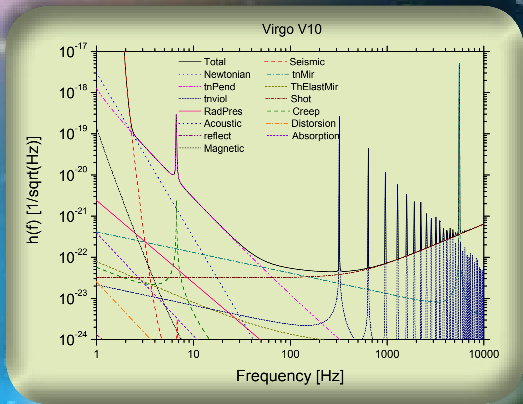
3rd ASPERA Technology Forum

13-14 March 2012 - Lichtenberghaus - Darmstadt

Vacuum & Cryogenics in Astroparticle Physics Infrastructures



Academia meets industry!

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SEVENTH FRAMEWORK PROGRAMME

«Vacuum and Cryogenics in Astroparticle Physics Infrastructures - *Academia meets industry*»

Report on the 3rd ASPERA Technology Forum

Work Package 3 - Task 3.2

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Content

Executive Summary

The 3rd and last ASPERA Technology Forum (ATF3)[1] was devoted to "Cryogenics and Vacuum". These techniques are among the paramount R&D endeavours within the future infrastructures in Astroparticle Physics (ApP), and to some extent they are also strongly related to efforts performed in neighbour fields such as elementary particle and nuclear physics, via R&D on both accelerators and detectors.

Those fields, as well as astronomy and astrophysics, bring together communities aiming at disentangling mysteries such as:

- What is the Universe made of?
- What is the nature of gravity? Can we detect gravitational waves? What will we learn about violent cosmic processes?
- What are the properties of neutrinos? What is their role in cosmic evolution?
- What do neutrinos can reveal about the interior of the Sun and Earth, and about Supernova explosions?
- Do protons have a finite life-time (Grand Unified Theory)?
- How to pin down the yet unknown nature of about 96% content of the Universe: dark matter, dark energy, or even more exotic entities / phenomena…

ApP can be considered as the science of rare events, arising in some cases from the far away and most violent phenomena in the Universe. Detecting such weak signals and investigating their nature / origins are of crucial importance in our understanding of the fundamental laws governing the Universe.

Identifying extremely rare and weak signals requires sophisticated and large size facilities with technical performances, often beyond the exciting technological abilities, especially to reduce the background by orders of magnitude with respect to the present performances. Accordingly, to constitute the indispensable large spectrum of expertise, close collaboration/cooperation between academia and industry is indispensable.

In line with the ApP Roadmap, the 2nd edition of which was released by ASPERA-2 in 2011, some of the main ApP topics were on the Agenda of the Forum, via six **experimental projects**:

- ✓ Gravitational waves: E.T.
- ✓ Neutrino mass: KATRIN, GERDA
- ✓ Low energy neutrinos & proton decay: LAGUNA-GLACIER
- ✓ Dark matter: DARWIN, EURECA

The requirements of those next generation facilities are, among various issues, cryogenics techniques allowing to reach temperatures as low as few mK and ultra-high vacuum below 10^{-11} mbar; with partial pressures lower by several orders of magnitude. Cryogenics and vacuum demands concern, detectors with unprecedented large masses and volumes, respectively.

In the present report, the next generation detectors in the above mentioned ApP topics are presented in the first section. The second section embodies contributions from companies dealing with challenges in cryogenics and/or vacuum, showing also a much extended area of needs to such technical performances and advances.

1 http://indico.cern.ch/conferenceDisplay.py?ovw=True&confId=169352

Vacuum and Cryogenics for a 3rd Generation Gravitational Wave Detector

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Abstract - ***Existing laser interferometers to detect Gravitational Waves and their future evolutions require vacuum and cryogenics. Ultra-high vacuum is required to allow laser beam propagation on kilometric distances. Cryogenics is required to cool down the mirror test masses to reduce thermal noise.***

1. Introduction

Gravitational waves (GWs) are ripples in the fabric of space-time produced by violent events in the universe, like collisions of black holes and supernova explosions. GWs are emitted by accelerating masses much in the same way as electromagnetic waves are produced by accelerating electric charges. Predicted by Albert Einstein in 1916 as a consequence of his General Theory of Relativity, the direct detection of GWs will open a new astronomy, allowing totally new insights into the universe. With GWs, we could probe parts of the universe hidden by cosmic dusts, or give a completely different perspective to astronomical events both visible and invisible in the electromagnetic spectrum.

GWs, being perturbations of the structure of space-time, produce minuscule changes in the relative distances of free masses. A Michelson interferometer can monitor such distances shooting laser beams in two directions and studying changes of the interference pattern after beam reflection on mirror test masses put at kilometric distances.

Existing detectors (Virgo [1] at the European Gravitational Observatory [2] in Pisa, the two LIGO [3] in US and GEO600 [4] in Hannover), with sensitivities better than 10^{-18} m/Hz$^{1/2}$, could detect GWs from Supernovae or binary neutron star coalescences up to a distance of 30 Million light years, with rates of one recorded event every 100 years. All these detectors are undergoing important coordinated upgrades to become second generation interferometers with a reach of 300 Million light years; they are expected to be operative around 2015. Having the ability to explore a sphere of universe with a 10 times larger radius, i.e. a 1 000 times larger volume, the estimated event rate will become tens of events per year of observation. This success is expected by 2016, just hundred years after Einstein prediction.

The Einstein Telescope (ET [5]), already under study constitutes a natural evolution with respect to first and second generation interferometers. The sensitivity will be improved with an arm length of 10 km, instead of 3 km as in Virgo. Further improvements will come from being underground, to reduce seismic noise and from cryogenic mirrors, to fight against thermal noise. With a sensitivity 10 times better than second generation detectors, ET will be able to explore a Universe region with a radius of billions of light years, collecting thousands of events (GW bursts) per year of observation.

These successive improvements go through progress in vacuum technology for undisturbed propagation of laser beams on kilometric distances and cryogenics to cool down mirrors, reducing vibrations induced by molecule thermal motion.

2. Vacuum

In laser interferometers for GW detection most of the instrument has to be kept under High-Vacuum or Ultra-High-Vacuum (HV, UHV) for several reasons:

- Reduce the noise due to vacuum fluctuations along the beam path to an acceptable level;
- Isolate test masses and other optical elements from acoustic noise;
- Reduce test mass motion excitation due to residual gas fluctuations;
- Reduce friction losses in the mirror suspensions;
- Contribute to thermal isolation of test masses and of their support structures;
- Contribute to preserve the cleanliness of optical elements.

A vacuum system of this kind is composed of two UHV pipes with kilometric length (Fig. 1 and Fig. 2), for the propagation of the interferometer laser beams, and several cylindrical vertical HV/UHV tanks (Fig. 3), containing the optical elements and their support structures. In general, it is necessary to have the whole vacuum system constituting one single volume, without physical separations (windows) on the laser beam path. HV volumes (the vertical tanks) contain parts of the apparatus not easily compatible with UHV. The separation between HV volumes (unbaked) and UHV volumes (baked), necessary to stop the migration of water and other high vapour pressure components, is obtained by differential pumping (Virgo) or by cryogenic traps (LIGO).
The vacuum enclosure is usually built of stainless steel (304L); this material is preferred for its easy availability, its price, the large experience in machining and welding, the mechanical properties (ductility), the chemical properties and the achievable outgassing rate.
The vacuum system must be extremely clean from heavy organic molecules, both to limit the phase noise and to prevent pollution of the optical components. Hydrocarbon partial pressure goal is at the level of 10^{-14} mbar.

Figure 1 - The Virgo North arm Vacuum pipe; 3 km long, 1.2 m diameter.

Figure 2 - The GEO600 vacuum pipe; 600 m long, 0.6 m diameter, 0.8 mm thick corrugated wall of 316L stainless steel.

Figure 3 - The Virgo towers; 11 m high, 2.0 m diameter.

2.1. State-of-the-Art

Average base pressure in the arm pipes

The noise due to pressure fluctuations (index instabilities due to statistical fluctuations of the number of molecules in the volume occupied by the laser beam in the arm cavities) has been calculated to be the largest contribution due to vacuum to the noise in the interferometer.

Vacuum systems for first generation detectors have been designed and built already compliant with second generation requirements, i.e. capable to reach a total residual pressure of 10^{-9} mbar, corresponding to a noise level below 10^{-24} m/Hz$^{-1/2}$, after bake-out, with a residual gas composition dominated by hydrogen. This goal has been achieved developing thermal treatments able to deplete by factors 100-1 000 the hydrogen content in the bulk stainless steel of the arm pipe walls. After keeping at 450°C for several days the stainless steel coils (LIGO) or the already built pipe elements (Virgo) an outgassing rate of 10^{-14} mbar l cm^{-2}s^{-1} has been obtained. It has been necessary also to set up economically affordable bake-out systems, based on very effective thermal insulation and on pipe heating by kiloAmpere current direct passage in km long circuits. Initial Virgo has been operated with unbaked arm pipes, the 10^{-22} Hz$^{-1/2}$ sensitivity being compliant with a 10^{-7} mbar residual pressure. For the upgrade to Advanced Virgo the 3 km pipes will be baked, but, to avoid baking the lower tower chambers, containing the mirrors, four large liquid nitrogen traps will be installed at all the pipe ends. In this way the separation between baked and unbaked volumes will be effective. The baking equipment is already installed and it has been successfully operated on the whole pipe length. The capability to reach the 10^{-9} mbar region with pumping speeds of a few 10^3 l/s per km of pipe length has been experimentally demonstrated.

2.2. Foreseen performances

The ET Design Study has shown that third generation interferometers will require to reach in the arm vacuum pipes a total residual pressure of the order of 10^{-10} mbar, corresponding to a noise level of about 10^{-25} Hz$^{-1/2}$. This goal will be reached by increasing the pumping speed per km of pipe length and taking advantage of the pumping capabilities of the large liquid Helium cryostats, needed to cool down the mirror test masses.

3. Cryogenics

The aim of increasing the sensitivity of a 3rd generation detector by a factor of 10 compared to the 2nd generation requires a significant reduction of thermal noise in optics and suspension components. This reduction can be achieved by cooling all relevant interferometer components to cryogenic temperatures as low as 10 K [5]. 1st and 2nd generation detectors use optical components made from fused silica. An operation of fused silica at cryogenic temperatures would lead to a significant increase of thermal noise due to its high mechanical loss at these temperatures. Alternatively silicon and sapphire show excellent mechanical properties within the desired low temperature range.

The reduction of another noise contribution called laser shot noise requires high laser power in the interferometer arms. Due to the presence of absorption (~1 ppm of the foreseen 18 kW) a higher laser power also leads to a higher thermal load on all optical components. So the effect of absorption increases the operating temperature for a given cooling power. At low temperatures thermal radiation does not provide a sufficient thermal coupling to the surrounding radiation shields. Thus, the heat must be removed by means of thermal conduction through suspension fibres of the optics (Fig. 4).

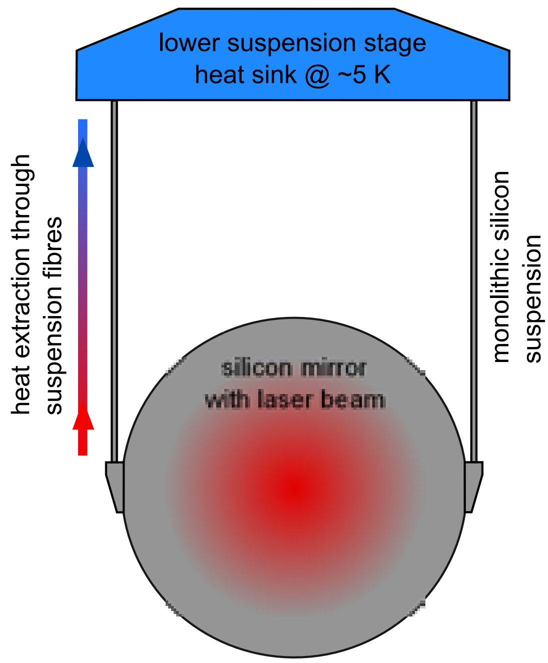

Figure 4 - Schematic of the heat extraction from a mirror substrate to a heat sink at about 5 K. To attenuate seismic disturbances the mirror is suspended by means of thin silicon fibres. These fibres also allow the extraction of heat which is due to optical absorption of laser light and thermal radiation.

3.1. State-of-the-Art

Gravitational wave detectors like Virgo [6], LIGO [7] or CLIO [8] already make use of cryogenics for vacuum applications. Cryotraps are used to separate vacuum volumes with different pressure requirements such as high and ultra-high vacuum. While all optical components of Virgo and LIGO operate at room temperature, the CLIO detector uses cryostats to cool its sapphire made end mirrors and cavity couplers down to 20 K. To reach these temperatures all relevant optical components are surrounded by two encapsulated thermal radiation shields at 8 K and 80 K (Fig. 5). The cooling power is provided by several low mechanical vibration two-stage Gifford-McMahon (GM) type pulse tube (PT) cryocoolers working at 4 K and 40 K respectively.

Direct measurements of the displacement noise spectrum at the cold head of two PT cryocoolers from Sumitomo (SRP-052A) and CRYOMECH (PT407) showed displacement peaks in the spectrum corresponding to their operation frequencies. In comparison the SRP-052A vibrates with an amplitude of about 8 μm at 1 Hz while the PT407 shows 29 µm at about 1.4 Hz. A new cryocooler concept realised by attocube [9] with a cold platform decoupled from the PT cold head offers 1.5 W at 4.2 K with a vibration amplitude less than 4.2 nm peak-to-peak.

For a further reduction of the coupling of any mechanical vibration from the PT to the interferometer the cryocoolers have active vibration isolation stages. In addition, the PTs are attached to a separate vacuum tower that has a thermal contact to an interferometer cryostat containing optical components that need to be cooled. The thermal connection between the optics cryostat and the separate PT cryostat is realized by several bundles of pure aluminium wires.

3.2. Foreseen performances

Based on the concept of cooling only the noise relevant parts of the interferometer, the previously discussed vacuum towers of the Einstein Telescope will contain cryostats at their basements (Fig. 5). These cryostats encase the lower parts of the suspension and optical components like mirrors, cavity couplers, beam splitters, several suspension elements etc. which mainly determine the noise performance of the gravitational wave detector. As already mentioned some of these cryostats are connected by 10 km long vacuum tubes which allow a laser beam propagation without disturbing influences (see Section 2). All vacuum tubes operate at ambient temperature which would lead to a thermal load of up to 500 W/m^2 on the optics surfaces. Taking the suspension fibre geometry and the temperature of the heat sink into account, a maximum thermal radiation power of 70 mW can be absorbed until the substrate temperature exceeds the desired operation temperature of 10 K. An efficient reduction of this radiation power can be achieved by implementing cryotraps beginning at and ending several ten meters away from the cryostat. Close to the cryostats their operating temperature will be around 4.2 K further away 77 K. Calculations have shown that the length $L_{4.2K}$ of the 4.2 K cryotraps should be about 10 m, for the 77 K shield L_{77K}~50 m (Fig. 5). This set of cryotraps reduces the direct transfer of thermal energy from the warm vacuum tubes to the mirror to approximately 3 mW.

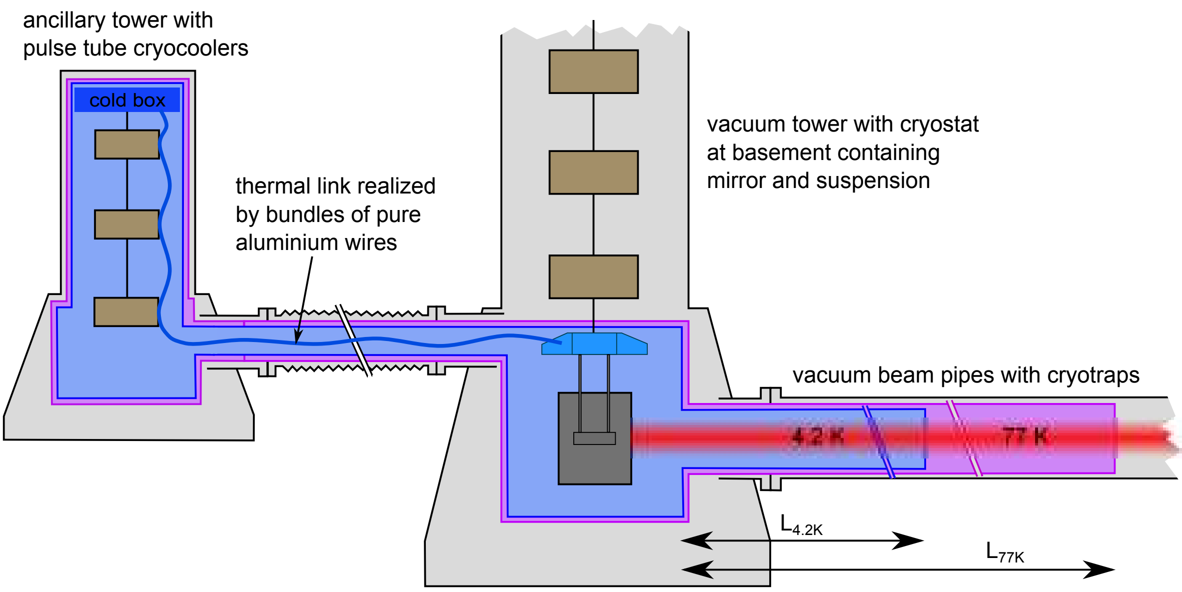

Figure 5 - Schematic of vacuum towers (containing optical components in cryostats) at the end of a beam pipe. The thermal load from the warm (ambient temperature) beam pipes is reduced by up to 60 m long cryotraps, which are attached inside the vacuum tubes in front of the mirrors.

As the use of PT cryocoolers offers high duty cycles with limited manpower it also involves significant levels of mechanical vibration and high electric power consumption (up to 10 PTs just for cooling only one 10 m long 4.2 K cryotrap) in the underground environment. An alternative is the use of cryogenic liquids in the form of liquid helium and liquid nitrogen circulating for a permanent cooling of the cryostats. As a big advantage all refrigeration plant infrastructures can be placed several ten to hundred meters away from the interferometer to avoid as much vibrations as possible. The connection between the cryogenic plant and the interferometer cryostats can then be established by flexible transfer lines developed at CERN with heat-in-leaks of ~30 mW/m. These transfer lines are based on a four-fold coaxial corrugated tube design that feeds the cryogenic liquid through an inner channel which is additionally cooled by the back streaming cold gas and insulated by an isolation vacuum. A future development of this concept is lowering the temperature of the liquid helium to the super fluid state. This would increase the cooling efficiency due to its higher thermal conductivity and the effect of boiling would be eliminated. The super fluid state of helium also provides an extremely low viscosity. In combination with the high thermal conductivity this prevents from small transient temperature fluctuations.

4. Conclusions

A further improvement of the sensitivity of 2nd generation gravitational wave detectors by a factor of ten can be achieved by cooling all relevant optical components and suspension elements to cryogenic temperatures around 10 K. In addition to the change of the operating temperature also the total residual gas pressures needs to be decreased to about 10^{-10} mbar. In principle the design of the ET cryogenic facility including cryostats and cryotraps is clear so far but additional R&D on a more efficient decoupling of PT vibrations from the interferometer is necessary.

This document is based on the ET Design Study funded through FP7 by the European Union.

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Neutrino Mass Measurement with the KATRIN Experiment

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Abstract - ***The KATRIN experiment will determine the neutrino mass with unprecedented accuracy by measuring the endpoint region of the energy spectrum from tritium beta-decay with a high resolution electrostatic spectrometer. Here we describe the demanding requirements and solutions for our vacuum and cryogenic systems. The vacuum system has to reduce the flow of tritium molecules between the windowless gaseous tritium source and the electrostatic spectrometer by 14 orders of magnitude. The vacuum components used to pump out tritium have to be radiation hard. The huge main spectrometer vessel with a volume of 1240 m^3 and its complex wire electrode system have to be maintained at a vacuum of 10^{-11} mbar in order to keep the background rate below 10 mHz. The major tasks of the cryogenic system are the cooling of the super-conducting magnets, stabilization of the temperature of tritium gas in the source below the 10^{-3} level, cryosorption of tritium on argon frost in the cryogenic pumping section and capturing radon atoms in the main spectrometer with nitrogen cooled cryo-baffles.***

1. Introduction

Neutrinos are, apart from photons, the most abundant particles in the universe. Even a small neutrino mass can contribute considerably to the total mass of the universe. The goal of the Karlsruhe Tritium Neutrino (KATRIN) experiment is the measurement of the absolute mass of neutrinos from tritium β-decay with an unpresedented sensitivity of 200 meV/c^2. A non-zero neutrino mass changes the shape of the energy spectrum of the b-electrons. KATRIN will measure this shape close to the endpoint of the spectrum at 18.6 keV, where the effect of the neutrino mass is most prominent.

