CHAPTER 6

ACTIVITY REPORT

2010 - 2012

ACCELERATORS RESEARCH AND DEVELOPMENT

Accelerator Research and Development

The Accelerator Division is in charge of research and development activities about the accelerator technologies and the operation of technological infrastructures of the Institute. The following article briefly describes a large variety of topics investigated by the Accelerator Division during the reporting period. Highlights concerning the operational aspects of the facilities are also presented as well as the performances and new developments achieved in different topics. The major part of these developments is related to the projects in which the Institute is engaged as a leader or as an important partner through its Accelerator Division. A significant part is also dedicated to technically very challenging R&D in the accelerator field.

1. General introduction

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During the last ten years, the IPNO, through its Accelerator Division (AD), has brought a significant contribution to the feasibility study of a large number of accelerator projects or programs: SPIRAL2, EURISOL, PDS-XADS, LHC, ETOILE… Through their increasing commitment and participation to these projects, the AD's teams play a prominent part in the community, especially in the linear accelerator field.

The mission of the Accelerator Division is focused on the research, development and the advancement of accelerator technology. On the one hand, its activity is carried out on the conception and completion of accelerators and associated instrumentation. On the other hand, a strong activity is focused on the operation of the transnational access facility Tandem-ALTO, serving users worldwide. The topics under investigation include:

- target and ion source for stable and radioactive beams;
- superconducting RF (SRF) accelerating cavities and associated RF equipment;
- instrumentation, including accelerator electronics and beam diagnostics;
- cryogenic systems.

The whole activity is carried out within national and international projects or collaborations such as ALTO, ANDROMEDE, Spiral2, IPHI, MYRRHA, ESS, SPL etc. In each one, IPNO plays a major role as a leader or an important partner. The activity covers the three general areas of the accelerator domain:

- accelerator components (particle sources, injectors, RF devices, magnets, diagnostics…);
- accelerator technologies needed for the operation of an accelerator facility (vacuum, RF, cryogenics, electronics…);
- new accelerator concepts.

The AD activity is mainly oriented following four axes:

- Stable and Radioactive Beams;
- High Power Superconducting linacs;
- LHC upgrade;
- Generic R&D.

In connection with these topics, forefront R&D work is promoted to maintain the level of expertise and also to anticipate solutions to relevant key technological issues related to the development of future accelerators. This R&D activity is mainly focused on the conception of

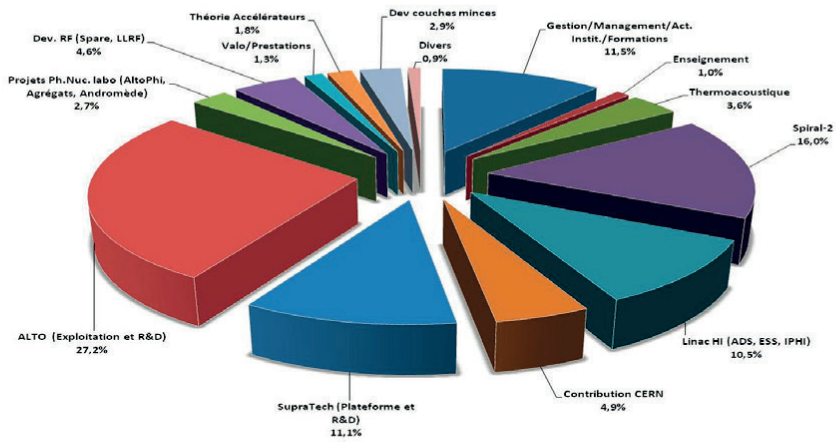

Figure 1: Distribution of the Accelerator Division resources over the whole activities.

accelerators and the associated systems: beam dynamics simulation, modeling of accelerator components (ion sources, SRF cavities, RF equipment…) and the development of new calculation tools.

The management of the activity is based on the organization of the division: through projects and around two thematic poles, ALTO and SupraTech. These poles are interfaced with three transverse groups: theory, electronic engineering and design office. The staff is composed of 49 engineers, 2 physicists and 45 technicians; 20 % of the staff works in priority for the operation and maintenance of the facilities, see figure 1.

2. Facilities

Tandem-ALTO facility

The Tandem-ALTO facility is powered by two major accelerators: a 15 MV- MP Tandem dedicated to stable beams (ions and cluster) and a 50 MeV linear electron accelerator dedicated to the production of radioactive beams. The facility offers the opportunity to produce, within the same place, cluster beams for interdisciplinary physics and stable and radioactive beams for astrophysics and nuclear physics. The delivered beams are dedicated to a large range of physics cases from nuclear structure to atomic physics, cluster physics, biology and nanotechnology. An additional 4 MV single-ended Van de Graff accelerator will also be available for a 'clusters' application (ANDROMEDE project): it will provide cluster beams for the investigation of surface analysis. The operation of this machine is planned by 2015.

