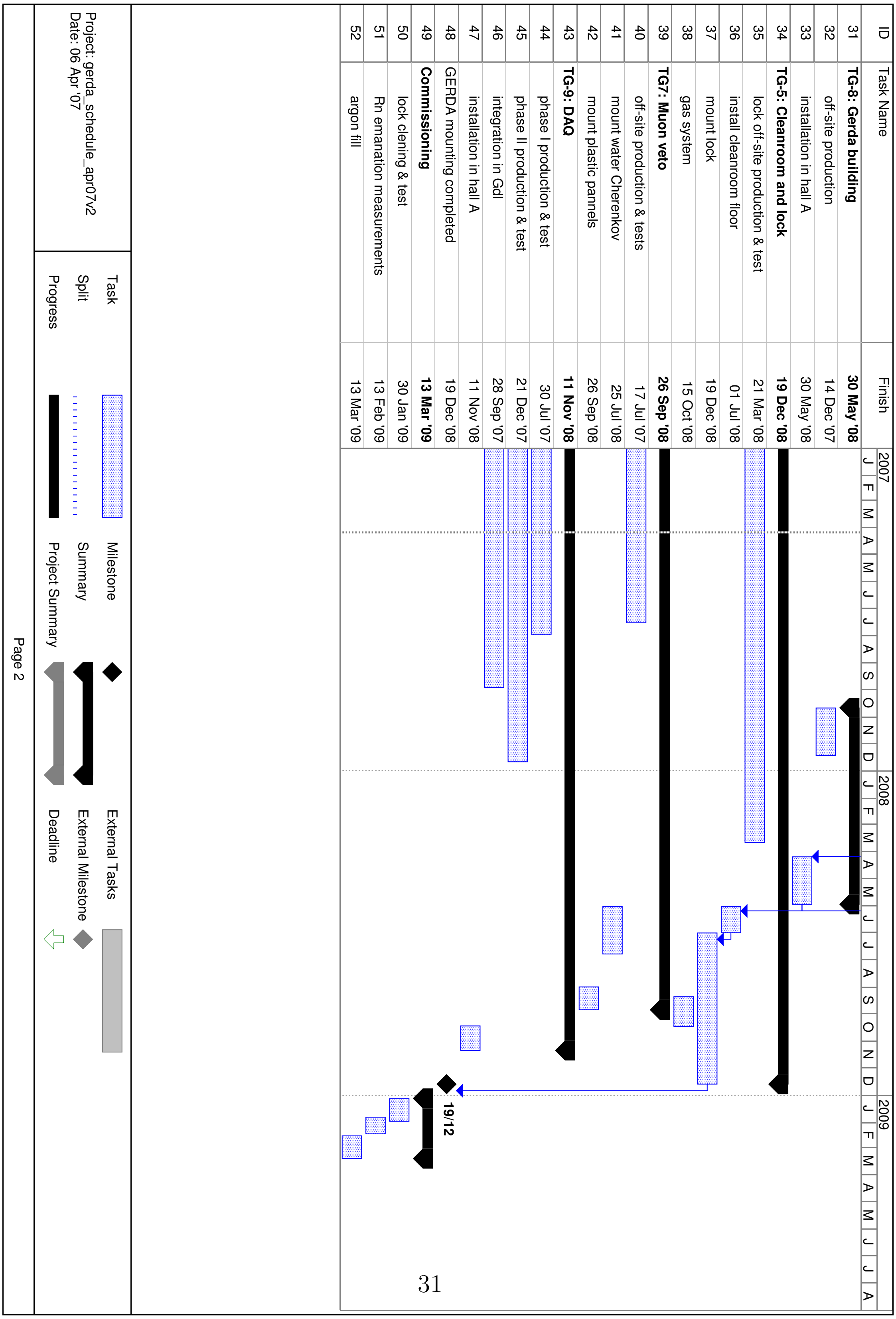

Figure 12: GERDA project schedule overview (continued).

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