The KATRIN experiment [1], currently under construction at the Karlsruhe Institute of Technology (KIT) in Germany, has two main sections (Fig. 1). The source and transport section provides a continuous flow of radioactive tritium gas with 10^{11} decays per second inside the beam tube of the windowless gaseous tritium source (WGTS). The transport section magnetically guides the decay electrons to the spectrometer section, using super-conducting solenoids, while at the same time almost all tritium molecules are removed by turbo-molecular pumps and cryogenic pumping. In the spectrometer and detector section the energy of the electrons is measured with high precision.

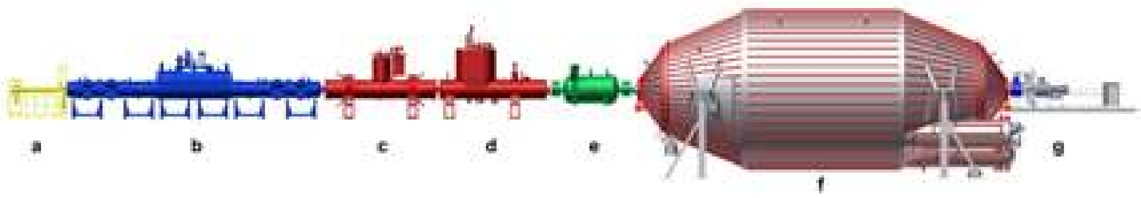

Figure 1 - Components of the KATRIN experiment are a) the calibration and monitoring section, b) windowless gaseous tritium source (WGTS), c) differential pumping section (DPS) with turbo-molecular pumps, d) cryogenic pumping section (CPS), e) pre-spectrometer, f) main spectrometer and g) the detector system. The setup has a total length of about 70 m.

2. Vacuum

The vacuum system of the KATRIN experiment faces different challenges. The majority of gas in the source and transport section is radioactive tritium. The first stage, the differential pumping section (DPS), uses turbo-molecular pumps (TMP) to circulate the tritium in a closed loop, which provides a constant tritium flow back into the source [2]. The second stage, the cryogenic pumping section (CPS), captures tritium on a layer of argon snow, frozen to the walls of the beam tube at a temperature of 3 K. Radiation hardness of components, in particular turbo-molecular pumps, is an important issue. From the source to the spectrometer the tritium flow has to be reduced by at least 14 orders of magnitude.

The spectrometer section with the smaller pre-spectrometer and the large main spectrometer requires a vacuum of 10^{-11} mbar in order to reduce the number of background events. The partial pressure of tritium has to be below 10^{-21} mbar. A pumping speed of 10^6 l/s is needed to achieve such a low pressure.

2.1. State-of-the-Art

The design of the source and transport system with its large tritium reduction factor of 10^{-14} has been simulated in detail [3,4,5]. First commissioning measurements in 2010 with the differential pumping section showed a four times smaller reduction factor than expected [6]. However, this should improve after installing dipole electrodes for ion removal, which will reduce the cross section of the beam tube.

The concept of cryosorption of tritium on argon frost at 3 K in the CPS has been tested in a prototype measurement [7]. The results indicate a better performance of the CPS than projected, compensating possible shortcomings in the pumping speed of the DPS. Adsorption of tritium on the gold coated inner surfaces of the source and transport system is another issue currently under investigation at the Tritium Laboratory Karlsruhe (TLK).

Some turbo-molecular pumps (Leybold MAG W 2800) of the DPS will have a large throughput of tritium. Since the maintenance of contaminated TMPs is not an option, it is important to know the lifetime of a TMP in a tritium environment. Currently a test experiment is running at TLK, exposing a TMP to a permanent tritium flow, comparable to the flow in KATRIN. After one year of operation the TMP will be disassembled inside a sealed glovebox in the TLK to investigate the influence of the tritium exposure on critical parts, such as electrical insulations, gaskets or internal sensors.

The TMPs of the source and transport section are mounted close to superconducting solenoids of the beam line. The magnetic fields pose another challenge for the safe operation of TMPs, as eddy currents can heat up the fast moving rotors beyond the maximum allowed temperature. A test experiment at KIT investigated the influence of eddy currents by placing a TMP in the field of a pair of Helmholtz coils and measuring the rotor temperature at full speed with an infrared pyrometer (Fig. 2). In addition, a model of the rotor heating has been developed [8], allowing us to extrapolate these data for other operating conditions such as slowly pulsed fields in fusion experiments [9].

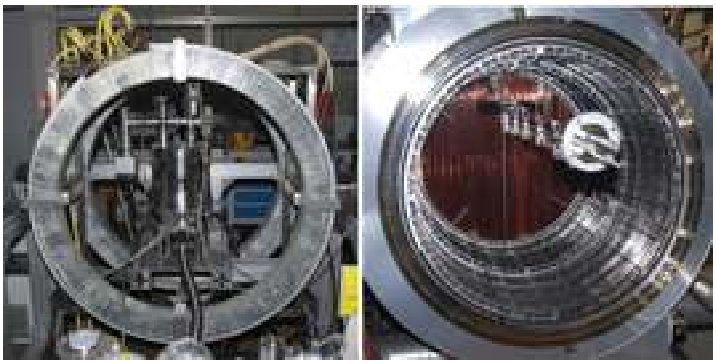

Figure 2 - Left: Helmholtz coils and TMP for the measurement of the rotor heating through eddy currents. Right: One getter pump in the main spectrometers (1000 m of SAES St707 NEG strips) with a pumping speed of 340 000 l/s and a LN2 cooled cryo-baffle for radon capture. The baffle reduces the effective pumping speed to 150 000l/s.

The largest component of the KATRIN setup is the main spectrometer, which has a diameter of 10 m and a length of 24 m and is made of 316LN stainless steel. Good vacuum conditions with a pressure of 10^{-11} mbar or better are mandatory. After bakeout at temperatures of up to 350°C an outgassing rate of 10^{-12} mbar·l/s·cm^2, dominated by hydrogen, has been achieved at room temperature in the main spectrometer [10] and the much smaller pre-spectrometer [11].

The main spectrometer is equipped with 3 getter pumps (3x 1000m of SAES St707 NEG strips; Fig. 2) with a total pumping speed of 10^6 l/s and 6 large TMPs [12]. A small amount of ^{219}Rn emanating from the getter material can produce enough background events to influence the measurement [13]. As tested with the pre-spectrometer, a LN2 baffle in front of the getter pumps can capture the radon atoms, thus reducing the background rate [14]. Finding a getter alloy without radon emanation would be of advantage, because the cryo-baffles reduce the effective pumping speed of the main spectrometer's 3 getter pumps to 450 000 l/s. The specially selected zirconium used in the St707 getter reduced the emanation by a factor of 2, but still not enough to omit the baffles. Several other getter alloys were also tested with a low background germanium counter, but all showed higher radon rates.

Both the pre-spectrometer and the main-spectrometer are equipped with inner wire electrodes. Their purpose is the fine-tuning of the electro-static field of the spectrometer and the suppression of background electrons that are emitted from the stainless steel of the spectrometer wall, induced by high energetic cosmic muons or ambient radioactivity. These low energy electrons are blocked by the electric potential of the wires that is slightly more negative than the potential of the wall. The complex inner electrode system was designed and built by the University of Münster [15, 16]. It consists of 248 electrode modules with two wire layers for improved background reduction that cover most of the surface of the vessel (690 m^2). The modules are mounted in 15 rings on a rail system inside the spectrometer (Fig. 3) that allows free movement during bakeout. More than 23 000 wires are held on both ends by ceramic insulators in stainless steel frames. A complex system of HV connections is used to route 46 different potentials to the proper electrodes.

For ultrahigh vacuum (UHV) compatibility only selected materials were allowed for the production of the modules and HV connections (mainly 316LN stainless steel, copper and Al_2O_3 ceramics). All of the roughly 130 000 components of the system were thoroughly cleaned, using a large ultrasonic bath and following procedures based on ASTeC specifications [17]. Ceramic parts were cleaned by air baking above 1 000°C. The behavior during bakeout and the outgassing rate at room temperature of the modules were checked using a prototype module that fitted into an UHV oven at the University of Münster. The outgassing rate was found to be compatible with the KATRIN requirement of less than 10^{-12} mbar·l/s·cm^2.

Figure 3 - Left: arrival of the large main spectrometer vessel at KIT after an 8800 km journey. Right: wire electrodes on the inner wall of the main spectrometer, which was installed under cleanroom conditions.

2.2. Foreseen performances

The performance and reliability of the source and transport section will strongly depend on the tritium compatibility of the TMPs. Results from the tritium test experiment are expected in summer 2012. The total tritium reduction factor will be determined after the CPS arrives in 2013.

The reduced pumping speed of the main spectrometer due to the LN2 baffles can be compensated by optimizing the bakeout temperature cycle to reduce the outgassing rate. Further tests are planned to find the optimum bakeout temperature for 316LN stainless steel. The main spectrometer can also be operated at a reduced temperature of 10°C, which would reduce the outgassing rate by another factor of 2. The final bakeout, getter activation and first electromagnetic tests of the electro-static spectrometer are planned for fall 2012.

The magnetic field tests of TMPs will be continued, extending the measurements to other models. The results are not only relevant for KATRIN, but have been used to predict the rotor temperature and stability of TMPs used in the JET fusion experiment [ref TMP2], with pulsed magnetic fields. These measurements have been supported by JET and by Oerlikon Leybold.

3. Cryogenics

The cryogenic systems of the KATRIN experiment have four major tasks:

- Cooling of the super-conducting solenoids along the beamline;
- Long term temperature stabilization below the 10^{-3} level of the tritium gas in the WGTS;
- Maintaining a layer of argon snow on the inner surface of the CPS for cryosorption of tritium;
- Capturing of radon atoms with cryo-baffles in the main spectrometer.

3.1. State-of-the-Art

Along the KATRIN beamline there are three large cryostats for the tritium source (WGTS) and the transport section (DPS and CPS) in addition to several smaller ones for stand-alone solenoids between the spectrometers and the detector section. The three major cryostats have a diameter of 1 m and a length of 16 m (WGTS) and 7 m (DPS, CPS), respectively. With the large amount of stored energy in the super-conducting magnets and a liquid helium content of 0.6 to 1.5 m^3, quench protection and accessibility in case of repairs are important issues in the design of these cryostats. A sufficient pressure rating is important for the implementation of several safety levels. The WGTS cryostat with 12 cryogenic circuits for different temperatures and gases is particularly challenging [18].

The magnets in the large cryostats are cooled by LHe bath cooling to 4.5 K. The cooling power is provided by a central helium refrigerator, which is connected to the cryostats by a 40 m long cryogenic transfer line with several valve boxes. Smaller magnets are cooled by cryogen free pulse tube coolers with low microphonics. This is especially important for magnets in the detector section, where microphonics can produce noise in the sensitive detector signal.

The 10 m long source tube in the WGTS will be kept at a temperature of 30 K by evaporating neon in tubes attached to the beamline [19]. KATRIN requires a stability of the source temperature better than 1‰ at 30 K operating temperature. The heat loads on the beam tube inside the WGTS cryostat are basically constant. On the other hand the temperature of the heat sink, i.e. gaseous helium in a primary cooling circuit, typically fluctuates by a few hundred mK due to the normal operating behaviour of the helium refrigerator. In order to smooth out those fluctuations and to provide a homogeneous temperature profile along the 10 m long beam tube, a two-phase thermosiphon with saturated neon has been developed. This novel system was tested successfully, achieving a temperature stability as low as 1.6 mK/h. The experimental result agrees on a millikelvin scale with the dynamic simulation published in [19]. The resolution of the temperature measurement with vapour pressure sensors was 1 mK [20]. The temperature stabilization is a passive feature of the system design, mainly influenced by the thermal capacitance and the thermal resistance of the heat exchanger between the primary helium and the secondary neon circuit.

The last stage of the beamline pumping system, which keeps out tritium from the spectrometer section, is the cryogenic pumping section. Instead of using charcoal on cryo-panels, as done in standard cryopumps, the CPS has cryo-panels at the inner surface of the beamline, which are covered with argon frost. This argon snow provides the large surface needed to cryosorb tritium at a temperature of 3 K. In order to regenerate the cryopump every 60 days, the beam tube is heated to 100 K and both sorbed tritium and argon are flushed out with helium gas. After cooling down again, a new layer of tritium-free argon snow is frozen onto the surface of the argon frost pump in the CPS.

3.2. Foreseen performances

The most challenging task for the cryogenic system, the temperature stabilization of tritium gas in the source tube has been successfully tested and is expected to exceed expectations, when the WGTS is ready in 2014. LN2 and LHe supplies are already in place, using standard technologies.

The radon capture efficiency of the LN2 baffles in the main spectrometer will be tested in 2012. They will be essential for achieving low background rates in the neutrino measurements.

4. Conclusions

The KATRIN project started in 2001 as an international collaboration with institutions from 5 countries. Merging physicist's ideas with the limitations of cutting edge technology proved to be a challenging task. Frequent communication between project engineers, scientists and manufacturers, adequate project management, quality assurance and documentation during the whole planning, manufacturing and commissioning process of large components are essential for the success of a project like this. Especially for components in the tritium-bearing section it is mandatory to procure materials and semi-finished parts together with the required certificates before manufacturing starts. Besides the construction of individual components, smaller R&D projects provided answers to many challenging technical issues. Final commissioning of the experiment is expected in 2015, followed by five years of measurements.

As a Helmholtz Large Facility, main funding for KATRIN comes from the German Helmholtz Association (HGF) and from KIT. German university groups in KATRIN are predominantly funded by the German federal ministry for education and research (BMBF) within the programme astroparticle physics. Specific R&D projects were also funded by DFG (SFB Transregio 27). In addition, KATRIN is supported by the Helmholtz Alliance Astroparticle Physics (HAP). The US groups (detector, software, monitoring) are supported by the US Department of Energy.

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KATRIN homepage: http://www.katrin.kit.edu.

Appendix

Schedule of the KATRIN project for different phases:

- **Design:**
  - 2001: Collaboration was founded, Letter of Intent (LoI).
  - 2012: Final design of the last component, the calibration and monitoring system.
- **Prototyping**
  - 2012: Various tests with TMPs (eddy currents, tritium compatibility).
- **Construction**
  - Until 2014: Components of the source & transport section.
- **Commissioning**
  - 2012: Main spectrometer & detector section.
  - 2015: KATRIN experiment, including source and transport section.
- **2015: Start of neutrino measurements**

The GERDA Liquid Argon Cryostat and its Infrastructure

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Abstract - ***The GERDA, the GERmanium Detector Array , is a new experiment at the INFN National Gran Sasso Laboratory (LNGS) for the study of the neutrinoless double beta decay of ^{76}Ge; the Phase I physics run has started in December 2011. It is taking advantage of a new shielding concept by operating bare Ge diodes – enriched in ^{76}Ge – in high purity liquid argon (LAr) supplemented by a water shield . The paper provides an overview of the design and performance of the LAr cryostat and its associated infrastructure, as well as a discussion of specific safety issues resulting from the operation of a cryostat in a large water tank.***

1. Introduction

Neutrinos are electrically neutral elementary particles of tiny mass. Next to photons, they are the most abundant particles in the universe; however, they are difficult to detect because they interact with matter very weakly. Thus big and sensitive detectors with excellent shielding against the environ- mental radioactive background are needed to study the properties of the neutrinos and to reveal their very nature. A still hypothetical but most interesting feature of neutrinos is that they could be their own antiparticles which – if true – would establish ΔL=2 lepton number violation with far reaching consequences for theory providing e.g. support for modern theoretical explanations of the baryon asymmetry in our universe.

Figure 1 - Model view of the GERDA experiment in Hall A of LNGS showing the germanium detector array (1), the LAr cryostat (2) with the internal copper shield (3), the surrounding water tank (4), the clean room (5) and the lock (6) through which the Ge detectors are deployed into the cryostat. For clarity, the detector array is enlarged.

The GERDA experiment [1, 2, 3], see Fig. 1, is studying this topic by searching for the neutrinoless double beta-decay (0νββ) of ^{76}Ge in which the ^{76}Ge nucleus of charge Z=32 decays in ^{76}Se with charge Z=34 and two electrons. This process can be viewed as the familiar 2νββ double beta-decay, $Z \rightarrow (Z+2)+2e^{-}+2\bar{\nu}$, where the two anti-neutrinos $\bar{\nu}$ annihilate. The experimental signature for 0νββ decay would be the observation of a peak at 2039 keV in the energy spectrum of the $2e^{-}$ final state. The GERDA experiment uses diodes fabricated from high purity Ge material enriched in ^{76}Ge which are outstanding ββ detectors being simultaneously the 0νββ decay source and a 4π detector with excellent energy resolution. Since 0νββ decay would be extremely rare (half-life $>10^{25}$ y) the Ge diodes need to be effectively shielded against external background. This is accomplished by locating GERDA in the LNGS underground laboratory below an overburden of about 3400m water equivalent of rock to suppress cosmic rays as well as by operating the bare Ge diodes in high purity LAr supplemented by a 3 m thick water shield to suppress the environmental radioactive background by more than eight orders of magnitude. The goal for the Phase I of GERDA is a background index (BI) in the region of the 0νββ peak of 0.01 counts per (keV·kg·y) which is 10 times better than achieved by any previous experiment, Phase II aims at a further reduction of the BI by a factor of 10.

2. Cryostat

The purpose of the GERDA cryostat is twofold: (i) a container for the cryogenic liquid in which the Ge diodes are operated, and (ii) an efficient shield against the external radioactive background. The second issue calls for an optimized design [4] taking into account the medium in which the Ge diodes are operated, liquid nitrogen (LN2) or argon, as well as the thickness of the water layer. In addition, all major construction materials need to be screened w.r.t. their intrinsic radioactivity with ^{228}Th being the most relevant isotope.

Materials, ^{228}Th radiopurity	
Vessel, compensators	1.4571 <0.2 - 5 mBq/kg
Multilayer insulation	al. polyester <10mBq/kg
Pads	Torlon <5 mBq/kg
Internal shield	OFRP copper 20 μBq/kg
Geometry	
Overall height x diameter	8.89 x 4.20 [m]
Neck height x inner diameter	1.72 x 0.80 [m]
Nominal volume	64 [m^3]
LAr fill level rel. to floor	6.81 [m]
Masses	
Empty vessel	~30 [t]
Max. load inner vessel LAr/Cu	90 / <48 [t]
Pressures	
Inner vessel max. press.	2.5 / -1. [barg]
Outer vessel max. press.	3.6/ -1.8 [barg]
Cryostat operating press.	0.3 [barg]
Multilayerinsulation	
Number of layers	20-40
Thermal loss	<300 [W]
Active cooling power	~500 [W]
Construction code	AD2000, EN 729-2
Fraction of x-rayed welds	100%
Earth-quake tolerance	hor. / vert 0.6g

Figure 2 - Characteristics of the GERDA cryostat, and its cross section with active cooling system (7), manifold (8) and the interface (9) to the lock consisting of a bellow and a DN630 shutter. The tiny red rectangles show the locations of the Torlon support and alignment pads of the inner vessel. The bellow in the neck of the inner vessel for compensating thermal shrinkage is barely visible. Detailed drawings are available at [5].

Various design options have been evaluated including a spherical superinsulated stainless steel vessel for LN2 of 11.5 m diameter (too large and expensive), and a custom designed flat bottom tank with styrene insulation and internal Pb lead shield (undesirable thick cold Pb shield, expensive). The optimum choice, an electron-beam welded superinsulated cryostat from low-radioactivity OFE copper (<20 µBq/kg ^{228}Th) for LN2 could not be realized because of an unexpected increase of cost.

The final solution consists of a double-walled superinsulated stainless steel cryostat with an internal copper shield, see Fig. 2; this choice implies that LAr has to be used as cryogenic shield to obtain the desired background suppression [4]. The cryostat has a nominal capacity of 64 m^3; its weight and overall dimensions allowed it to be transported by flat bed truck from the manufacturer to the LNGS. The inner vessel is supported by eight Torlon pads and Inconel Belleville springs at the bottom. The only opening of the cryostat is in the neck. A manifold on top of the neck is connected by a bellow and a DN630 ultra high vacuum shutter to the lock and provides the interface for all tubing and cabling. To exclude leakage of radon from the atmosphere into the cryostat, only metal-sealed joints and valves are used; in addition, the cryostat is operated at slight overpressure of about 300 mbar. Nevertheless, the design and construction of the cryostat is subject to the European Pressure Equipment Directive PED 97/23/EC since both inner and outer vessel are designed for maximum pressures of 2.5/-1.0 barg and 3.6/-1.8 barg, respectively.