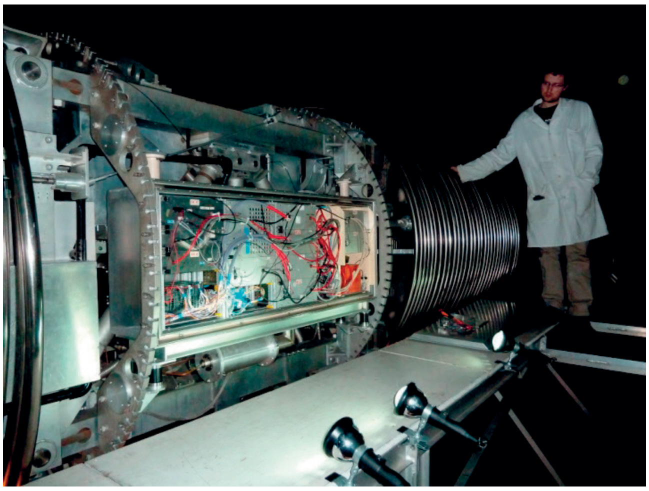

Figure 2: New Command-Control system set up at high voltage for the Orion ion source

A large number of scientists, engineers and technicians work at the facility, for the benefit of users, to ensure smooth operation, continuous improvement in performance and technical and logistic support.

The Tandem accelerator was routinely operated during 2010-2012. About 75 beams were tuned for experiments and delivered:

- 45 % for Nuclear physics and Astro-physics;
- 17 % for the clusters and Astro-Chemical;
- 30 % for instrumentation and other applications;
- 8 % for irradiation.

The number of operational hours (beam availability or used) has increased to 4904 hours/year, with 86% availability. About 406 hours of unscheduled downtime were due to failures predominantly occurring within the injector, the laddertron and the ion source. The failures related to the accelerator were caused mainly by the bearings of the laddertron wheels at the terminal and the rupture of the chain. The failures of the injector were due mainly to problems with the power supply and the cesium ionizer.

During the last 2 years, an effort has been made to improve the reliability and the beam quality. Technical improvements have been marked by the setting up of a new remote control based on a control command system at high voltage up to 15 MV, see figure 2. Such a system will allow a better operation of the Orion ion source which is dedicated to the production of Au clusters.

Moreover, a new generation of surface ionization ion source has been tested on the injector. The yields obtained have been compared to those of the usual Cs sputter ion source (IONEX 834). A significant gain of a factor 10 has been observed (100 μA of ^{12}C instead of 10 μA). The next step will consist of providing and accelerating a high intensity ^{48}Ca beam (100 nA).

Regarding the radioactive beams, many tasks have been achieved to reach a routine production at the ALTO facility. A large part of these tasks has been accomplished to meet safety standards. In particular, the shielding designed for a target-ion-source unit producing about 1011 fissions/s has been experimentally validated; the array of nγ detectors which covers the sensitive area of the experimental hall has been successfully tested; the system collecting radioactive gas from the

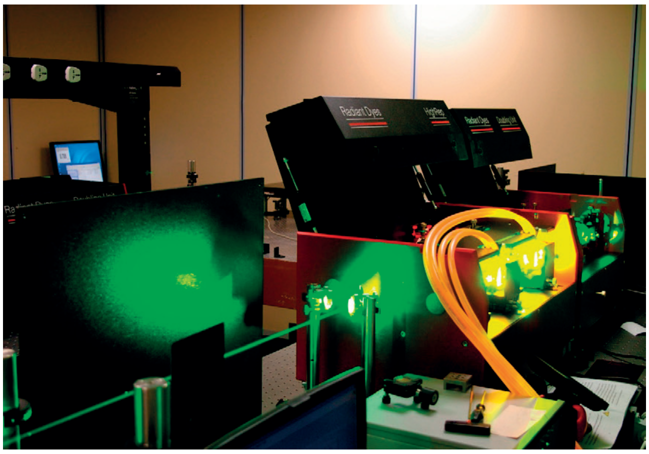

Figure 3: First dye laser system installed inside the laser platform dedicated to on-line selective ionization and laser spectroscopy

vacuum pumps has also been validated. An equally important part of these tasks has been realized to produce the nuclear beams more efficiently. Various developments have been achieved on the target-ion-source unit, which is the central component. To produce the best target materials, various synthesis methods have been investigated. Experiments with irradiation have been achieved to determine and compare the release efficiencies of each target prototype. In parallel, experiments have been carried out to run a new FEBIAD-type ion source. The prototype, called IRENA (Ionization by Radial Electron Neat Adaptation), has given very promising off-line results in unfavorable operating conditions. These tests are still in progress to get the best configuration for the production of radioactive nuclear beams on-line. In addition, a laser platform based on the dye laser technology has been completed to run the resonant ionization by laser ion source (RILIS) at the ALTO facility, see figure 3. In particular, neutron-rich Ga beams have been selectively and efficiently produced. Taking into account all these achievements, the Nuclear Safety Authority (ASN) issued the operating license to the ALTO facility at the beginning of 2012.