Based on Monte Carlo simulations [4] the cryostat is designed to accommodate an internal cylindrical copper shield of almost 50 tons in order to reduce the contribution from external gamma radiation to a BI of less than 10^{-4} counts per (keV·kg·y). However, by identification of batches of stainless steel of unexpected low ^{228}Th radioactivity of less than 0.2 up to 5 mBq/kg [6] the amount of cooper could be reduced to 16 tons corresponding to a shield thickness of 3 and 6 cm, respectively.

2.1. State-of-the-Art

The GERDA setup represents the first realization of a proposal [7] to operate bare Ge diodes in a cryogenic liquid (LN2, in fact) for improved background performance. In this context, the idea to trade part of the cryogenic shield by a water layer has been discussed previously in [8]. Since the successful implementation of the GERDA experiment similar experimental arrangements are considered or being built for dark matter searches, e.g. at LNGS or SNOLAB, Canada.

2.2. Infrastructure

The infrastructure needed to operate the cryostat includes storage tanks for LN2 and LAr (~6 m^3 each), a 30 m long tri-axial line from the storage tanks to a valve box close to the cryostat with a particle and radon filter in the LAr line, an ullage vessel of 2.6 m^3, an active cooling system for the LAr in the cryostat, a pumping system for the insulation vacuum, a heater for the exhaust gas, sensors for temperature, pressure, and fill level, control devices for pressure and flow of cryoliquids, as well as safety devices to prevent overpressure. With one exception (see below), the total system is supervised by a S7 based programmable logic controller (PLC) which is supplemented by a web interface for easy remote access (Fig.3, for a sample page). To warrant enhanced reliability and safety, all the sensors and the critical control and safety devices are implemented redundantly. All data are stored in a data base which can be accessed by the common GERDA slow control system. Below, we provide a few details for some components; additional details will be given in section 3.

The active cooling system [9] serves to avoid losses of LAr during cryostat operation and LAr refills; it has to compensate a thermal loss of about 300 W and is realized by two LN2 evaporators. The larger one is mounted in the main volume immediately below the neck (Fig. 2); it provides a stable convection of sub-cooled LAr in the cryostat; the second one is located in the neck and used to adjust the working pressure at the liquid-vapour interface. The LN2 flow through the evaporators is fine-tuned such that the vapour fraction dominates the flow in order to avoid boiling in the lower parts of the evaporators. In fact, no detrimental micro-phonic effects have showed up in the Ge detectors, so far. The daily consumption is less than 300 ℓ of LN2.

The heater for the argon exhaust gas can accept a maximum flow of 10 000 m^3 gas per hour. Being of the TEMA type BEU, the rather compact device uses the LNGS cooling water as heating medium, or - in case of emergency – the water stored in the GERDA water tank (Fig. 3).

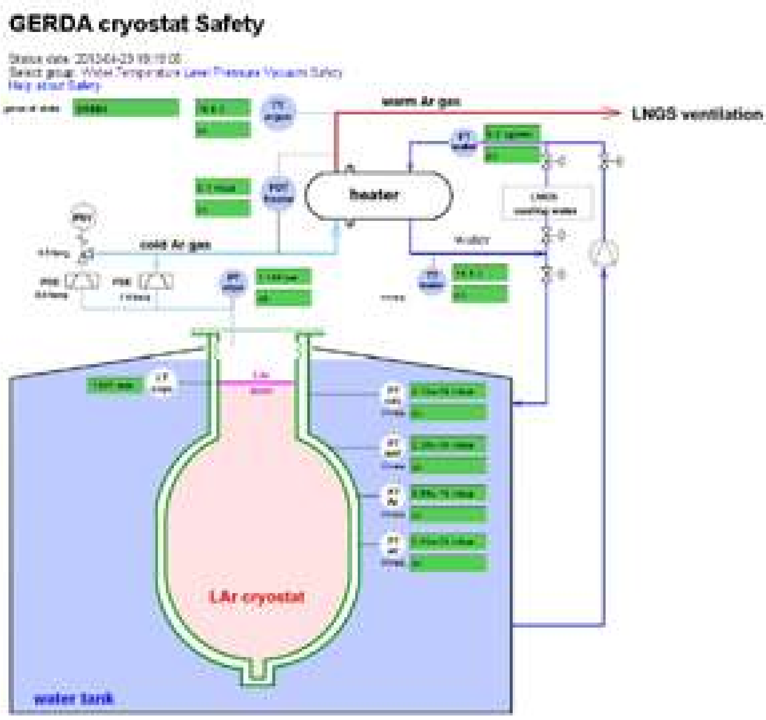

Figure 3 - Safety status of the GERDA experiment at 18:19:05 on April 23, 2012. The safety relevant parameters are cryostat pressure, fill level, residual and total vacuum pressures, the flow rate and the temperature of the LNGS cooling water, as well as the temperature of the argon exhaust gas. The flow rate of the argon exhaust gas is deduced from a measurement of the differential pressure at the input and output of the heater.

Since a S7 PLC cannot be considered to be an ultra-high-reliability device, the most critical safety-relevant task, the control of the cryostat's operating pressure, has been sourced out to two independent autonomous devices with a MTBF of more than 200 years.

The temperatures in the cryostat are monitored throughout the volume and on the surfaces of the evaporators by more than 11 pairs of Pt100 sensors. Even higher redundancy is obtained by using various devices for the determination of the fill level - swimmer, radar, Pt100 sensors or condensation tubes – all of which but the last showing good performance.

2.3. Performances

At the manufacturer's site, the acceptance tests of the cryostat included the pressure equipment tests required by law for inner and outer containers as well as Helium leak tests for both containers which established the absence of leaks at the level of 10^{-7} mbar/(ℓ·s). Evaporation tests with LN2 at the manufacturer and at LNGS (after installation of the copper shield) yielded similar rates below the specified value of 300 W. Pumped with a turbo pump of 550 ℓ/s, the insulation vacuum dropped from 10^{-5} mbar to $2\cdot10^{-8}$ mbar after cool down. The residual outgassing (or leakage) rate has been determined to be in the order of 10^{-7} mbar/(ℓ·s) so that the turbo pump is kept running.

A non-standard yet crucial performance figure is the radon (^{222}Rn) emanation in the cryostat's inner volume. One possible source of Rn emanation has been avoided by TIG welding with screened non-thoriated electrodes. The measurements have been performed with the MoREx apparatus [10] and ultra-low background proportional counters. After repeated cleaning cycles the excellent value of (14±2) mBq could be achieved. After the installation of the copper shield this value had doubled although the NOSV copper had been freshly produced, etched at elevated temperature after rolling and installed under grey room conditions. After the installation of the remaining infrastructure through the cleanroom on top of the cryostat, the Rn emanation value had increased to (55±4) mBq.

The cryostat has been filled with LAr in December 2009, and since then its operation is very stable and smooth. After the commissioning of the active cooling system in January 2010 practically no refill of LAr was needed due to a negligible evaporation rate.

2.4. Safety aspects

As the cryostat is operated in a tank filled with about 580 m^3 of water special safety measures have been taken to mitigate the specific risks due to the leakage of one of the two cryostats shells. The mixing of water and LAr and the resulting rapid phase transition has been evaluated by independent experts to be most unlikely (10^{-8} ev/y) since design and construction warrant the 'leak before break' principle, and the two stainless steel containers are mutually independent. To limit in worst case of leakage the exhaust gas rate to less than 10 000 m^3/h, that is the ventilation capacity of LNGS, both inner and outer vessel carry individual thermal shields of polycarbonate and extruded polystyrene, respectively. In addition, a large number of accidental events has been studied in FMECA and HAZOP analysis with acceptable results.

Specific mitigation measures are implemented in both the design and construction including the absence of penetrations in the cryostat below the water level (8.4m), earthquake tolerance up to 0.6 g, and certified pressure vessel performance for 1.5 bar while operation is well below 0.5 bar. Enhanced safety is due also to the redundant implementation of all critical elements including rupture disks, pressure control and the additional monitoring of the insulation vacuum with a residual gas analyser for most sensitive and early identification of water, air or argon leaks. All system parameters, see Fig. 3 for the safety relevant ones, are monitored continuously by the PLC which in case of an unexpected pressure increase would start automatically the drainage of the water tank at up to 80 ℓ/s; thus the water tank would be emptied completely in less than 2 hours.

In addition, safety has been enhanced and risks mitigated by organizational measures including the engineering of an evacuation plan, the allocation of oxygen monitors and masks, and the locking of the hall crane such that it can no longer enter the GERDA site.

3. Conclusions

The GERDA experiment is the first realization of a novel shielding approach using a cryostat for LAr that is immersed in a large water tank, a concept that has been adopted by other experiments in the meantime. The associated risks have been carefully analysed and mitigated. The major construction materials of the cryostat have been all screened and adequate cleaning and assay techniques have been developed. The cryogenic setup is running since December 2009 without any problem. The present results from the GERDA Phase I physics run indicate that the background goal of 0.01 counts per (keV·kg·y) in the region of the $0\nu\beta\beta$ line has been almost reached.

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Vacuum and Cryogenics in Neutrino Physics: LAGUNA-GLACIER

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Abstract - ***GLACIER is a large liquid argon time projection chamber to be host in an underground observatory, with the goal of studying proton decay, neutrino astrophysics and CP-violation studies in the lepton sector. The concept is scalable to very large masses, of the order of 100 kton.***

Possible underground sites in Europe have been and are under study within the FP7 LAGUNA project and the follow up LAGUNA-LBNO project (together with the study of the neutrino beam).

1. Introduction

Looking at the future of neutrino long-baseline experiments, T2K and NOvA can be considered as "Phase I" experiments, with good sensitivity to the "small" mixing angle θ_{13}, but with limited sensitivity to the effects of CP violation in the neutrino sector. The next generation of "Phase II" experiments is expected to have significant discovery potential for CP violation, and capability to establish the mass hierarchy. In order to do so, a "Phase II" experiment must be designed to have very large statistics, excellent background rejection and very good energy resolution, to measure very precisely the oscillation pattern as a function of neutrino energy. The detector must therefore be very massive, and must have the capability to accurately reconstruct neutrino interactions for energies of about 1 GeV. A liquid argon time projection chamber (LAr TPC) provides high efficiency for ν_e charged current interactions (the "signal" events for CP measurements), with high rejection power against ν_μ neutral and charged currents backgrounds in the GeV and multi-GeV region. In particular, excellent electron / π^0 separation comes from fine longitudinal segmentation (few % of a radiation length), and a transverse segmentation finer than the typical spatial separation of the 2 γ's from the π^0 decay. The e, μ / π, K, p identification capability is also excellent down to energies as low as few tens of MeVs. Embedded in a magnetic field, a LAr TPC gives the possibility to measure both wrong sign muons and wrong sign electrons samples in a neutrino factory beam. Unlike Water Cherenkov detectors, detection and reconstruction efficiencies do not depend much on the volume of the detector, therefore a direct comparison between the near and far detector is possible (apart from flux extrapolation). A very large LAr TPC as the one needed in a "Phase II" long baseline neutrino experiment would also have unprecedented sensitivity to proton decay and neutrinos from astrophysical and terrestrial sources (solar and atmospheric neutrinos, neutrinos from stellar collapse, or neutrinos from Dark Matter annihilation).

GLACIER (Giant Liquid Argon Charge Imaging ExpeRiment) is a proposed multi-kton LAr detector.

The basic concept of GLACIER was originally put forward in [1], where many details can be found. The key points of the proposed design are:

- Single module non-evacuable cryogenic tank based on industrial liquefied natural gas (LNG) technology, of cylindrical shape with excellent surface/volume ratio;
- Simple, scalable detector design, possibly up to 100 kton;
- Single very long vertical drift (up to 20 m) with full active mass;
- For the readout structure, a very large area, up to 3 500 m^2, instrumented with Large Electron Multipliers (LEM) operating in double phase argon (liquid-vapor);
- Possibly immersed visible light readout for Cherenkov imaging;
- Possibly immersed (high Tc) superconducting solenoid to obtain a magnetized detector;
- Reasonable excavation requirements (<250 000 m^3).

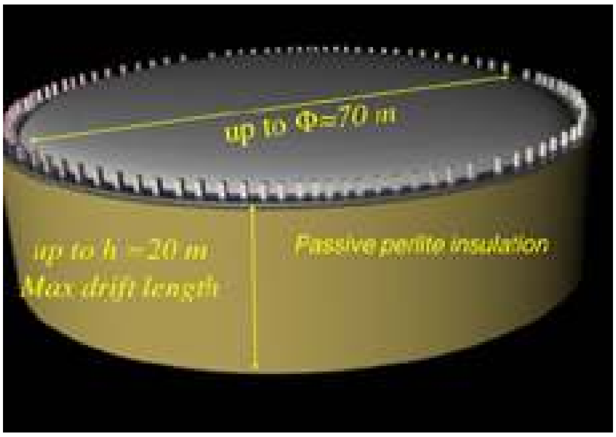

Figure 1 - Artist's view of the GLACIER detector (100 kton).

2. Vacuum

Cryogenic detectors for proton decay searches and neutrino physics all use liquid argon as detector medium (other liquefied noble gases as Xe, Kr, Ne and He are of interest in different applications). So far, large-scale liquid argon detectors have been housed in a vessel that is at the same time a vacuum chamber and a cryostat. The largest single vessel built and operated so far (ICARUS T300) has a volume of ~250 m^3. Future projects foresee a scale-up by a factor of ~300 (100 kton detector). During operation, the vessel is filled with liquid argon. Vacuum for cryogenic detectors for proton decay searches and neutrino physics covers three separate functions:

- Remove air from the vessel prior to cooling and filling with liquid argon;
- Remove outgassing (water and other elements) from the detector materials and the vessel walls (baking is also sometimes performed);
- Verify the integrity (tightness) of the system itself.

It is debatable whether future generation detectors will make use of UHV vessels. The main concerns are cost and feasibility of such a large vacuum chamber, including underground operation.

Even more important, it is increasingly clear that non-vacuum vessels may work as well. An alternative being pushed is the use of a non-vacuum vessel based on the technology developed for liquefied natural gas (LNG) tanks.

2.1. State-of-the-Art & Foreseen performances

The State-of-the-Art, in terms of vacuum for large liquid argon detectors, is given by the two ICARUS T600 modules. Each semi-module (T300) was pumped to a vacuum of about 10^{-4} mbar, and the operation took about 10 days; details about the vacuum procedure can be found in [2]. The goal, at least for the GLACIER design, is to abandon all together the approach of using a UHV vessel and a cryostat, and to host the detector in a non-vacuum cryostat. Preliminary results are reported in [3].

3. Cyogenics

A very large liquid argon detector intrinsically requires massive cryogenics, being liquid argon a cryogenic liquid. The basic thermal properties of liquid argon are summarized in Table 1. A very important requirement for a liquid argon detector, which must be built in the cryogenics, is an extremely low level of contamination due to electronegative impurities (O_2, water…) in the argon medium.

Temperature (1 bar)	87.2 K
Density	1.396 g/cm^3
Heat capacity [Cp] (boiling point)	0.2670 cal/g K
Thermal conductivity (boiling point)	3.00×10^{-4} cal/s cm K
Latent heat of vaporization (boiling point)	38.4 cal/g
Gas/liquid ratio (1 atm, 15°/BPT)	835 vol/vol

Table 1 - Thermal properties of liquid argon.

3.1. State-of-the-Art

The ICARUS experiment sets again the current standard for existing massive LAr detectors, being the only large LAr detector actually in operation in an underground location (LNGS, Italy). Many details can be found in [2]. The ICARUS T600 experiment is made of two vessels, each containing about 300 tons of liquid argon. The mass scale required for future experiments is much larger, and a new approach to cryogenics is likely needed. The foreseen performances/requirements for a GLACIER detector are listed in the next section.

3.2. Foreseen performances

Cryostat

The cryostat must be adequate for holding ~100 kton of liquid argon in an underground location. Examples of such cryostats are available from the LNG industry, but experience related to deep underground installations is lacking. Another very stringent requirement is on leak tightness of the cryostat, due to the fact that the oxygen contamination of the liquid argon must be kept at the part-per-trillion (ppt) level.

Cooling

Once the detector is full of liquid argon, there is an estimated heat load of about 80 kW. Therefore a cooling system must be designed to liquefy the evaporated liquid argon back into the vessel. Again, requirements for an underground installation must be taken into account.

Cryostat purging

As discussed in the vacuum section, the cryostat must be purged from air to few part-per-billion of residual oxygen. If the cryostat is not a vacuum vessel, this must be obtained by flushing the vessel with argon gas, which is continuously purified.

Cryogens handling

Handling of 100 kton of liquid argon is critical. Several items have to be considered: procurement, delivery, and storage. Moreover, the purity (at the level of 1 ppm oxygen contamination, or better) of the liquid argon must be checked on small batches to avoid large scale contamination of the liquid argon. One critical aspect that needs to be addressed is the transfer of the liquid argon from the surface to the deep underground location.

Liquid argon purity/purification

In order to have ultra-pure liquid argon, with oxygen contamination at the ppt level, several aspects have to be considered:

- Integrity of the vessel, which must have a leak rate compatible with the purity requirements;
- Outgassing of the materials inside the vessel;
- Virtual leaks.

Once these aspects related to the cryogenic vessel have been considered and accounted for, there are at least three fundamental issues related to liquid argon handling:

- Argon purification while filling to bring the oxygen contamination down from the ppm level to the ppt level. To do so, appropriate filters have to be developed.
- Purification and recirculation of the argon gas and of the evaporated argon (prior to recondensing inside the vessel). For this purpose, an efficient gas recirculation system with clean, leak tight pumps is required, together with appropriate filters.
- Purification and recirculation of the liquid argon. Purifying liquid argon directly, without going through the steps of evaporation and recondensation, is much more efficient, and is fundamental in order to keep the purity of ~100 kton of liquid argon. Clean pumps, compatible with cryogenic operation, are needed to force the circulation of the liquid through purification cartridges.

4. Conclusions

The proposed GLACIER detector is giant liquid argon time projection chamber for neutrino physics and proton decay, with a well defined conceptual design intended to bridge the gap between the existing large liquid argon detectors, like ICARUS, and the next generation detectors which need to be much more massive. From the point of view of vacuum and cryogenics, the basic idea is to rely on existing technology developed for LNG, which does no contemplate vacuum and offers the possibility to handle large quantities of cryogenic liquids (at the 100 kton scale). In this respect the main challenges are the underground location and the extreme purity required for the liquid argon medium.

Part of the GLACIER activities are within the LAGUNA-LBNO FP7 project [4].

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The XENON Experiment and the DARWIN Project

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for XENON collaboration and DARWIN consortium

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Abstract - ***Dark matter direct detection experiments based on noble liquid detectors are among the most promising strategies to determine the nature of dark matter, by looking for a theoretically well motivated candidate, the Weakly Interacting Massive Particle (WIMP). Based on the success of the XENON100 experiment, XENON1T, which will contain 2.4 t of liquid xenon, is being constructed to continue the WIMP hunt, probing deeper into the theoretically favored region. DARWIN (dark matter wimp search with noble liquids), a detector R&D and design project for a dark matter facility with multi-ton liquid xenon and/or liquid argon in Europe, will continue to the next generation of dark matter detectors, covering an even larger part of the predicted regions, and in the event of a dark matter discovery, allowing to perform "WIMP spectroscopy" to constrain its properties such as mass and interaction cross section.***

1. Introduction

In the last decades, more and more evidence was found that the matter of our universe is dominated by a so far unknown component. Astrophysical observations show that our universe is made of 4% atoms, 23% dark matter and 73% dark energy. No dark matter particle has been observed so far. However, the generic Weakly Interacting Massive Particle (WIMP) could have been produced with the correct abundance in the early universe and it is independently predicted by beyond-standard-model theories such as supersymmetry or extra dimensions. WIMPs can interact gravitationally and very weakly with ordinary matter, the predicted interaction rates are thus ultra-low and the energy deposits below a few tens of keV, therefore they are extremely difficult to detect.

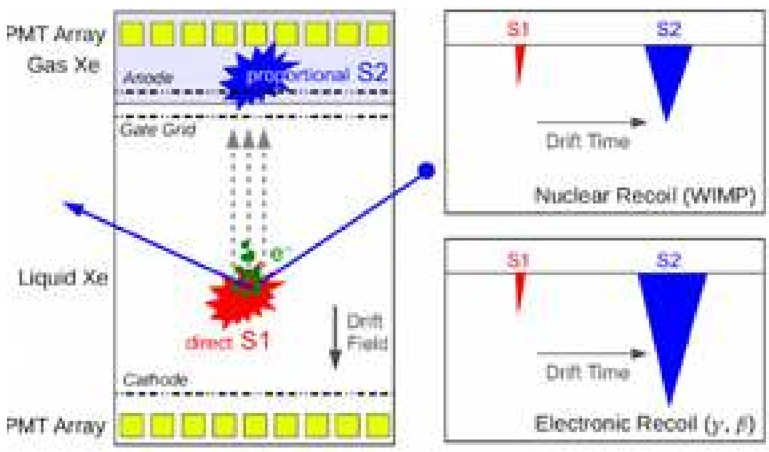

Figure 1 - The principle of a typical two-phase TPC.

In the competitive search for WIMPs, one of the leading experiments is the XENON Dark Matter Project, which is a phased program aiming at a progressively improved sensitivity by a series of dual-phase time projection chambers (TPCs): XENON10, XENON100 [1], and XENON1T, the numbers referring to the order of magnitude of target mass in kg / ton. Figure 1 presents the principle of a typical dual-phase liquid xenon (LXe) TPC.

Both the scintillation and ionization produced by radiation in the sensitive LXe volume are detected. Ionization electrons drift toward the anode due to an applied electric field but once they reach the liquid surface, they are extracted into the gas phase where they emit proportional scintillation light. The direct scintillation (S1) and the proportional scintillation (S2) are detected with Vacuum Ultraviolet (VUV) sensitive photomultiplier tubes (PMTs), located in the gas and in the liquid. The (x,y) event localization is provided by the proportional light pattern in the PMTs in the gas; the third coordinate, along the drift direction, is inferred from the time difference between S1 and S2 and the known electron drift velocity in the liquid. The ratio of the S2 yield over S1 yield is used to distinguish hypothetical WIMPs and background events mostly due to radio-impurities. In 2011, the XENON Collaboration has presented results from the direct search for dark matter with the XENON100 detector, which leads to the most stringent limit on dark matter interactions today [2]. XENON1T, the next step of XENON project, which will use 2.4 ton of xenon in total, is already under construction and will start data taking before 2015.

If current predictions from SUSY theories are correct, XENON1T has a high potential for measuring a WIMP signal and claiming a discovery (Fig. 2). The next step should then be focused on the identification of the WIMP properties, which requires sufficient statistics from a WIMP signal. To obtain at least 50 dark matter events, the target mass has to be at least 5 tons of LXe or 10 tons of LAr (Fig. 3). DARWIN is an international consortium which brings together experts from the LAr experiments WARP [3], ArDM [4] and DarkSide [5] and from the XENON experiment in order to design Europe's next-to-next generation dark matter facility based on LXe and/or LAr.

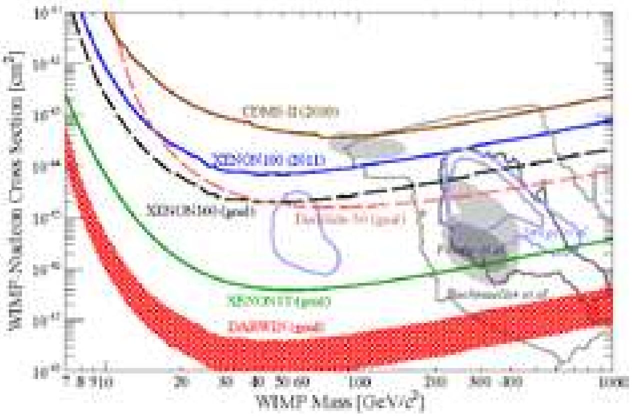

Figure 2 - DARWIN's sensitivity goal for spin-independent WIMP nucleon cross sections, future goals and updated theoretical predictions from supersymmetry [8].

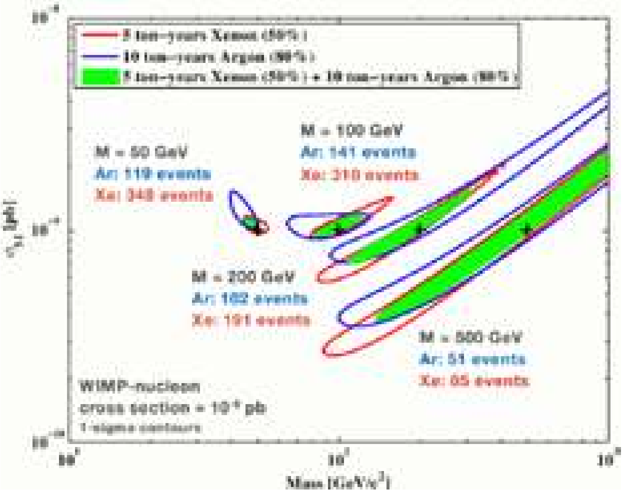

Figure 3 - Estimation of observed WIMP events with 5 ton-years xenon and/or 10 ton-years argon target [8].

Direct dark matter search detectors are complex experimental setups placed in underground laboratories to ensure ultra-low cosmic backgrounds. The technical requirements of these experiments employ well established techniques from vacuum and cryogenic technology and call for the implementation of new and novel approaches as well.

2. Vacuum

The vacuum techniques required for direct dark matter research using LXe/LAr dual-phase noble TPCs are mainly constrained by the following requirements:

- Before filling the cryostat with LXe (LAr), the surface inside the cryostat has to be cleaned to reduce the impurities that desorb from the materials. Pumping the cryostat to ~10^{-6} mbar at room temperature for several days is commonly used to reduce the outgassing due to desorption from the treated surface.
- To verify the leak-tightness of the cryostat, a leakage test has to be performed (usually with argon to prevent helium contamination of the PMTs).
- To reduce radon emanation from the materials which have direct contact with xenon (argon), the components of detector have to be baked in high temperature (if possible) with continuous pumping.

2.1. State-of-the-Art

One key function of the detector is the drift of electrons in the liquid xenon, which is impeded by trace amounts of contaminants, such as water and oxygen. These must be reduced to the level of one part in 10^9, and maintained at that level on the timescale of years. Another challenge is the radioactive impurities in the selected materials have to be as low as possible in order to reduce the background events, since the event rate of the WIMP signal is extremely low. The materials used for double-wall insulated cryostat and TPC have to be made using low-radioactive material with special surface treatment to reduce the outgassing and background from radiation. The sealing and welding have to be checked carefully to avoid any leakage. Concerning the selection of valves, viton and other elastomers are avoided as materials of valves since they have higher radon emanation.

2.2. Foreseen performances

In order to achieve the required pre-cleaning by pumping for a ton-scale detector, the pumping system has to provide a pumping speed of ~1 000 l/s. Several pumps may be required to distribute the effective pumping speed in different positions within the detector, since some components are connected by lines with low conductivity. Turbomolecular pumps will be used before filling xenon(argon) in order to reduce the outgassing rate. In case of emergency or cooling failure, a powerful evacuation system is necessary to release several tons of xenon/argon in a short period of time, avoiding a potential explosion due to cryogenic failure.

3. Cryogenics

The cryostat not only has to hold several tons of LXe/LAr in an underground facility, but also has to be made of a material with very low radioactivity to reduce backgrounds. Dedicated shielding surrounding the cryostat, which reduces the background from cosmic-rays, has to be designed according to the depth of underground facility. Special surface treatments (e.g. electropolishing, baking, degreaser) have to be performed in order to reduce the outgassing rate, not only because the electronegative impurity level (oxygen-equilibrium) of LXe(LAr) must be reduced to part-per-trillion (ppt) level to obtain high charge yield, but also to avoid the radioactive impurities (e.g. krypton 85, radon) which cannot be removed easily by the purification circuit. The successful operation of the cryogenic system is also quite challenging, especially concerning a continuous purification, a fast recuperation in emergency cases and the storage of the xenon. All operating devices must be designed for a long term operating period with minimal maintenance and all heat loads must be minimized. Additionally, the cryogenic system is designed with redundancy to ensure unimpeded detector operation in the cases of emergencies and routine maintenance.

3.1. State-of-the-Art

One key component of the xenon experiment is the remote cooling tower. A pulse tube refrigerator (PTR) provides the required cooling power to liquefy the gaseous xenon. The liquid xenon is collected by a funnel and runs through a dedicated, superinsulated pipe into the detector. The decoupling of the cooling tower and the detector has two big advantages. First of all the trace amounts of radioactivity contained in the cooling devices (motor valves, He buffer tank, connecting lines) which limit the sensitivity of the detector, are kept as far away as possible from the detector. Secondly this design allows to service or to replace the PTR without exposing the inner detector volume to air. A liquid nitrogen coil is equipped in order to provide an emergency cooling in case of power failure.

3.2. Foreseen performances

For the next generation of dark matter experiments like XENON1T the continuous purification of the xenon is a large challenge due to cryogenic aspects. To enable a sufficient purification in the gas phase about 100 standard liters per minute (slpm) of xenon must be evaporated, purified and liquefied again. This leads to a required cooling power of more than 1 kW. Therefore the use of a heat exchanger is intended to cool down and even liquefy the purified gas before running back into the detector [6]. Since only 10% of the required cooling power is needed to cool down the gas from ambient temperature to 180 K but 90% is needed to liquefy the gas, it must be ensured that the phase transition takes place inside the heat exchanger. This can be achieved by providing a pressure difference and hence different boiling points between both lines and by using the Joule Thomson effect while expanding the xenon.

The key unit of the storage and recovery system is a high-pressurized liquid xenon storage tank with foam insulation [7]. The tank is designed for a pressure up to 65 bar and therefore allows the storage of gaseous xenon. A liquid nitrogen cold head will be mounted on the top of the tank, providing a net cooling power of about 1 kW in order to allow a fast LXe recuperation (~800 kg/h) from the detector. The storage tank can also provide a fast filling of the detector by using a built-in fast self-pressurization system to push the liquid xenon into the detector.

4. Conclusions

Noble liquid dark matter detectors deliver the most stringent limits on the interaction of dark matter particles with standard matter today. The technology offers the opportunity to build massive, homogeneous and position-sensitive detectors with a realistic chance of a discovery in the near future and the potential to determine the properties of dark matter should it be composed of WIMPs [9]. The construction of XENON1T will start in late 2012, the funding, which comes from Europe, USA and Israel, is mostly in place. DARWIN has received R&D funding through the first ASPERA common call, a proposal for a continuation will be submitted after the end of the current phase.

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DARWIN homepage: http://darwin.physik.uzh.ch.

XENON homepage: http://xenon.astro.columbia.edu/index.html.

5. Appendix

XENON1T Schedule:

- Design and R&D activities: 2011/2012
- Prototyping (demonstrator, test-column): 2012/2013
- Construction at LNGS/ Commissioning: 2013/2014
- Start of Dark Matter search: 2014

DARWIN Schedule:

- Design and R&D activities: 2010-2013
- Prototyping: 2013-2014
- Construction and commissioning: 2015-2016
- Start of Dark Matter search: 2016

Technical Issues for the EURECA Experiment

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Abstract - ***We present an overview of the current design status of the EURECA direct dark matter search experiment, paying particular attention to the proposed cryogenic system. A ton of detective material comprising Ge bolometers and $CaWO_4$ scintillators will be cooled to 10 mK with a dilution refrigerator to provide the most sensitive cryogenic dark matter detector.***

1. Introduction

Current value of the mass-energy density of the universe estimate around 23% is in the form of dark matter [1]. Evidence for dark matter comes from a variety of sources, from the relatively small-scale galactic rotation curves [2], through to large-scale structure formation [3], and on the largest scales the temperature fluctuations in the residual heat from the big bang known as the cosmic microwave background radiation [1]. These observations combine with predictions made within particle physics of a new class of particles within a framework known as super symmetry (SUSY). Of these, the most likely candidate for dark matter searches is the neutralino, the lightest of the SUSY particles. The neutralino belongs to a class of particle given the generic name of a weakly interactive massive particle (WIMP) [4].

Many experiments around the world are currently competing to make the first direct detection of dark matter, e.g. [5, 6]. These operate with the basic principle of measuring the energy deposited in a detector from the interaction of a WIMP from within the halo of our galaxy with a nucleus of detector material. Detectors operate by minimising background noise and maximising detector mass and acquisition times thus increasing the probability of detection of an interaction between WIMP and detector. Most dark matter detectors operate by combining two out of the most common three possible detection techniques of measuring light, heat, or electronic charge. Since different particles produce different amounts of these quantities, the ratio between any two quantities provides a measure of the particle type enabling discrimination between the background electron recoils of alpha, beta and gamma particles from the nuclear recoils of neutrons and WIMPs. However, due to the finite discrimination power of these detectors, a reduction of the overall radioactive background is of paramount importance. Background events due to residual radioactivity are found in practically every material. The radioactive background within dark matter detectors occurs from a number of sources including the materials of detector construction, the immediate laboratory environment, atmospheric radon, and cosmic rays. The desire to reduce the last of these leads all direct dark matter detection experiments to be located in deep underground locations where an overhead covering of rock shields the experiments from cosmic rays, reducing the flux by up to six orders of magnitude. The deepest of these sites in Europe is the Laboratoire Souterrain de Modane underneath the Fréjus mountain on the French-Italian border. Access to the site, which affords a rock overburden of 1 700 m (4 800 metres water equivalent), is relatively easy provided by a horizontal road tunnel. The laboratory is due to be enlarged by the addition of a new cavern approximately four times larger in volume than that currently in existence, and it is into this that we plan to place EURECA – the European Underground Rare Event Calorimeter Array.

We plan to build a dark matter detector containing up to 1 t of detective material. The detectors will be a mixture of Ge heat and ionisation detectors, and $CaWO_4$ heat and scintillation detectors, all cooled to 10 mK. Ge detectors have given highly competitive dark matter search limits for the EDELWEISS collaboration [6], whilst $CaWO_4$ has been championed by the CRESST groups [7]. The existing search experiments of EDELWEISS and CRESST can thus be used as a test bed for the EURECA detectors and associated electronics. A variety of target masses such as these offer an additional benefit since the detection rate for WIMP-nucleon scattering depends on nucleon mass. Figure 1 shows the planned infrastructure layout for EURECA. The detectors will be housed within a cryostat, itself housed within a water tank providing at least 3 m thick of ultrapure water in each direction to shield against residual gamma and neutron radiation which exist within any environment. The water tank will be internally furnished with up to 200 photomultiplier tubes enabling the shield to act as an active veto against cosmic rays by detection of the Cherenkov radiation emitted by passing muons, formed as a product of cosmic ray interactions in the atmosphere. Since the water will be of ultrapure quality, necessary to limit the background of the detectors and to enhance light transmission for the detection of the Cherenkov light, the water tank will function as a cleanroom of class ISO 7 or better. Access to the water tank, and cryostat, will be solely through a dedicated ISO 7 cleanroom which will form the top floor of an adjacent four-storey building. Additional space within the building will be available for storage of delicate components, DAQ and slow control systems, and the recirculation plant for the ultrapure water. A separate water storage tank is necessary to contain the water which will be drained from the shield when access to the cryostat is required.

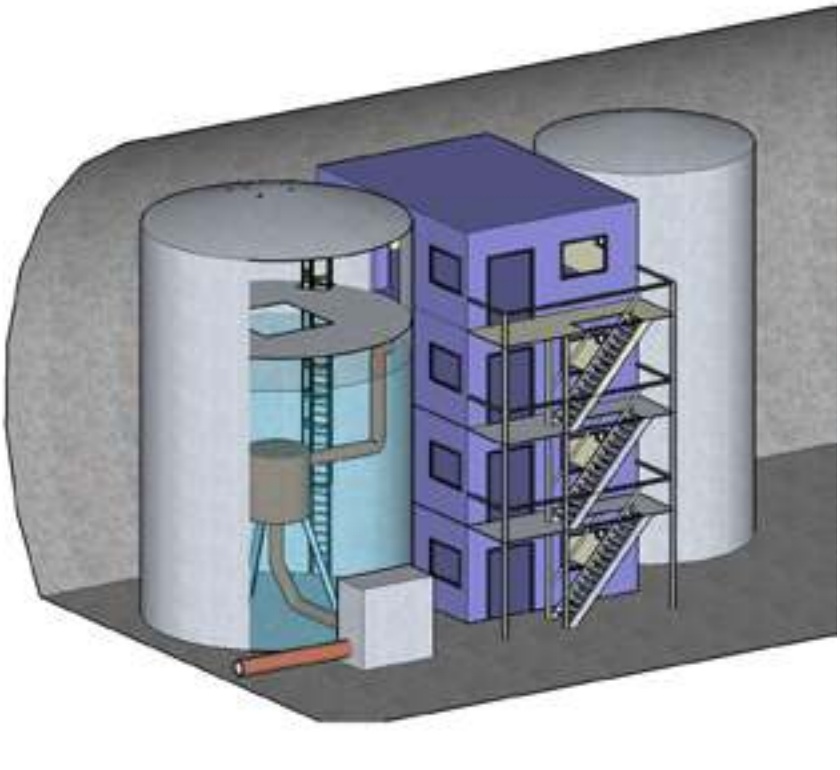

Figure 1 - Infrastructure for EURECA. The cryostat, shown in orange, is housed within the water shield tank, towards the left of the image. The proximity cryogenics are pictured in front of this tank. A building housing the cleanroom and other facilities separates the water shield tank from the water storage tank.

2. Cryogenics

The base temperature of EURECA will be at 7 mK to cool one tonne of detective material down to 10 mK. The low temperature will be achieved with a dilution refrigerator (DR) operating with a helium liquefier-based system to provide cooling to surrounding thermal shields.

2.1. Cooling system

A cooling power of 20 μW is expected at 10 mK due to the thermal relaxation on the bulk material at low temperature. Such high cooling powers have been reached in several past experiments, for example in the investigation of ^{3}He polarisation [8] and in the current development of the CUORE experiment [9]. The DR provides the necessary cooling power for the 10 mK stage, and also passively cools additional thermal shields to 80 and 500 mK. Further shields will be at temperatures of 1.8 and 60 K actively cooled by a helium liquefier, which also provides the initial precooling of the entire cryogenic system. A schematic of the cooling system is shown in Figure 2.

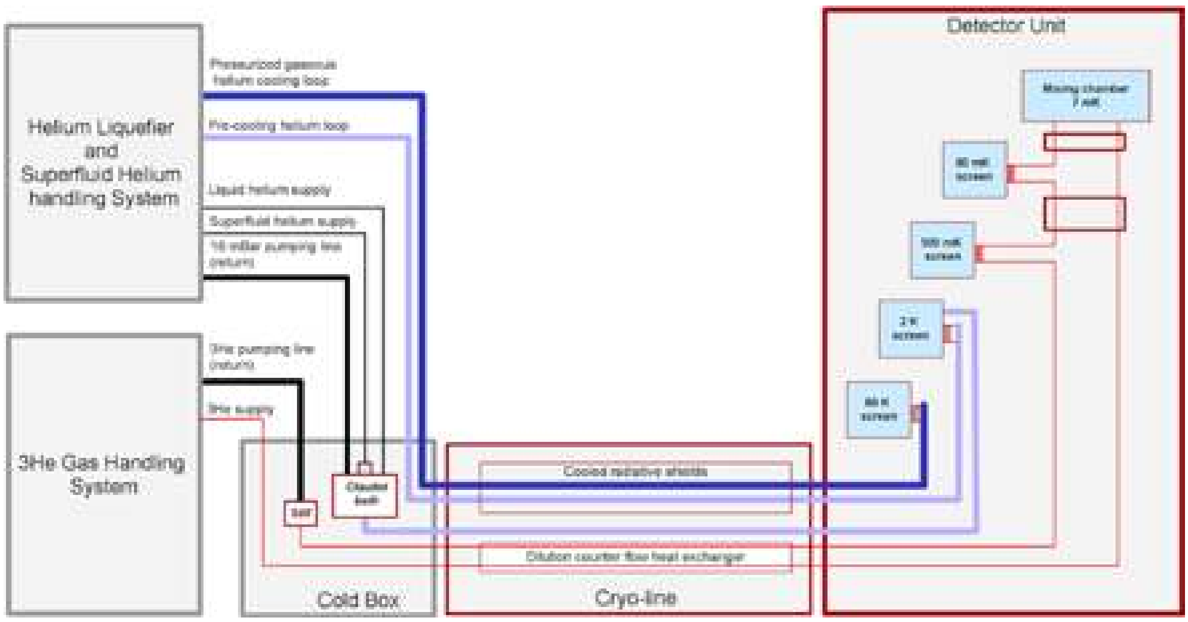

Figure 2 - Schematic of the EURECA cooling system.

Cooling of the 60 K shield is achieved with He gas at 40 K, pressurised to 7 or 15 bar. As an example, a flow of 20 g/s (5 mol/s) with a temperature elevation of 20 K gives a cooling power of 2 200 W. For the 1.8 K stage, a direct Joule-Thomson expansion of He to 16 mbar will create a 1.8 K bath which will then be combined with a Claudet bath [10] to provide pressurised HeII to the cryostat at 1.25 bar. The use of the Claudet bath avoids microphonic noise created by He boiling within the pipe. A cooling power of 10 W extracted from the superfluid helium heat pipe creates an evaporation rate of 0.05 g/s/W (0.013 mol/s/W). This flow is low compared to the 40 K cooling loop, allowing a direct extraction of 1.8 K vapours without circulation in the regenerative heat exchangers.

Hardware for the He refrigerator consists of a 5 m^3 gas tank for the closed cycle ^{4}He storage, a compressor and pumps. These items will be placed up to 100 m from the detectors, possibly in a separate underground cavern, to limit noise generated by the high level of vibration, particularly from the compressor. The only limit is the pumping speed for the low pressure flows (1.8 K He bath and dilution still). Additional items include heat exchangers, two gas-bearing turbo expanders, a Joule-Thomson valve and the control system contained with the cold box which will be sited immediately next to the water tank, approximately 10 m from the cryostat.

A suitable unit would be a modified HELIAL ML series fridge offered by Air Liquide [11]. This draws 75 W at full power, during cooldown, reducing to 50 W under part load once the system is at operational temperature. An additional pump will be required for the 1.8 K HeII within the Claudet bath.

The DR comprises a gas handling unit also placed with the compressor of the He refrigerator, a heat exchanger and still within the cold box, and the mixing chamber placed within the cryostat. Due to the 20 μW cooling power requirement combined with the low temperature of 7 mK, the performance of the dilution refrigerator depends on the properties of the sintered material used for the discrete counter-flow heat exchangers. The classical choice is to use sintered silver heat exchangers. However, commercial silver powders are known to have a radioactivity incompatible with the low background requirements. Electrical power drawn by the DR is likely to be up to 20 kW during cooldown, estimated at 15 days for 1 t of detective material from the helium refrigerator-cooled temperature of 2 K; reduced to 10 kW during low temperature operation. A design based on sintered Cu has been tested at CERN for EURECA [12] showing 10 cm^3 of sintered copper is required to achieve the requirements. The procurement of commercial powder and the sintering process will be fully characterised in order to have a detailed design for EURECA. Several commercial powders have been identified and will be characterised as part of the validation process which will include porosity characterisation and optimisation of the sintering process, measurement of the Kapitza resistance, and measurement of the radioactivity level.

2.2. Mechanical Infrastructure

Within the EURECA cryostat, we plan to cool 1 t of detective material to an operating temperature of 10 mK. Since measurement periods will be for a minimum of one year, the temperature of the detectors needs to be stable for periods in excess of this time. Unusual for standard cryogenic systems, perhaps the most stringent requirement for EURECA is that of the radiopurity of any materials contained within the outer shielding of the system. Additional constraints come from EURECA's proposed location of operation being within a confined space within an underground site. A minimal amount of cryogenic fluids should be used. Not only is delivery of liquid cryogens more difficult at remote underground sites, but also timetabling the necessary manpower to perform cryogenic refills is not as easy as in surface-based laboratories. A further issue with liquid cryogens is that of safety. He and N_2 expand by factors of many hundred when undergoing the phase transition from liquid to gas. Such expansion presents serious safety issues in terms of asphyxiation when working with liquid cryogens within confined spaces.

The Ge and $CaWO_4$ detectors will be placed within 19 towers arranged in a close-packed hexagonal array. Towers will be mounted from the top of the cryostat, with the $^3He/^4He$ mixing chamber of the DR situated below the detectors. Each tower will consist of twelve layers of detectors, each layer containing either up to six 800 g Ge bolometers, or up to twelve 300 g $CaWO_4$ scintillators. The size of the 280 mm diameter towers is in part dictated by the wish to reserve an option of installing different masses of detector; individual detector masses of up to 1 kg are being considered for both the Ge and $CaWO_4$ crystals, and each tower layer would retain the ability to hold several 1 kg detectors.

Figure 3 shows a schematic of the towers placed within the cryostat coldplate for the case of the Ge detectors. The 15 cm thick coldplate also functions as a radiation shield which, when used in conjunction with a similarly sized thickness of polyethylene, will limit stray radiation from the electronics. Gold wire will form the basis of the seal for each tower to maintain vacuum and achieve the necessary high thermal conductivity to the detectors. The mechanical force necessary to reach the excellent thermal contact necessary for the detector towers can be achieved by gold-plated copper springs. A design is also possible which utilises the differential thermal contraction between copper and titanium, and is currently being considered. For a force of about 100 daN/interface/tower, a thermal conductance of 10 mW/K is considered a good value at 4 K [13]. This limits the available power for the electronic readout at 4 K to around 800 mW. The same remark is valid for the lower temperature heat intercepts at 80 and 500 mK.

We plan for two separate vacuum chambers within the EURECA cryostat. One is maintained for the detectors, whilst the other contains the large portion of the cabling and for the electronics, mounted at the 1.8 and 60 K stages. This enables any radon released by the electronics not to provide background noise in the form of surface events on the detectors through radioactive release from radon progeny. The innermost detector vacuum is formed from the coldplate and additional shielding at around 10 mK.

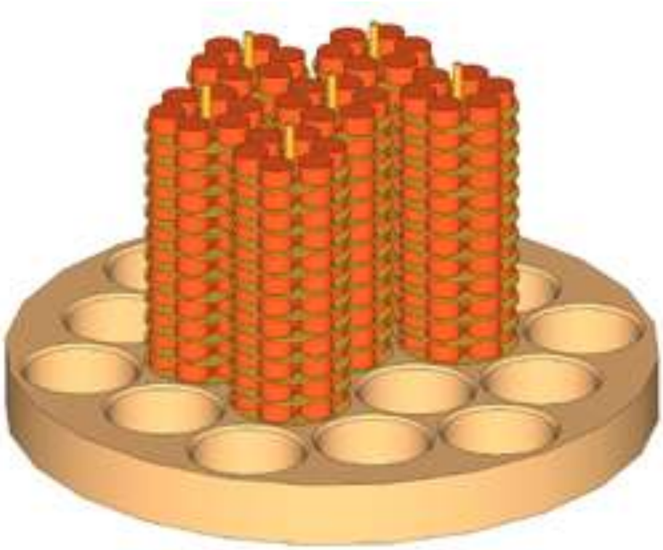

Figure 3 - Schematic showing positioning of the detectors within towers. Also shown is the cryostat coldplate.

3. Conclusions

EURECA, at the time of writing, is nearing completion of its Conceptual Design Review. It is the most sensitive cryogenic dark matter search experiment currently under design. The high sensitivity will be reached by use of a large target mass, uninterrupted long acquisition times, and low background materials of construction.

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The FAIR Vacuum and Cryogenics Systems

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Abstract - ***FAIR, the Facility for Antiproton and Ion Research is a new, unique, international accelerator facility for research with antiprotons, heavy ions and radioactive beams.***

The facility consists of two large accelerator rings (SIS100 and SIS300) with 1 100 meters in circumference, where approximately 80% of the beam line vacuum system is operated at cryogenic temperatures, a storage and accumulator ring complex (HESR, CR, RESR and NESR) with a length up to 550 m, which is operated at room temperature and the beam transfer system including the experimental beam lines with a length of about 2.5 km. Here we will describe the challenges of the approximately 6 km long beam vacuum system of the accelerators with operating pressures form 10^{-6} mbar down to 10^{-12} mbar. These low pressures are required to guarantee a long ion beam life time.

In addition to the beam vacuum system, there will be an isolation vacuum system of the superconducting magnets and cryogenic transfer and bypass lines. The required vacuum is in the range of 10^{-6} mbar.

1. Introduction

FAIR, Facility for Antiproton and Ion Research is a new international accelerator facility for experiments with antiprotons and ions. It will be built by an international community of countries. On 4th October 2010, the international owners founded the FAIR GmbH [1] and the countries' representatives signed a treaty under international law (Convention, Final Act).

The facility will be financed by a joint international effort of so far ten member states. The Federal Republic of Germany together with the State of Hesse is the major contributor to the project; the nine international partners - Finland, France, India, Poland, Romania, Russia, Slovenia, Spain and Sweden - pay about 30% of the construction costs.

The FAIR facility [2] will offer the possibility to provide high intensity, high quality beams of antiprotons and ions to study fundamental questions in the fields of nuclear structure physics and nuclear astrophysics with radioactive ion beams, hadron physics with antiprotons, physics of nuclear matter with relativistic nuclear collisions, physics of dense plasmas with highly bunched laser and ion beams, atomic physics, fundamental symmetries and applied sciences and accelerator physics. The goal of FAIR is to address fundamental questions in the above mentioned fields and topics such as:

- Structure of exotic nuclei far off stability
- Nuclear synthesis in stars and star explosions
- Fundamental interactions and symmetries
- Quark gluon structure and dynamics of strong interacting particles
- Origin of the confinement and mass of hadrons
- Studies of hadronic matter at high densities
- Phase transitions in quark matter
- Properties of neutron stars
- Bulk matter at high pressure, densities and temperatures

For more information on the physics of FAIR see [3].

The FAIR accelerator facility consists of two large heavy ion synchrotrons, and four storage, cooler and accumulator rings, a new proton linear accelerator (Linac), the high energy beam transfer system, the production targets for the secondary beams and the experimental areas. An overview of the FAIR accelerator facility can be seen Figure 1.

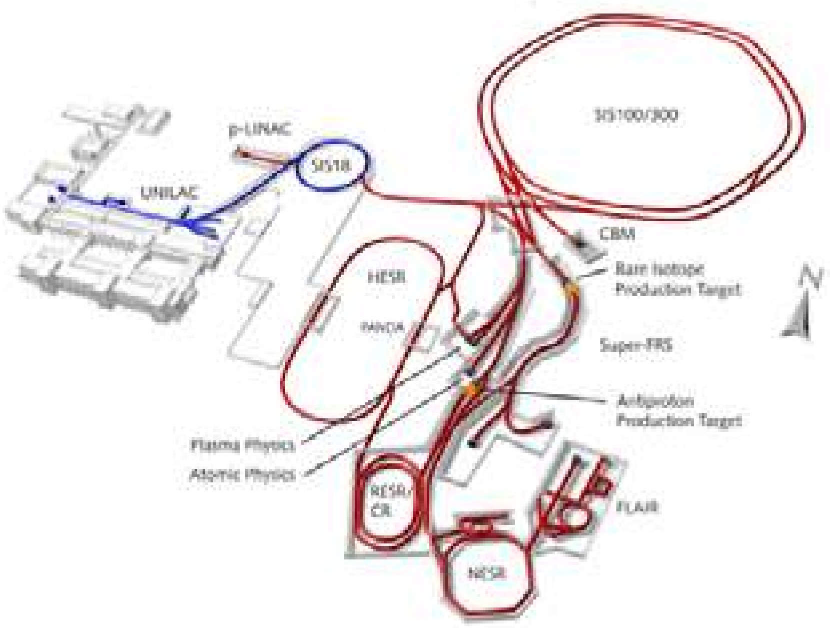


Figure 1 - Overview of the FAIR accelerator facility.

2. Vacuum

The vacuum system of the FAIR accelerator facility consists of the beam vacuum system with a length of about 6 km and the isolation vacuum system for the superconducting magnets and cryogenic transfer and bypass lines. To guarantee a sufficient life time for all ions at all stages of the accelerator a vacuum pressure in the range of 10^{-7} mbar in the Proton Linac down to the lower 10^{-12} mbar in the heavy ion synchrotrons SIS100 & SIS300 and in the NESR are required. The beam vacuum system of the synchrotrons consists of cold sections, which are operated at cryogenic temperatures and of room temperature operated sectors with a bake-out system up to 300°C to reach the required ultra-high vacuum conditions. In the cryogenic vacuum sectors of the synchrotrons the cold vacuum chamber walls (temperatures have to be lower than 20 K) will serve as extended cryo pumps. The vacuum requirements for the Collector Ring (CR) and the High Energy Storage Ring (HESR), designed by Forschungszentrum Jülich [4], are moderate in the range of $>1\times10^{-9}$ mbar. For these rings no in-situ bake-out is foreseen. To run the accumulator ring RESR with heavy ions all vacuum components have to be designed to be bakeable in order to reach a pressure of about 1×10^{-10} mbar. For the High Energy Beam Transport System (HEBT) pressures of 10^{-11} mbar in direct vicinity of the synchrotrons and the bakeable storage rings, and 10^{-9} mbar in all other sectors are foreseen.

2.1. Design Principles

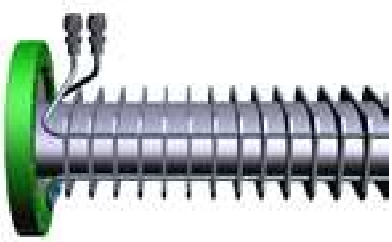
The beam vacuum systems for FAIR are designed as state-of-the-art vacuum system with commercially available hardware components. The roughing of the beam pipes is done by turbomolecular pumps in combination with suitable roughing pumps. Most of these pumping systems will be design as mobile pumping groups, which will be removed after pump-down and bake-out (where necessary). The vacuum then will be maintained with sputter ion pumps and where a vacuum better than 10^{-9} mbar is required with capture pumps, like titanium sublimation pumps, NEG cartridge pumps or NEG cartridge/sputter ion combination pumps. At the Proton-Linac and the Super-Fragment-Separator (Super-FRS) permanently installed turbomolecular pumps will be used.

For diagnostics of the vacuum system various types of commercially available total pressure gauges will be used. Depending on the vacuum requirements, these will be Penning/Pirani gauges, wide range ion gauges, hot and cold cathode ion gauges. In addition to the total pressure measurements residual gas analyzers with a detection limit of 10^{-15} mbar will be used in the synchrotrons and storage rings to analyze and monitor the residual gas composition.

To separate the vacuum system of the accelerator into smaller sections commercially available all-metal and Viton sealed gate valves will be used.

For the bakeable sections of the FAIR vacuum system all components must be able to withstand temperatures of up to 300°C. Therefore, only all-metal gate valves will be used in SIS100 and SIS300. To obtain the required low outgassing rates, austenitic stainless steel will be used. The required low outgassing rate of the stainless steel vacuum chambers is guaranteed by a special cleaning procedure, followed by a vacuum firing at 950°C. Due to the high beam intensities there are high radiation environments in the target region of Super-FRS and in the antiproton target area, where all vacuum components have to be radiation hardened.

The beam vacuum system of the heavy ion synchrotron SIS100 is the most challenging system. Besides the room temperature operated, bakeable sections, about 80% of the beam vacuum is inside of the cryostats for the superconducting magnets. SIS100 will use superferric dipole magnets with a maximum magnet field of 1.9 T and a ramp rate of 4 T/s. This fast ramped magnetic field changes introduce eddy currents in the dipole vacuum chambers, which heat up the walls. As these walls have to work as extended efficient cryopumps, the temperature of the chamber has to be kept lower than 20 K. At these temperatures all gasses except helium and hydrogen will be pumped. To reduce the eddy currents the wall thickness of the dipole and quadrupole chambers is reduced to 0.3 mm. To stabilize the chambers there will be a rib structure on the outer side. In addition, there will be four electrically isolated cooling tubes with liquid helium along the body of the chamber. The position of the tubes was optimized to guarantee the lowest possible chamber temperature. A schematic drawing of the chamber together with the FEM calculations for the temperature distribution can be seen in Fig. 2.



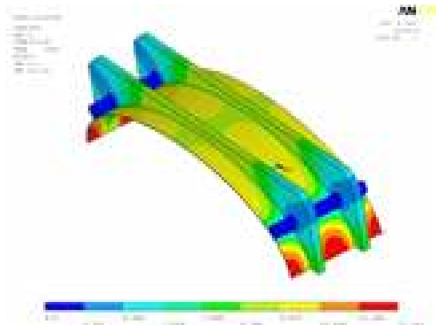


Figure 2 - Left: Schematic drawing of dipole chamber with cooling tubes and ribs. The length of the chamber is 3.35 m with an aperture of 120x60 mm² and a bending angle of 3.33°. Right: ANSYS calculations of the temperature distribution of the dipole chamber.

To provide additional pumping speed for helium and hydrogen cryo adsorption pumps will be installed between the dipoles and quadrupoles. The pumps consist of a set of charcoal coated copper discs which are cooled by liquid helium.

2.2. Design Status

The vacuum system for FAIR is still in the design phase, some components are not yet designed. This is only an engineering task. First measurements on prototype dipole chambers showed the calculated behaviour. For the series production of the chambers a call for tender is issued.

The prototype set-up of the vacuum control system, which is Siemens PLC based and works with a WinCC in the UNICOS framework developed by CERN will be tested this year. The connection of the vacuum equipment to the control system will be done via digital and analogue I/O's.

A still open question is the pressure measurement in cryogenic sections. Hot filament extractor gauges work well in this pressure range, but cause non-tolerable heat load to the cryogenic system. Therefore research is going on to develop an extractor ion gauge with a cold electron source, like Spindt cathodes, CNT cathodes or electron guns.

3. Cryogenics

During the operation of FAIR the main request for cooling capacity at helium temperature is given by the synchrotron SIS100 (rigidity 100 Tm, approx. 480 superconducting magnet) and by one of the experimental set-ups: the Super FRS (approx. 180 superconducting magnets). As the experiment scheme of FAIR foresees several different beams, all parts of the facility should be able to be operated independently from the status of other machines.

The supply of liquid helium for FAIR is realized by two refrigerators and one small liquefier, supplying small consumers or short term experiments. Due to the topology of FAIR the requirement for the two refrigerators is dominated by one main consumer per refrigerator. Refrigerator Cryo1 supplies the SuperFRS and some detector magnets. Cryo2 supplies SIS100. The heat loads are summarized in Table 1.

Heat load	Static @ 4.2 K [W]	Dynamic @ 4.2 K [W]	Static @ 50 K-80 K [W]	Liquefaction [g/s]
Cryo1	1821		11400	9.1
Cryo2	3410	<10500	11940	8

Table 1: heat loads for the two refrigerators

For the installation phase a series testing facility for the SIS100 dipole magnets is presently under preparation. It will allow GSI to test the 108 SIS100 dipole magnets on site and after the tests the facility can act as a service facility for magnet maintenance of FAIR magnets and for external users.

3.1. Current Installations at GSI

The experiment facility at GSI consists of two detectors based on superconducting magnets. Both machines (one liquefier, one refrigerator) are standalone machines, operated by the experimental groups.

For the preparation of FAIR presently GSI operates a prototype test facility (PTF) with two test benches including a universal cryostat. The PTF is used mainly to test prototype magnets and liquid helium cooled vacuum chambers for FAIR. The two test benches can be used independently. The refrigerator has a power of 500 W at 4.5 K. The refrigerator has a total operation time of 73 500 h up to now and works since 36 000 h at the PTF, including 2 200 h of operation with a liquid helium pump providing a mass flow rate of 60 g/s. The helium inventory is 300 m^3 with a loss between 40 to 80% per year depending on the operation modes.

3.2. Future Cryo Plants for FAIR

For magnet testing, quality control, experiments and FAIR operation GSI will build four new cryo plants in the near future.

FAIR operation, Cryo1 and Cryo2

For a reliable operation of the FAIR cryogenic system which has to provide sufficient cooling capacity to all consumers independently, a common system layout has to be carefully designed to take care of the transitions during different operation modes. Therefore a common control system for all cryogenic infrastructures is foreseen. In addition the two large refrigerators will operate at the same pressure levels to be able to share redundant compressors. The distribution system for liquid helium at FAIR will have a total length of 1.6 km to the loads and additional 1.5 km within the structures.

The total helium inventory is about 12.5 t (1.7 t for SIS100 and 8.5 t for the SuperFRS). The helium storage is centralized. Approximately 80% of the inventory can be stored at ambient temperature in pressurized vessels. The remaining helium is stored in liquid phase in separate dewars independent from the main cryogenic system. These storages are located next to the refrigerator. In the case of an electricity failure, the pressure in the system can increase up to 18 bar. Within 15 min a special compressor (with an independent control system) will be started. In this way (most of) the helium can be transferred into the gas storage.

Magnet Testing

For the magnet testing GSI will install a completely new series test facility (STF) including a 1.5 kW at 4.5 K cryo plant together with a distribution system to four independent test benches usable for three magnets and one string tests. The magnets are is cooled with 2 phase forced flow Helium and require subcooling at the inlet. In addition, the beam vacuum chambers will be cooled with a separate inlet line. The full test facility including the power supplies requires a cooling water capacity of about 1.1 MW.

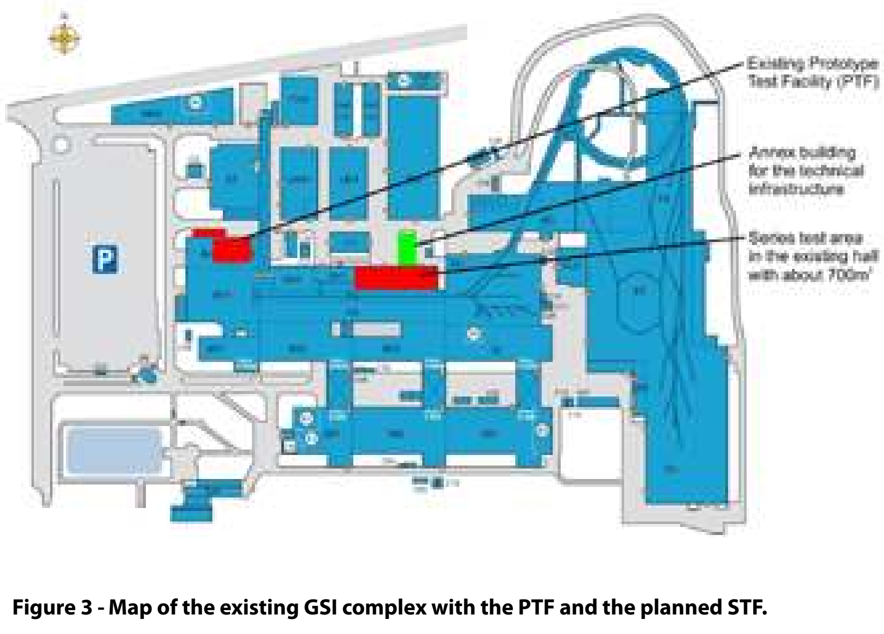


Figure 3 - Map of the existing GSI complex with the PTF and the planned STF.

Helium Supply

For small consumers, for the testing of prototypes like vacuum chambers we will install a helium supply station called HeSu. Here, helium can be filled up to dewars of up to 200l. Evaporated helium can be recovered. One recovery line to a central testing area at GSI is already considered, recovery lines to different locations can be installed. The liquefier has a liquid helium production capacity of 20 l/h. Liquid helium storage of 3 500 l will be realized. The HeSu will be available in mid of 2014.

4. Conclusions

During the last years the challenges of the FAIR vacuum and cryogenic systems were intensively studied in order to find solutions for the unique requirements, like actively cooled, thin walled vacuum chambers or a cryo plant with a high dynamic load. At the present state these technical challenges are solved, prototypes are tested and first series production, e.g., the helium cooled SIS100 dipole chambers is ongoing.

The work was supported by the European Union within FP7.

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[3] http://www.fair-center.eu/public/what-happens-at-fair.html.
[4] http://www.fz-juelich.de/ikp/DE/Forschung/Beschleuniger/_doc/HESR.html?nn=497786.
[5] FAIR Green Paper – The modularized Start Version (2009)

Appendix

Schedule of the FAIR project:

2001	Conceptional Design Report
2006	Baseline Technical Report
2007	Project Start
2010	Founding of the FAIR GmbH
2011	Application for Building and Operation Permit
Dec. 2011	Start Construction Site Preparation
2012	Start Civil Construction
2016	Start Hardware installation
2017	First stage ready for experiments
2018	Modules 0-3 completed (see [5])

Present and Future Research Activity of Vacuum Science Division at ASTeC

M. D. Pendleton, R. Valizadeh

ASTEC, Vacuum Science group, Daresbury Laboratories, Daresbury, Warrington, WA4 4AD, UK

Abstract - ***The ASTeC Vacuum Science Group is based at the Cockcroft Institute STFC Daresbury Laboratory. Currently the main focus of ASTeC is to establish a new Electron Beam Test Facility (EBTF) which eventually can drive a compact FEL. The Vacuum science group provides the necessary vacuum facilities to underpin ASTeC programmes as well as running advanced R&D programs and offering commercial services for vacuum metrology and calibration.***

1. Introduction

Members of the vacuum science group have a wide range of experience in the design and operation of large vacuum systems for particle accelerators. The Group's main strengths lie in the development and use of advanced modelling techniques for vacuum system design; knowledge and understanding of specific particle accelerators vacuum problems as well as Ultra-High (UHV) and Extreme-High vacuum (XHV) technique. We use our skills both in the support and improvement of existing accelerator facilities and in the design and specification of new facilities.

The vacuum science and instrumentation laboratories are used to run an advanced programme of R&D as well as to provide the necessary vacuum facilities to underpin ASTeC programmes.

The principal areas of activity include:

- Investigating the properties of Non Evaporable Getters (NEG) and novel coatings for vacuum applications.
- Investigating the outgassing characteristics of materials for use in vacuum.
- Developing the techniques for producing thin films on vacuum vessel walls.
- Development of XHV technique for Photoinjectors and SCRF.
- Development of the materials used as photocathodes and processes involved in improving their performance.
- Vacuum metrology and calibration service.
- Investigating new cleaning techniques for UHV and XHV applications.
- Advanced modelling and design of vacuum systems.
- Evaluation and development of vacuum equipment including pump speed measurements.

In addition, members of the group are actively involved in training and education in the field of vacuum science and technology, paper reviewing for peer-review journals, organising vacuum conferences, workshops and other events, having links with a number of universities and departments as well as active involvement in the work of the International Union for Vacuum Science, Technique and Applications (IUVSTA), the American AVS and the vacuum group of the Institute of Physics (IoP).

2. ASTEC commercial services

2.1. Pumping Speed Test Facility

The Fischer-Mommsen test dome meets an ISO standard for methods of measuring the performance characteristics of a range of Ion pumps and turbo-molecular pumps.

Using this facility we are able to measure the total pressure and the volume rate of flow (pumping speed) for each individual pump. The test dome is a circular cross-section with two chambers of a known volume, separating the upper and lower chamber is a thin flat plate with a small aperture (conductance) in the centre. Each chamber has a calibrated hot-cathode ionization gauge for measuring pressure, p1 and p2. An RGA (residual gas analyser) is also attached to the test dome to study the gas partial pressures in the system and a having the facility for leak detection. A number of test gases can be introduced into the top chamber via a leak valve at a controlled rate, the manifold at the front of the rig enables a selection of gas species of high purity. The pumping speed test facility in the vacuum science laboratory is used for a number of reasons, it enables us to gain knowledge and experience of new products on the market, make comparisons to the manufacturers data and as part of the process provides us with a valuable database for a whole range of pumps that may be utilised in future applications. This service is also available to customers who may require a new pump to be tested for a particular application or verification of its capabilities.

Figure 1 - Pumping speed test facility.

2.2. Outgassing Test Facilities

The ultimate pressure in any vacuum system is basically limited by two factors, pumping speed and the outgassing rate of the materials inside the chamber. Normally it is extremely difficult to increase the pumping speed by several orders of magnitude, therefore the most effective technique for any vacuum system is to try and reduce the outgassing rate of the materials. The outgassing systems below enable the characterisation of outgassing rates using measurement techniques such as the 'throughput' or 'conductance' method and rate of rise method. The measurement of these outgassing rates allows the vacuum scientist to determine which materials are suitable for particular applications or pressure regimes. Materials with low outgassing rates would typically be used in construction of vacuum systems which can achieve $<10^{-9}$ mbar, for example, particle accelerators. These materials are deemed to have low outgassing rates because they do not have large 'sinks' of gas and they can be conditioned for use in vacuum. Such materials are; stainless steel, titanium, aluminium, glass, ceramics and many other metallic elements. Materials with high outgassing rates are generally non-metallic type materials, examples are, porous metals, plastics, wood, liquids and paper. These materials whilst being large 'sinks' of gas are also difficult to condition for use in vacuum.

Figure 2 - Conductance method.

The conductance system, in Fig. 2, consists of two chambers, one for the sample, the other for the pumping system, separated by a small hole of known conductance. By measuring the pressure difference across the conductance plate, the outgassing rate can be determined:

$$Q_{Sample} = \left(\frac{P_{Samples} - P_{Pumping}}{A_{Samples}}\right) \cdot C - Q_{Blank}$$

Where C is the conductance between the two chambers.
This system benefits from a load lock, which allows samples to be loaded without the need to vent the sample or pumping chambers. This allows for a faster turnaround between samples, as the system does not require baking between samples. Also the samples are placed on a heater stage; this can either be used to determine the outgassing rates at elevated temperatures, or to determine the outgassing rate after being baked.

In addition, we have a second "throughput outgassing facility " which also uses the conductance method to determine the outgassing rate of a whole range of materials for various applications, examples are;

1) Particle accelerators, electron, neutron and proton machines
2) Telecommunications
3) Satellites.

Figure 3 - Rate of rise method.

The "outgassing rate of rise chamber" is one such way of determining the outgassing rate of a sample. A sample is placed within a chamber of known surface area and volume. On pumping down to UHV, the pumping system is isolated and the pressure recorded against time. By determining the rate of pressure rise and knowing the volume of the chamber, the combined outgassing for the chamber and sample can be calculated. If a test has been performed prior, without a sample, then a figure giving the outgassing for just the chamber, would have been obtained, which may be deducted from this value, to give a figure for just the outgassing of the sample.

2.3. Gauge Calibration Facility

The ASteC Vacuum Science Group also hosts a vacuum gauge comparison facility to a secondary gauge calibration standard. This will enable gauges to be compared in the range between 10^{-5} and 10^{-9} mbar to an Extractor gauge calibrated against a primary standard at the Physikalisch-Technische Bundesanstalt (PTB) in Germany which is renewed every twelve months. Now that collaboration between ASTeC, PTB and SS Scientific is underway the facility will not only play an important role in the laboratory for high accuracy and consistent pressure measurements but will also be available as a service for external customers.

Figure 4 - New vacuum gauge calibration service.

We are now able to offer 3 packages to calibrate Ionisation gauges to a secondary standard;

- A 15 point calibration from 10^{-5} mbar to 10^{-9} mbar
  (3 points per decade)
- A 5 point calibration from 10^{-5} mbar to 10^{-9} mbar
  (1 point per decade)
- Custom calibration requirements

The calibration will be performed within short timescales. On completion a calibration certificate will be issued highlighting the measurement procedure and a table of results with the determined correction factor at each calibration point.

3. Conclusions

Since the ultimate pressure achievable in any vacuum system is limited to the pumping speed and out gassing rate of the materials inside the chamber, the activity of the vacuum science group is based on the a very diverse program from vacuum metrology to synthesising new material with low out gassing properties. This diverse activity gives us unique opportunities to develop advanced modelling techniques for vacuum system design, and to enhance our knowledge and understanding of specific particle accelerators vacuum problems as well as Ultra-High and Extreme-High vacuum technique. We use our skills both in the support and improvement of existing accelerator facilities and in the design and specification of new facilities. Our strength in delivering successful projects lies on our total commitment to work closely and share information with both commercial and scientific partners and suppliers.

Further information: http://www.stfc.ac.uk/ASTeC/default.aspx or contact mark.pendleton@stfc.ac.uk direct.

Agilent Technologies

Vacuum Products Division

Since the invention of the Ion Pump, through major developments in Diffusion Pump and Leak Detection, and innovations in Dry Scroll pumping, up to the revolutionary TwisTorr turbo pump, Agilent Vacuum, formerly Varian, has always been at the forefront of vacuum technology, setting the industry standards.

A one-stop global supplier with a complete range of vacuum products and services for scientific research and industrial applications. Varian's 60+ years of technology leadership and innovation in vacuum and leak detection is now a part of Agilent, the world's premier measurement company.

Some of the most relevant aspects to this Forum are as follows:

- ***Benefits of our shared values: customer satisfaction, commitment to quality, ethical standards, and technology leadership.***
- ***High level of customer support, with best-in class processes, resources, infrastructure, and better coverage assured for end users worldwide.***
- ***Dedicated R&D and Application Engineering Teams offering enhanced capabilities and partnership in design, test and application of custom solutions to specific OEM vacuum requirements.***

Agilent is leader in High- and Ultra-High Vacuum solutions for physics research, mass spectrometry and electron microscopy, and with new solutions for the thin film deposition industry.

Submitted by: **Christian Hilbert**

Field of activities

Agilent was spun off from Hewlett-Packard Company in 1999 as part of a corporate realignment that created two separate companies. On November 1, 1999, Agilent began operation as an independent company. On May 14, 2010, in the largest acquisition in its history, Agilent acquired Varian Inc., a leading provider of analytical instrumentation and vacuum products.

Historically synonymous with UHV, and world leader in Ion Pumps and Diffusion Pumps, major player in Turbomolecular pumps for Nano/Mass Spec applications, Agilent Vacuum Products Division plays an important role in dry vacuum solutions (thanks to its innovative line of dry Scroll Pumps) and is one of the largest manufacturers of small and medium size turbomolecular pumps.

Now we also have a complete product offer range for industrial vacuum applications, with the new line of high capacity MS rotary vane pumps and RPS Roots pumps and pumping systems.

Products & services

- **Rough Vacuum Pumps**
  - Rotary Vane Pumps
  - High Capacity MS/RPS Pumps and Roots Systems
  - Dry Scroll Pumps

RPS Roots Pumping System

IDP-3 Dry Scroll Pump

- **High Vacuum Pumps:** Diffusion and Turbomolecular Pumps
- **UHV Pumps:** Ion Pumps and TSP Titanium Sublimation Pumps
- All-in-one **Turbo Pumping Systems**
- **Vacuum Measurement and Control:**
  - Gauges and Controllers
  - Active Gauges
  - Hardware
  - Valves
- **Leak Detectors:** Helium Mass Spectrometer LD, Portable Sniffer LD
- **Service Plans** for all Product Lines
- Vacuum and Leak Detection **Training**

Turbo-V 850
TwisTorr Turbo Pump System

IONICA-55
Vac-Ion Pump

Relationship with academic research

Agilent VPD offers vacuum solutions to the following market segments:

- Nanotechnologies/Electron Microscopy;
- Mass Spectrometry/Analytical Instruments;
- Industrial Vacuum,
- Academic/R&D/Accelerators,

serving customers such as

- SLAC,
- Brookhaven National Lab,
- CERN,
- ESRF,
- Hitachi,
- Carl Zeiss,
- AB Sciex,
- Bruker,
- Applied Materials,

Thanks to the acquisition of Varian by Agilent, two of the science industry's best companies are writing a new story together: it's a story that will strengthen our commitment to deliver unmatched quality, innovation and service to our customers, while maximizing the power of our portfolio and global support network. Varian was an historical vacuum pioneer, with a tradition of innovation; this storehouse of knowledge and experience in vacuum is now enhanced by Agilent technologies' excellence in Research and Development.

Agilent Technologies

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Babcock Noell

Babcock Noell is active in the product areas of nuclear service, nuclear technology, magnet technology and environmental technology throughout the world and, in doing so, successfully implements the experience gained over four decades. With approximately 320 employees who are predominantly employed in the engineering area, our performance spectrum extends from the development, planning, supply and commissioning right up to the operating of the plants and equipment we supply.

Babcock Noell is a global leader in the production of superconducting magnet systems for fusion facilities and particle accelerators. We produce normal and superconducting magnet systems as well as permanent magnetic and superconducting undulators – tailored to the specific needs and requirements of our customer. Our current activities include the production of a superconducting undulator for the Karlsruhe Institute of Technology (KIT) in Germany.

Where larger-volume production is concerned, we can also provide you with support and assistance based on our long years of experience in the fields of series production and project management. Recently, Babcock Noell received a contract from GSI for the delivery of 113 fast ramped dipoles for the FAIR Project in Darmstadt.

Submitted by: **Michael Gehring**

Field of activities

We develop and manufacture **cryostats**, **vacuum vessels and mechanical structures**. We also supply **special-purpose tools and manipulators** to ensure the optimal implementation and outcome of your project.

We provide support in the form of **design, feasibility and production analyses** already in the early phases of your project.

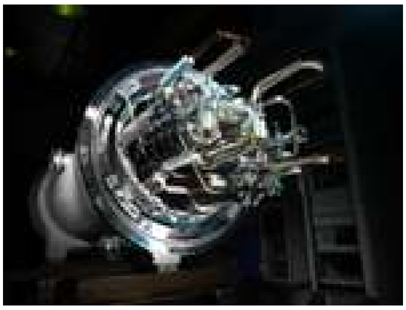
In the field of **High Temperatur Superconductors (HTS)** we develop magnets and coils for special application like **electrical thrusters, undulators or solenoids**.

Spin Echo Spectrometer

Superconducting Undulator

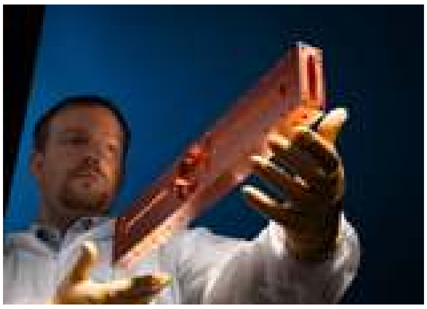
HTS undulator

Products & services



Fast Ramped Dipole

- Cryogen free and liquid cooled superconducting magnets
- Design, calculation and manufacturing of resistive and SC magnets



Cold Diag

- Vacuum and cryo-technology
- FE calculation (magnet fields, forces, multiphysics)
- Studies (feasibility, costs, design of magnets, industrialization)
- Project management
- Series production of magnets

Series Productions

Relationship with academic research

We can look back on many years of successful collaboration with research institutes and facilities, for example.

- CERN
- DESY
- GSI
- the research centers in Karlsruhe and Jülich
- and the Max Planck Institute for Plasma Physics

BABCOCK NOELL

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COMVAT

COMVAT is the leading European supplier for welded bellows for applications like semiconductor industry, medical technology, R&D as well as automotive industry. The extremely precise components, which are optimised for a high degree of reliability, are designed for cycle numbers of ten thousand up to ten million. Different bellows materials are available. Revolutionary production techniques in the field of laser or plasma welding permit the production of large or small quantities always with consistently high quality and very short processing times.

Submitted by: **Markus Spanbalch / Gert Mayer**

Products & services

- Production of welded bellows in various sizes and shapes
- Customised manufacturing of endpieces for the bellows in-house
- All bellows welding steps in cleanroom Class 8
- Complex bellows assemblies in cleanroom

Cleanroom Class 8

Relationship with academic research

- GSI
- DESY
- PSI
- CERN
- KIT
- BESSY

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Oerlikon Leybold Vacuum

Oerlikon Leybold Vacuum (OLV) offers a wide range of advanced vacuum solutions for use in manufacturing and analytical processes, as well as for research purposes. Using the experience of 160 years in vacuum technology, OLV offers a broad know how of processes and applications. OLV ranks among the top three providers in its specific business segments, which are Process Industry, Information Technology, Analytical Processes and Research & Development.

Figures 2011: 1,472 employees, 32 global sites, sales 409 MCHF

Submitted by: **Dieter Müller**

Field of activities

Oerlikon Leybold Vacuum develops and sells a complete range of vacuum equipment. Moreover, OLV has the capability to develop and construct highly customised complete vacuum systems for both OEM and stand-alone applications.

Products & services

The product range of Oerlikon Leybold Vacuum comprises:

- Fore vacuum pumps,
- High vacuum pumps,
- Vacuum systems,
- Vacuum gauges,
- Leak detecting instruments,
- Flanges, fittings and valves

as well as consulting and engineering of complete vacuum solutions for specified customer applications.

Relationship with academic research

Oerlikon Leybold Vacuum has developed customised turnkey vacuum systems for various research centres, for example large Helium pumping systems for DESY and CERN.

External research institutes are supporting OLV R&D programmes in development of dry pump mechanisms and turbo-molecular pumps.

Mr Dieter Müller
Global Head of Market Segment
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FMB Feinwerk- und Messtechnik Berlin

Since it was founded in 1990, FMB Feinwerk- und Messtechnik GmbH has developed into a successful system provider for equipment used for conducting research with synchrotron radiation. More than 50 employees are highly skilled with the knowledge required for dealing with vacuum and beamline technology.

Our engineers and technicians are always setting themselves new challenges, and go right to the limits of the technically feasible. Getting internationally-respected experts actively and heavily involved in the development and testing of our products ensures that the latest scientific findings are available and also that there is a good understanding of the needs of our customers.

We provide professional management for the entire development, engineering, production, testing and installation. Analyses and physical calculations such as optical ray tracing, strength and thermal load calculations, made using the latest computer science, form the basis of innovative and reliable products.

Production is done at our own location or at reliable cooperation partners with constant supervision by the responsible FMB project manager. Turning, milling, drilling and grinding are all done both on conventional machines and also on CNC machine tools. Different welding methods, such as MAG, TIG or microplasma welding, can also be used.

Submitted by: **Michael Gehringer**

Field of activities

- Extensive customer service even during the preparation phase of projects
- Integration of external scientists, experts and consultants
- Development, engineering, manufacture and testing
- Installation, testing and commissioning at the customer's location
- Training and transfer of know-how

Products & services

The products (Manufacturing, Reseaech and Development)

- Ultra-high vacuum systems and components
  - Storage ring vacuum chambers for installation in dipole-, quadrupole-, sextupole-magnets and insertion devices made of high-grade steel, copper and aluminium
  - Radiation absorbers
  - Tapers
  - Vacuum chambers for industrial and experimental applications
- Front Ends und Beamlines
  - Double crystal monochromators
  - Grating monochromators
  - Mirror systems
  - Beamline diagnostics
  - Aperture and slit systems
  - Filtering systems
  - Bremsstrahlung shutters
  - Photon shutters
  - Delay lines
- Systems and components for research and industry developed according to customer requirements

Relationship with academic research

Beamline devices

Detailed design, manufacture, test and delivery

BESSY	1 PGM and 1 IR beamline
DESY	2 PGM
National Institute of Standards and Technology Brookhaven National Lab	1 PGM
NT-MDT / Kurchatov Institute, Moscow	3 front ends, 3 beamlines, 3 control systems & 1 endstation

Detailed design, manufacture, test, delivery and installation

Australian Synchrotron Project	1Soft-X-Ray-beamline with PGM and 1 IR-beamline
Diamond Light Source	1 IR beamline
Karlsruher Institute of Technology – ANKA	SUL-Beamline

Vacuum devices

Detailed design, manufacture, test and delivery

University of Saskatchewan – Canadian Light Source	All storage ring vacuum chambers
Paul Scherrer Institut – Swiss Light Source	All storage ring vacuum chambers
Karlsruher Institute of Technology – ANKA	All storage ring vacuum chambers and front ends for ANKA
ALBA Light Source	All storage ring vacuum chambers and front ends
Australian Synchrotron Project	All storage ring vacuum chambers, all front ends and diagnostic for storage ring
Diamond Light Source	Storage ring vacuum chambers

FMB Berlin

Uwe Schneck
Managing Director

Wolfgang Drewitz
Managing Director

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Focus

FOCUS GmbH - Instruments for Electron Spectroscopy and Surface Analytics, has been developing and manufacturing scientific instruments since 1991. Most of these products are designed for use in applied and basic research and industrial quality control.

With a sound foundation of long experience in the development and construction of electron beam reliant devices, FOCUS has firmly established itself in the field of electron beam welding.
All products are developed, built and tested in-house.

FOCUS is today operating with 12 full-time employees, more than 50% of them with an academic degree. All the electronic devices and the related software are developed and fabricated by our closely related partner company FOCUS electronics GmbH in Leipzig with today 9 employees.

FOCUS is fully privately owned and did make a turnover of nearly 3.4 Mio € in 2011. The most of the annual assets are reinvested for R&D activities aiming in new products or improving the state of the art of the existing ones.

Submitted by: **Michael Merkel**

Field of activities

FOCUS has developed a photoemission electron microscope (PEEM) that is established in many laboratories for the nano-analytics worldwide. This development is one central item of the patented NanoESCA, being developed in a joint project together with OMICRON nanotechnology GmbH, our long-standing sales and R&D partner.

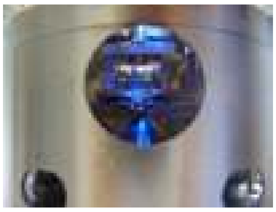
A special PEEM, developed by FOCUS, has been used successfully within a large FP6 project of the EU. There we developed a so called @wavelength inspection tool for EUV lithography masks for the next generation semiconductor chip production.

Our recent activities on the field of Micro Electron Beam Welding have established already a new main pillar for FOCUS. Within a project, ("AUTOKOST", funded by the EU and the Free State of Saxony, Grant-No. 13529/2310) we go forward in widening its potential for the industrial market. This instrument is for example already successfully used for the production of parts for space research.

Since 2001 we did put a lot of engagement into the new field of high energy electron spectroscopy. We developed a so called HAXPES electron energy analyser and recently we tested successfully a HAXPEEM microscope. Both instruments are used preferentially by our customers at synchrotron light sources where the needed high brilliant x-rays are available.

Products & services

- Photoemission Electron Microscopes (IS-PEEM, NanoESCA, HAXPEEM)
- Micro electron beam welding instrumentation (MEBW-60)
- Electron energy analysers for UPS, XPS, AES, ISS and HAXPES (SHA50, CSA200/300, HV CSA)
- Ultra high vacuum electron beam evaporators (EFM3, EFM4, EFMT3, EFM6,…)
- UV and VUV sources (Hg source, HIS 13)
- Ion sources for charge balancing, sputtering, depth profiling (FDG 150)
- Electron spin detectors (SPLEED, FERRUM)
- Specialised electronics and software (Preamplifier, e-beam heating)



Relationship with academic research

A close collaboration with various universities and research institutes ensures that the products are fulfilling the current demands of science and high-technology branches on a long-term basis. We are working with them on basis of dedicated licensing contracts in case of using essential technical inventions of our partners.

e.g.:

- Fraunhofer Geselschaft
- Max-Planck Gesellschaft
- Forschungszentrum Jülich
- Academy of Science of the Czech Republic

FOCUS GmbH

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FRIATEC - Ceramics Division

The company was founded in 1863 in Mannheim, Germany, as a brickyard and succeeded in developing its first pathbreaking innovation, chemical stoneware, in 1888. Numerous new developments followed. Among other things, the company started in the mid of the past century processing plastics and combined modern and traditional materials when producing chemical devices and facilities.

FRIATEC AG today, with about 1 100 employees and 161 M€ turnover, offers a spectrum of innovative solutions for many industries, e.g. jointing technology for pipe systems, products for water-carrying building services, special pumps for aggressive, volatile or explosive media, but also ceramic components which are used in laboratory and electrical engineering but also in medical engineering.

Submitted by: **Sven Wacker**

Field of activities

Engineering ceramics

Fields of application
- Mechanical
- Pharmaceutical
- Chemical
- Biochemical

Properties
- Abrasion resistant
- Temperature resistant
- Mechanical strength
- Corrosion resistant

Ceramics-To-Metal Assemblies

Fields of application
- High voltage
- High current
- Measurement instrumentation
- Vacuum and accelerator technology

Properties
- Electrical insulating
- Temperature resistant
- Mechanical strength
- Corrosion resistant

Products & services

Product s

- High Purity Alumina (FRIALIT© F99,7)
- High Purity Alumina (FRIALIT© F99,7hf)
- Alumina Typ ZTA (FRIALIT© FZT
- Zirconia Typ Mg-PSZ (FRIALIT© FZM)
- Zirconia Typ Y-PSZ (DEGUSSIT© FZY)
- Silicon Carbide (SiC)
- Silicon Nitride (Si3N4)

Services

- Customised Solutions and Engineering
- 40 years' experience in combining ceramic to metal assemblies
- R&D and Construction Department

Relationship with academic research

We are in supply relationship mainly with academic institutions such as:

- DESY
- BESSY
- MPI
- FZ Jülich
- GSI
- HIT
- CERN
- Budker Institute
- Joint Institute for Nuclear Research
- Indiana University
- Cornell University
- Brookhaven National Laboratory
- Triumf
- NSRL
- IHEP
- BARC
- Gov. of India Department of Atomic Energy, Centre for Advanced Technology,

as well as industrial partners for Medical, R&D, Energy and UHV applications.

FRIATEC

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Application Engineer

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Garlock

Garlock has 16 global operations employing over 2,400 people in eight countries.
Garlock Sealing Technologies has specialised in fluid sealing technology since 1887 and offers a range of more than 100,000 high-performance sealing products for companies.
Our aim is to develop our sealing solutions continuously to meet increasing industrial and environmental requirements. Input from continuous dialogue with our customers is utilised in Garlock development work, thus enabling optimised production processes.

Innovative sealing technology is a Garlock trademark. Since its formation, Garlock has been continually and successfully engaged in the development of innovative products of highest quality. Many national and international patents, the first comprehensive asbestos-free seal range worldwide, outstanding solutions for static and dynamic sealing systems and high-quality valves are just some examples of the progressive technology offered by the Garlock group.

Submitted by: **Artur Friedrich and Nils Beatty**

Field of activities

Garlock provides a range of sealing and gaskets solutions to meet needs in the following applications/ industries:

- Ultrahigh Vacuum
- Cryogenics
- Nuclear Dome Reactors
- Turbine Engines
- Semi-Conductor Fabrication
- Aerospace
- Oil & Gas
- Chemical Industry

Products & services

Garlock Neuss manufactures:

- Hydraulic and pneumatic seals
- KLOZURE® oil seals
- PS-SEAL® lip seals
- GYLON ® PTFE gaskets
- Fibre gaskets

Klozure Familyhi

- HELICOFLEX® spring energised seals
- Valve packing
- Spindle packing,
- Graphite packing,
- CEFIL'Air® pneumatic seals and valves.

HELICOFLEX®

In addition to production facilities, sales, coordination and customer service departments are also headquartered at our location in Neuss.

In close cooperation with our business partners and customers, our engineers here develop special solutions
with innovative technology boasting new materials, designs and application possibilities to meet individual requirements.

GYLON BIO Line

Relationship with academic research

- FZJ research centre Jülich GmbH
- KIT Karlsruhe Institute of Technology
- GSI Helmholtz Center for Heavy Ion Research GmbH
- Institut for nuclear physics, University Mainz
- Max-Planck-Institut for nuclear physics, Heidelberg

Garlock
an EnPro Industries family of companies

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HTMS - High Tech Metal Seals

Technology, research, and manufacturing of high performance elastic metal seals.

Established in 1999, High Tech Metal Seals NV (HTMS), a privately owned company, became rapidly a well know name in the industry. We thank our growth from the original 3 people to over 30 employees today, to our long time relationships with our customers, our partners and last but not least our people. Our success is built on teamwork, unique skills and our cooperation with our customers.

HTMS became a qualified supplier for the Aerospace industry, Scientific and Medical equipment and for the Oil and Gas industry.

High Tech Metal Seals is located in new offices and production facilities in Mechelen, close to Brussels. HTMS consistently invests in state of the art production equipment and instrumentation. For R&D, and Finite Element Analysis (FEA), HTMS joins forces with Sirris, the technology provider in Belgium.

Submitted by: **Francis Lebeau**

Field of activities

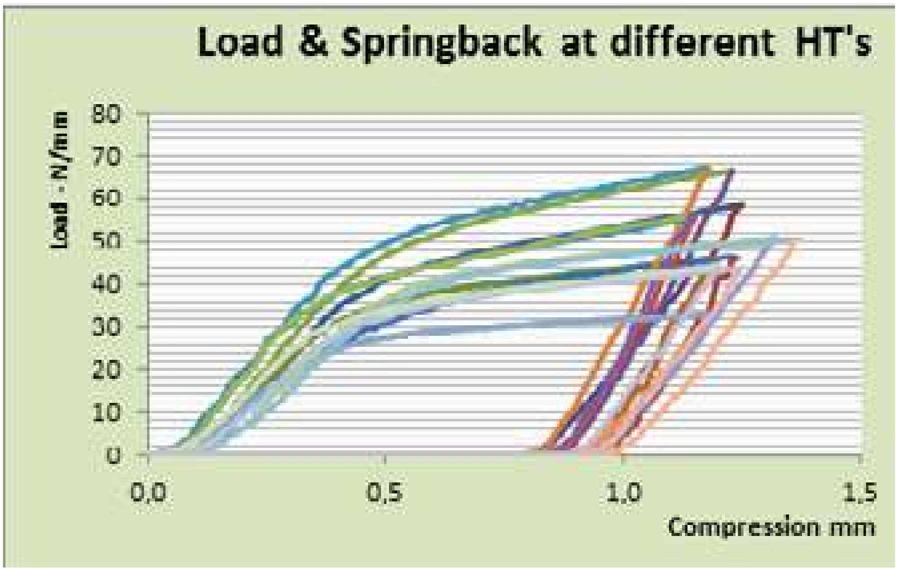
HTMS specialises in the development and manufacturing of high performance elastic metal seals, which are used in high vacuum and cryogenic applications.

Recently, a high flexible all metal seal has been developed. This seal can operate in temperatures ranging from close to zero Kelvin to +200°C, exhibiting extreme leak tightness.

Re-usability, depending on the selected plating and handling of the seal is not excluded.

Depending on the required tightness our high performance seals can and are used from -270°C up to +600°C.

Often very high pressures are combined with high temperatures.



Products & services

- Resilient or elastic metal seals typically, are built up from a C-shape with an inner spring. For some special applications a welded hollow tube with an inserted helicoil spring (OS type) provides the required seating load and elasticity.
- These seals are available in a wide variety of cross section and seating loads/elasticity. The required tightness in combination with the available load and the application temperature drives the selection of the ductile layer.
- The maximum diameter we can manufacture is 3 meter, but there is room to expand this to well over 5 meters.
- Apart from circular shapes, these seals can also be made in rectangular, racetrack and other odd shapes. The OS type seal is very well suited for being manufactured in these shapes.

Relationship with academic research

- Sirris, technology provider in Belgium for FEA
- KUL, Katholieke Universteit Leuven for material science

HTMS
High Tech Metal Seals

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MAN-DWE

With over 50 years of experience and more than 700 reactors and items of special apparatus installed worldwide, the know-how of MDT Deggendorf is generating wide-ranging synergy effects.

MAN Diesel & Turbo SE (MDT) employs around 14,000 people worldwide. MDT Deggendorf site, founded 1924, is 150 km north east of Munich and located directly at the river Danube. With about 450 employees MDT Deggendorf fabricate supply single components up to 10 m in diameter, 80 m in length and 1,500 metric tons in weight.

Main products are reactors for chemical and petrochemical industry and physical research facilities. Furthermore we perform turnarounds and revamps on FCC Units and Reformer Furnaces (Process heaters, Hot Oil Furnaces etc.).

MDT Deggendorf is a reliable partner for studies, engineering, fabrication and tests, logistics and on site assembly.

Submitted by: **Franz Leher**

Field of activities

MDT Deggendorf is divided in two Business Segments with different main fields of activities.

DWE®-Reactors

- Tubular Reactor Systems (molten salt operated) for production of e.g. acrylic acid, acrolein, maleic anhydride, phthalic anhydride and others;
- Pilot and experimental reactors;
- **X**TL reactors (X = **G**/**B**/**C** – **G**as/**B**iomass/**C**oal) for production of synthetic fuel;
- After sales service

Energy-related Engineering

- Apparatus and Plant Components for refineries and petrochemical industry e.g. Hydrocracking Reactors, Hydrotreating Reactors, FCC Reactors, Ammonia Reactors, Reformer Furnaces and others.
- Shut-down engineering, Revamps and Turnarounds for Reformer Furnaces and the main focus on FCC units more and more as a unit contractor.
- Systems and components for power engineering, nuclear technology and physical research facilities.

FCC Reaktor; CPC Taiwan

For realisation of large-scale experiments MDT Deggendorf develops plant of sizes never previously constructed: Steel structures of carbon steel or stainless steel with diameters of 15 m and all-up weight 6,500 mto, 10 m long flow condensers for exhaust gases at 3,000 °C, or high and ultra-high vacuum chambers of anti-magnetic stainless steel up to 1,250 m^3 volume and down to the 10^{-11} mbar.

In physical apparatus construction, special solutions are the rule, requiring not only enormous technical knowledge but also creativity and willingness to accept a certain degree of risk.

Products & services

We are proud to have contributed as a partner of science to the success of outstanding projects as the CERN LHC accelerator in Geneva, the ESO Very Large Telescope, the KIT KATRIN experiment and the Wendelstein 7-X Stellarator experiment of Max Planck Institute for Plasma Physics.

- High and ultra-high vacuum chambers
- Thermal insulation or superinsulation for fusion experiments
- Support structures for fusion experiments
- Magnet yokes for experiments in high energy physics
- First wall cooling elements
- High Altitude Test Bench for ARIANE 5 rocket engine VINCI
- Prototyping and R&D for ITER and other experiments

CMS Barrel; CERN LHC

KATRIN Main Spectrometer; KIT

Wendelstein 7-X Stellarator; IPP

Relationship with academic research

- IPP – Institut für Plasmaphysik, Garching und Greifswald
- KIT – Karlsrüher Institute of Technology
- ESO – European Southern Observatory
- DLR – Deutsches Zentrum für Luft- und Raumfahrt
- CERN – Conseil Européen pour la Recherche Nucléaire

MAN

Franz Leher
Senior Project Engineer
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Neue Technologien & Co. KF (NTG)

NTG Neue Technologien GmbH (NTG) is a worldwide operating mechanical engineering company located right in the middle of the European Union. The company was founded in 1968. Actually approximately 85 employees are doing their best to satisfy our customers. From prototype to mass production – from the study to the complete product – we realize your projects – worldwide – with highest quality.

Our spectrum ranges from the design study to the manufacturing of complex systems, from the production of prototypes to the production of complete series, from components made of steel, aluminium and plastics to special materials (for instance ceramic metal assemblies).

Submitted by: **Johannes Maus & Roger Weber**

Field of activities, related products & services

Nanotechnology

- Ion Beam Figuring (IBF) systems and accessories for the ultraprecise polishing error correction of optical surfaces by means of ion beams.

IBF

Contract manufacturing

- Treatment of metal and plastics components by means of welding, tuning on lathe and milling.

Cup

Particles accelerators

- Our product spectrum ranges from linear particle accelerators to components for synchrotron radiation sources.
- Beam diagnostics such as Fast-Faraday-Cups, Beam Position Monitors, Wire Scanners, Emittance Scanners and complex systems according to your demand.

Vacuum technology

- Ultrahigh vacuum technology for special demands for pressures down to less than 10^{-11} mbar.

Engineering technology

- Construction and project design at several 3-D CAD/CAM workplaces (Solid Works, Pro Engineer, CAM-Works).

We can accomplish all steps starting from the first drawings up to the commissioning of the machines.

SARAF

Tank: Length 4m

Relationship with academic research

NTG is involved in several collaborations with different institutes.
With the Institute of Applied Physics (Frankfurt University) we are improving accelerator technologies in a close contact for instance for the FRANZ project or the CH-proton linac for FAIR.

We deliver vacuum components to many laboratories such as:

- GSI (Darmstadt)
- DESY (Hamburg)
- CERN
- HMI (Berlin)
- HZB (Berlin)
- Soreq (Israel)
- LMU (Munich)
- MSU (Michigan USA)
- ESRF (France)

NTG

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Pfeiffer Vakuum

Pfeiffer Vacuum is one of the world's leading providers of vacuum solutions. In addition to a full range of hybrid and magnetically levitated turbopumps, the product portfolio comprises backing pumps, measurement and analysis devices, components as well as vacuum chambers and systems. Ever since the invention of the turbopump by Pfeiffer Vacuum, the company has stood for innovative solutions and high-tech products that are used in the markets Analytic, Industry, Research & Development, Coating, Semiconductor and Chemistry. Founded in 1890, Pfeiffer Vacuum is active throughout the world today. The company employs a workforce of some 2,300 people and has more than 20 subsidiaries.

Submitted by: **Alexander Räuchle & Eileen Nennstiel**

Field of activities

Pfeiffer Vacuum is a provider of solutions for industrial applications and research projects requiring vacuum in the very low pressure range. In this connection, the vacuum solutions include all processes and steps that are needed to create perfect vacuum conditions, including advice, products, accessories, training and service.

Products & services

Vacuum generation

- Rotary Vane Pumps
- Piston Pumps
- Diaphragm Pumps
- Pumping Stations
- Screw Pumps
- Side Channel Pumps
- Turbopumps
- Roots Pumps
- Multistage Roots Pumps

Vacuum analysis and measurement

- Vacuum Measuring and Control Devices
- Helium Leak Test Systems
- Leak Detectors
- Mass Spectrometer

Installation elements

- Components and Feedthroughs
- Manipulators
- Control Units
- Vacuum Chambers
- Valves

Training

- Application Support and Technical Service
- Customer Training

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PSTproducts

PSTproducts GmbH is the market leader for industrial state of the art Elector Magnetic Pulse technology (EMPT) -machine systems and for the implementation of the EMPT in industrial manufacturing processes. PSTproducts fabric EMPT Systems are used by international companies for mass production of components in automated production lines. The Electromagnetic pulse technology is capable to be used for forming, cutting and joining of tubes. Manufacturing of form fitting tube joints as wells as atomic bonding is possible. Moreover, PSTproducts EMPT systems are capable to do atomic bonding of sheet metal structures.

Submitted by: **Ralph Schäfer**

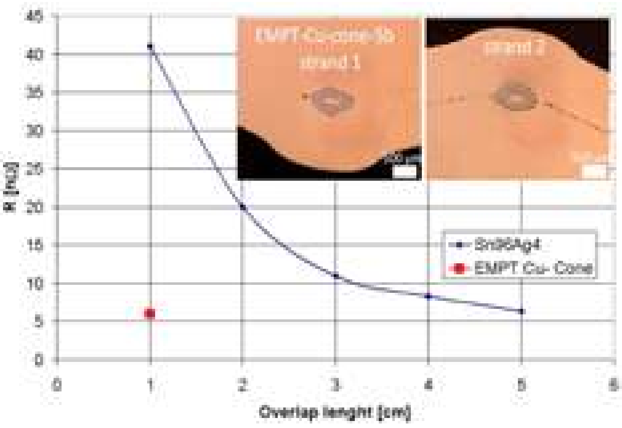
Field of activities

PSTproducts develops and manufactures equipment for EMPT: With the help of this equipment production of low resistivity cable crimps, helium tight welding of dissimilar metals or welding of superconductors is possible.

Products & services

Systems for Electromagnetic Pulse Technology (EMPT)

- High density cable crimping
- Helium tight welding of vessels
- Helium tight welding of thin walled structures
- Welding of superconductors



Relationship with academic research

PSTproducts cooperates with several German national universities, the Fraunhofer society, Tecnalia (Spain) and CERN.

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PINK Vakuumtechnik

Established in1986, PINK is well known in nearly every area of vacuum technology. Today, the two companies PINK GmbH Vakuumtechnik and PINK GmbH Thermosysteme with about 300 employees operate on a global scale from Wertheim / Germany. The company does not only supply individual, reliable plants and systems to its international customers as the automotive and component supplier sectors, the semiconductor, aerospace, chemical and pharmaceutical industries. It also produces UHV-components, which are successfully used by leading, famous medical as well as science and research institutes.
PINK´s capabilities reach from consultancy, engineering and project planning via design and production to supply, installation and dependable on-site service.

Submitted by: **Jörg Egly**

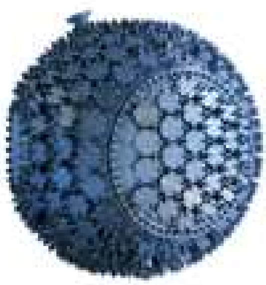
Field of activities

UHV conditions can only be reached with vacuum components of highest quality and precision, as they are required to run an accelerator. One example is the tumour therapy accelerator at the university clinic in Heidelberg/Germany, which started running in 2009. It consists of over 300 suitable UHV components. Highlight of those components is the IH-tank which is integrated as an essential part in the linear accelerator. Besides that the accelerator includes an amount of UHV chambers as dipole, septa and quadrupole chambers. PINK is also able to offer an extensive bake-out-test for such components. This test involves the pressure measurement, the determination of the leakage rate as well as the recording of a mass spectrum and the desorption rate.

Products & services

Special vacuum plants and custom-made systems as

- Accelerator systems (switching mirror units / dipole chambers / UHV-chambers etc.)
- UHV-coating technologies (cluster tool coating systems / magnetron sputter systems / modular UHV-systems)
- Customer-commissioned clean-room assembly
- Systems for high-vacuum thermal treatment
- Helium leak test systems
- Chambers and systems for aerospace technology



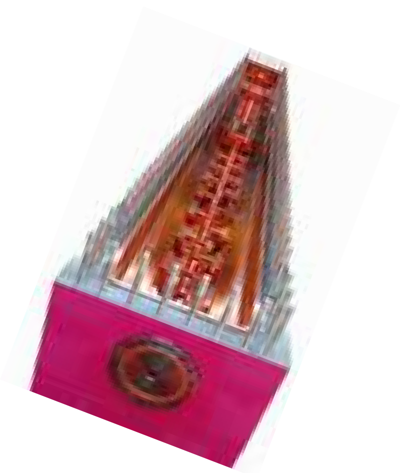
Special spherical chamber with a diameter of 650 mm and 230 CF flanges DN 40 for BESSY II, Berlin

- Vacuum soldering systems
- Low pressure plasma technology (activation, cleaning, coating, etching)
- Vacuum drying systems

Relationship with academic research

Synchrotron bumper chamber

- Helmholtz-Zentrum Berlin (BESSY), Germany
- DESY Hamburg, Germany
- CERN Geneve, Switzerland
- ESRF Grenoble, France
- Universitätsklinikum Heidelberg, Germany
- GSI Darmstadt , Germany
- PSI Villigen, Switzerland



Interdigital H-field structure, used in the LINAC section of tumor therapy accelerators

PiNK®

Jörg Egly (Dipl.-Physiker)
Project Manager

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PREVAC

Since its foundation in 1996 in Rogów, Upper Silesia, PREVAC Ltd. has been an internationally known leading manufacturer of scientific-research equipment used for studies under conditions of high and ultra-high vacuum. PREVAC specializes in delivering custom deposition and analysis systems to clients who find that standard, off the shelf "solutions" simply do not meet the expectations demanded by the very latest cutting edge experimental investigations. Its products, including ion, electron, x-ray, UV and thermal sources, chambers, sample conditioning, transfer and manipulation are fabricated entirely in-house and are installed globally and used by many of the world's leading researchers.

PREVAC can be distinguished by its highly skilled, young, dynamic and ambitious personnel consisting of the best specialists, who along with the longtime experience in the field of vacuum technology constitute the greatest potential of the company. The company employs of 160 professionals, of whom 38 are R&D constructors, manufacturing engineers and software developers.

Submitted by: **Andreas Glenz & Justyna Kowalska**

Field of activities

Precision and vacuum technology

Manufacturer of HV and UHV customized systems, manipulators, chambers, sample holders, instruments (like ion, electron, x-ray, UV, thermal sources), electronics and dedicated software.

Supplier of scientific equipment for laboratories, universities, research centers and industry.

A committed activist working for popularization of science, development, technology and applications of vacuum as a member of Vacuum Societies in various countries.

Products & services

Products

- HV and UHV customized systems
- Manipulators
- Chambers
- Sample holders
- Instruments
- Accessories
- Electronics
- Software

Services

- Design and manufacture of vacuum systems and components
- Electronic design services
- Repair of vacuum pumps and leak detectors
- Leak detection
- Vacuum baking of vacuum components
- Machining, welding and finishing
- Vacuum training courses

Relationship with academic research

France

- Synchrotron SOLEIL
- CNRS (Centre national de la recherche scientifique)
- ESRF (European Synchrotron Radiation Facility)
- LMSPC (Université de Strasbourg)

Germany

- Max-Planck-Institut
- Helmholtz-Zentrum Berlin für Materialien und Energie GmbH
- BESSY GMBH
- DESY
- Universität Rostock
- Universität Hamburg
- Technische Universität München
- Chemnitz University of Technology
- Universität Bielefeld
- Ruhr-Universität Bochum
- Darmstadt University of Technology
- Universität Duisburg-Essen Institut für Experimentelle Physik
- Universität Frankfurt
- Freie Universität Berlin
- XFEL

Spain

- Institut de Tecnología Química UPV-CSIC - Universidad Politecnica de Valencia
- Instituto de Ciencia de Materiales de Madrid, CSIC
- Universidad Autónoma de Madrid

Poland

- Adama Mickiewicza University
- Jagiellonian University in Cracow
- University of Science and Technology in Cracow
- Foundry Research Institute
- Polish Academy of Science
- Military University of Technology

Australia

- Australian Synchrotron

Italy

- CNR - Laboratorio Nazionale TASC-INFM
- Sincrotrone Trieste
- University of Camerino
- University of Genova, Department of Physics

China

- Chinese Academy of Science
- University of Science and Technology of China
- Shanghai Synhrotron Radiation Facility
- Shandong University

PREVAC

Adam Dziwoki
Technical and Production Director

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Reuter Technologie

REUTER TECHNOLOGIE was founded in 1953 as an apparatus engineering company. Most of the around 55 employees are with the company for a long time building a well-interacting and knowledgeable basis. Being situated between the Rhein-Main area and the Spessart hills convenient traffic requirements are met just as recreation opportunities needed for innovative ideas. Continuously having an eye on the technological and market developments REUTER has evolved to being an engineering specialist in UHV solutions and joining technologies.

Partners of REUTER TECHNOLOGIE are research institutes and universities just as industrial businesses of all sizes looking for innovative solutions in process technology.

Submitted by: **Markus Veldkamp**

Field of activities

REUTER TECHNOLOGIE sees itself as a development partner for customers in basic research as well as industrial environments. We offer a complete supply chain starting at R&D followed by engineering, machining, joining, assembly and testing of customer specific products. Knowledge and possibilities to run small to medium series production in house is also available.

Ceramic chamber

We develop high accuracy chipping and joining technologies for new materials just as subsequent cleaning procedures and functional characterisation. Our primary focus for product and process development is on joining technologies, particularly vacuum brazing, ultrahigh vacuum (UHV) technologies, cooling/heating systems and components and solutions for thin film deposition processes. REUTER TECHNOLOGIE is a member of the German "Fachgesellschaft Löten" (DVS).

Waveguide flange

Products & services

In terms of engineering, REUTER TECHNOLOGIE offers a wide range of services based on the CAD systems Pro/ENGINEER Wildfire 4, CATIA V5, Math-CAD and FEM calculations. Manufacturing of the designed solutions takes place using CNC turning, CNC milling, circular and face grinding, wire-cut EDM, surface treatment and laser marking. Vacuum brazing, also in an all-metal vacuum furnace, is being realized for dimensions up to 900 mm x 900 mm x 3700 mm. Additional joining possibilities cover TIG welding, laser welding as well as electron beam welding. REUTER TECHNOLOGIE operates a clean room ISO class 7 with an integrated flowbox ISO class 3 and offers highly specialised cleaning technologies to achieve SPC class 5 particle cleanliness (picture shows a diagnostic beamline section having been assembled in clean room ISO class 3).

For characterisation purposes, REUTER TECHNOLOGIE offers a wide range of services in-house. The outgassing behaviour of vacuum parts can be measured in a high-resolution UHV residual gas analysis work station. A very flexible helium leak test system down to 5·10-12 mbar·l·s-1 leak rate is available, too. For material properties characterization, we offer surface tests, hardness tests, pressure tests, permeability tests as well as ultrasonic and x-ray tests up to 3D. High-precision 3D-coordinate measurement systems are available for in-house manufactured parts, and as a customer service.

Diagnostic beamline section

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RI - Research Instruments

RI Research Instruments GmbH (RI) is a world leader in the development and manufacturing of electromagnetic and mechanic components and systems for particle accelerators and other applications in science, energy, medical and industry.
RI employs some 120 people, about 30% physicists and engineers, 60% manufacturing specialists and 10% employees with corporate function.

Submitted by: **Michael Pekeler**

Field of activities

As a worldwide accepted project oriented engineering and manufacturing company, RI's scope includes physics layout, design, production, assembly, testing and service. Key technologies are radio frequency (RF), particle accelerator, superconductivity and cryogenics, precision manufacturing and joining, surface treatment and system integration. Typical deliverables are normal and superconducting accelerator cavities and RF couplers, beam-line and diagnostic elements, particle sources, RF accelerator modules, linear accelerators, and special manufacturing products.

Products & services

Our main products and services are listed as follows:

- Linear accelerators
- Superconducting RF accelerator modules
- Superconducting and normal conducting RF cavities and couplers
- Radio frequency quadrupoles (RFQ)
- Particle sources (electron and ion sources)
- Particle beam-lines
- Beam diagnostic elements
- Special manufacturing projects (fusion, fission, nuclear)
- Prototype manufacturing

Superconducting 1.3 GHz cavity for the European XFEL

Turn key superconducting accelerator module

Turn key electron linac

High heat loaded components for JET

Relationship with academic research

Since many years RI is trustfully cooperating with the worldwide leading labs in accelerator and special manufacturing technology.
Special license agreements exist with several universities and institutes (Cornell University, DESY, Forschungszentrum Rossendorf). Those agreements enable us to manufacture components developed and designed at those universities and institutes for other international customers.

research instruments

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SDMS Technologies

Founded in 1962, SDMS technologies is a Manufacturer and Integrator of Innovative Technical Solutions, the Industrial Partner of reference for highly demanding customers.

With a worldwide presence on most high technological fields (Energy, Research, Defense & Space), SDMS technologies is today a company which employs 200 people, of which more than 40 engineers and managers.

- ***Consolidated Turnover : about 26 M€***
- ***Export rate : 15%***
- ***R & D budget : 4% of sales***

Submitted by: **Pascal Schummer**

Field of activities

SDMS technologies is a key supplier in the field of high-technology metal work and instrumented devices for Vacuum and UHV Technologies, Cryogenic Systems & Equipment, Mechatronics assemblies and HF power components for accelerators.

SDMS technologies designs and builds in clean workshops specific equipment made from noble metals: Stainless Steel, Aluminum, Copper, Nickel, Niobium, Titanium & alloys ...

Management of complex «turnkey» projects includes design, manufacture, assembly, testing and integration in our premises and on site, as per ISO 9001-2008 Quality Management Standard.

Products & services

Vacuum and UHV Equipment

- Vacuum and UHV chambers, dipole & quadrupole UHV chambers, thermal vacuum chambers, collimators, absorbers,…

Cryogenic Systems

- Cryostats, cryotanks, Dewars, cryopumps, cryomodules, cryogenic valves boxes, cryogenic transfer lines, HTS current leads, cold neutron sources, thermal shields and shrouds,…

HF power components for accelerators

- NC and SC accelerating cavities, HF resonators, RF coupling devices, wave guides,
- HF plasma heating antennas, RF sources components,…

Relationship with academic research

More than 50 % of SDMS technologies' activity is dedicated to Institutional Research Laboratories : CEA, CERN, CNES, CNRS, DESY, ESA, ESO, ESRF, FZJ, GANIL, GSI, ILL, KIT, ONERA, PSI, SCK, SOLEIL, US LABS (...), including:

EGO-VIRGO (interferometric gravitational wave detector): manufacturing of 10 UHV Vacuum Towers hoisting the SuperAttenuator (ultra-precise antiseismic suspensions system for the optical components).

GSI-FAIR: manufacturing of the Large Acceptance Dipole Magnet Vacuum Chamber @ 4.6 K & 6 T (Spectrometer for exotic beam analysis from Super-FRS) – 25 tons.

KIT Karlsruhe KATRIN Project: Electrostatic Beta pre-spectrometer - vacuum chamber at 10^{-10} mbar, for electron neutrino mass measurement.

CERN-LHC: Local cryogenic distribution system for liquid Nitrogen and liquid Argon supply to calorimeters of ATLAS instrument (transfer lines + valves boxes).

CEA - LMJ: design and manufacture of large cryostat for Laser Megajoule targets fill-up with deuterium/tritium at 1400 bar & 19 Kelvin.

GANIL - SPIRAL 2: manufacturing of pure niobium superconductive acceleration cavities including UHV electron beam welding and clean room assemblies.

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Sumitomo Heavy Industries

Sumitomo Heavy Industries, Ltd. (SHI) has a tradition of excellence and innovation that spans over 400 years. From its very beginning as a small shop selling medicines and books in Kyoto, Japan in the early 17th century, to its current status as a diverse, $6 billion corporation, SHI has continued to grow and flourish in an ever-changing international market.

SHI's acquisition of IGC-APD Cryogenics, Inc. in 2002 brought together two of the world's leading cryogenic companies to form the SHI Cryogenics Group, with an unsurpassed tradition of design, development and success in the manufacture of cryogenic equipment.

SHI Cryocoolers, Pulse Tubes and Cryopumps continue this tradition by supporting both global research & development, as well as state-of-the art technologies. Today, applications of cryogenic technologies can be found in our daily lives. SHI's cryogenic products are used directly or in the manufacturing of many of the world's medical, semiconductor, telecommunications, electronics, biochemical and other industrial products.

The SHI Cryogenics Group now has nine locations to serve its customers, with two offices in Europe, three in the United States and four in Asia. In addition, a worldwide network of sales and service representatives strengthen the company's position as an international leader of cryogenic equipment.

Submitted by: **Hermann Boy**

Field of activities

SHI Cryogenics Group's global offices participate in a combination of R&D, design, manufacturing, sales and service of Cryocoolers, Pulse Tubes and Cryopumps. R&D activity is based in Tokyo (Cryogenics Division), Yokosuka, Japan (Corporate R&D Centre) and Allentown, PA, USA (Sumitomo (SHI) Cryogenics of America, Inc.).

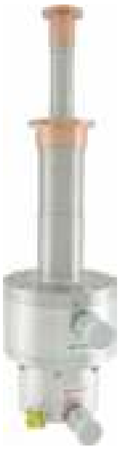
Products & services

SHI Cryogenics Group designs and manufactures a variety of Cryocooler types, including: Gifford-McMahon, Solvay, Pulse Tube and GM-JT, with a temperature range from 4 to 77 Kelvin.

In addition, the company designs and manufactures a variety of Cryopumps, ranging in size from 200 mm (8 in.) to 500 mm (20 in.), with the option of fully-automated operation.

RP-062B Pulse Tube (0.5W @ 4.2K)

RDK-408D2 4K Cryocooler (1W @ 4.2K)



CH-204 10K Cryocooler

CP-12 Cryopump (320mm)

Relationship with academic research

Over the last several years, the SHI Cryogenics Group has collaborated on projects with national research facilities around the world, including:

- National Astronomical Observatory of Japan (NAOJ)
- Atacama Large Millimetre Array (ALMA)
- Rutherford Appleton Laboratory (RAL)
- European Organization for Nuclear Research (CERN)
- Deutsches Elektronen-Synchrotron (DESY)
- GSI Helmholtz Centre for Heavy Ion Research GmbH
- Helmholtz Center Berlin
- FRM II Munich
- Oak Ridge National Laboratory

SHI Cryogenics Group

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VACOM - Vakuum Komponenten & Messtechnik

VACOM is one of the market leaders for vacuum technology in Europe. The company with more than 160 staff members develops and produces a wide range of vacuum products coupled with technical expertise. VACOM is specialized in custom vacuum components and chambers, vacuum metrology and vacuum optics for HV to XHV. The wide product range is complemented by comprehensive service for highly demanding requirements in industry and research.
Innovative companies e. g. in the field of analytics, semiconductor process vacuum incl. EUV technology, optics, analytics, accelerators, and renowned research institutes like Max Planck, Fraunhofer and Leibniz association members as well as international synchrotrons rank among VACOM' s long-term customers.

VACOM has own R&D staff, up-to-date construction and production equipment as well as highly qualified personnel. The entire production process is carried out in-house and supervised throughout. This enables us to meet your special needs and requirements in a flexible and efficient way. VACOM is ISO 9001:2000 certified. In addition welding procedures are certified according to ISO 3834-2.

Submitted by: **Wilfriede Fiedler & Andreas Müller**

Field of activities

VACOM's core competencies are: The design and production of a wide variety of customised components and chambers, the development of vacuum metrology and different vacuum optics solutions including viewports and optic fiber feedthroughs especially for UHV to XHV conditions. This includes experience in the special needs of accelerators. In addition to the highest precision during CNC processing and welding we turn our special attention to a sophisticated surface treatment and cleaning procedure under clean room conditions.

Our processes are under constant development. More than 20 members of our R&D team will be on your side to give any support possible. Brainstorming sessions can be performed efficiently by means of video conferencing.

Products & services

VACOM custom component

- Stainless steel 1.4429 ESU according to CERN and DESY standard on stock
- Customised chambers and components e. g. button BPM for beam position monitoring
- VaCFix® the quick CF solution → combines the principle of KF with the vacuum properties of CF (saves up to 90 % of assembly time)
- Gauges from atmospheric pressure down to < 5x10-12 mbar
- BARION® XHV → hot ionization gauge with x-ray compensation
- Cleaning of components according to customers' demands including the verification of the cleanliness by residual gas analysis and cleanroom packaging
- Viewports and optic fiber feedthroughs
- Safety caps for x-ray shielding

VACOM BARION XHV gauge and MVC3-B controller

VACOM VaCFix quick CF clamp chain

VACOM optic fiber feedthrough

VACOM ultrasonic cleaning system

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WESGO Ceramics

WESGO Ceramics GmbH (WESGO) is a premium supplier of high purity Aluminium Oxide ceramic components specialising in engineered and metallised products, as well as ceramic-metal assemblies, and active braze technology for a variety of demanding applications. WESGO produces ceramic parts and components according to customer requirements.

Size of the company: 130 employees
Markets served: Space/Aerospace, Laser, X-ray, and Scientific/Research
Turnover in 2011: €18,6Mio.

Submitted by: **Dieter Steudtner**

Field of activities

Besides medical diagnostics, industrial applications or electronics WESGO has a considerable share in the field of Astrophysics. WESGO produces vacuum chambers and feedthroughs, microwave tubes, couplers and ceramics for mass spectrometers.

Products & services

Starting with Al2O3 powder in different grades WESGO presses the parts machine them in the "green stage" and finally sinter the ceramic. WESGO ends up with "as fired" parts, precisely machined bare parts, metallised ceramics (MoMn) up to brazed assemblies covering the entire range of engineered technical ceramic parts. If it is a wave guide for Lasers or Anode- or Cathode-ceramic for x-ray finally the decisive factors are the material properties and the tight tolerances we keep, actually the entire production process that guarantees parts of excellent quality.

Relationship with academic research

Since many years WESGO has been a very reliable partner for DESY, CERN, ESA, Astrium, University of Bern, Max Plank Institute, GSI, Jefferson Lab (US) and a lot more. These tubes, rings or special designed, shaped parts with very tight tolerances are used in high end applications.

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