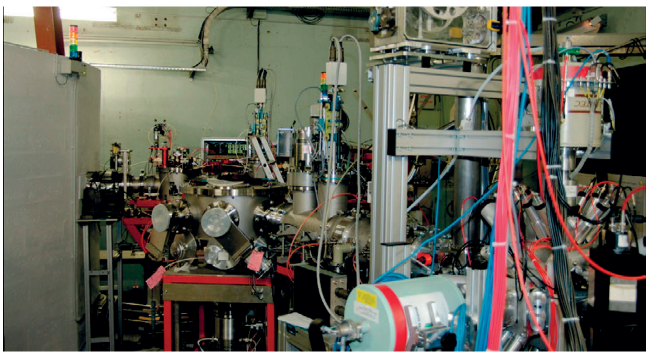

Figure 4: BEDO,the ALTO experimental beam line for beta decay spectroscopy

The ALTO facility can deliver the radioactive nuclear beams to five different experimental set-ups. One of these five set-ups, dedicated to beta-decay spectroscopy, has already been completed, see figure 4.

The first scheduled experiment at ALTO has successfully validated the transmission of the radioactive beams up to the set-up and the efficient operation of the set-up itself.

Thin targets facility

A dedicated facility is available at the Pole ALTO for the development and manufacturing of stable and radioactive self supported thin targets. They are particularly used as targets for the study of nuclei and molecules and as filters in high power laser shots.

The facility provides metallic thin layers (natural elements and isotopes) and various polymers. These targets may be monolayer or multilayer. To meet the demands and the difficulty of finding isotopes in metallic form, the group has begun the implementation of a reduction process. For example, a study is ongoing to reduce the strontium carbonate to strontium oxide and the strontium oxide to strontium. The laboratory is equipped with a centrifuge to provide thicker targets. Molybdenum targets of 10 µm thickness have hence been realized. Recently, the laboratory has received a roller mill operating at atmospheric pressure for thinning foils. First tests have been performed with titanium and silver. Other tests with uranium samples are underway.

Since 2010, the group has been involved in the CACAO project (Chimie des Actinides et Cibles radioActives à Orsay) which consists in the installation of a hot laboratory dedicated to the production and the characterization of thin radioactive layers. The objective is to fulfill the needs of the whole French community and to be able to coordinate the different activities related to radioactive targets. The new facility is presently in operation. The production is based on the electrodepositing process.

The first deposed targets of ^{232}Th/0.8µm-Al, ^{235}U/20µm-Al and ^{238}U/20µm-Al have been developed and used for experiments at CERN, Tandem-Orsay and IRRM. A further study of the electrodepositing of the gadolinium is underway. This study allows to optimize different parameters such as dissolution, current/voltage ratio etc. The characterization uses different techniques: alpha spectrometry, alpha autoradiography, AFM, SEM and RBS in collaboration with a team from CSNSM.

Technical platform SupraTech

SupraTech is a technological platform dedicated to the research and developments on superconducting cavities for the future high power and high energy particle accelerators. The platform provides all necessary equipments to prepare, condition, assemble and test superconducting cavities for the superconducting technology based projects in which the IPNO is involved. The main equipments of SupraTech are:

- the surface treatment laboratory for the chemical etching of the cavity surface;
- the 85 m² clean room for preparing and assembling cavities in a mandatory dust free environment;
- cryogenic test halls hosting vertical and horizontal cryostats to perform cryogenic experiments, both equipped with high capacity pumping stations to allow cryostat operation down to 1.6 K;
- high power RF sources at 88 MHz, 352 MHz and 704 MHz for cavity and coupler conditioning and testing;
- a 70 liter/hour helium liquefier to provide liquid helium for the cryogenic experiments, and a recovery/compression/storage network for the helium gaz.

These equipments have been progressively installed and commissioned since 2006 and are now intensively used for the completion of research programs like SPIRAL 2, MAX and ESS. Since 2010, the development of the platform has been pushed further on with the installation, in the 106 building, of a new experimental hall dedicated to cavity cryogenic tests, see figure 5. Located in the former "AGOR's cyclotron pit", this new experimental facility increases the cavity test capability, and especially will give the possibility to test complete cryomodules at 352 and 704 MHz thanks to the concentration, in one area, of the RF power sources and the high cryogenic power capacity down to 1.8 K.

To host the required two large helium pumping stations, a 150 m² extension of the building 106 has been constructed and achieved in 2011. Helium pumping lines are now being installed between this extension and the cryogenic hall, see figure 6; two large pumping stations have been ordered and their installation will finalize the platform.

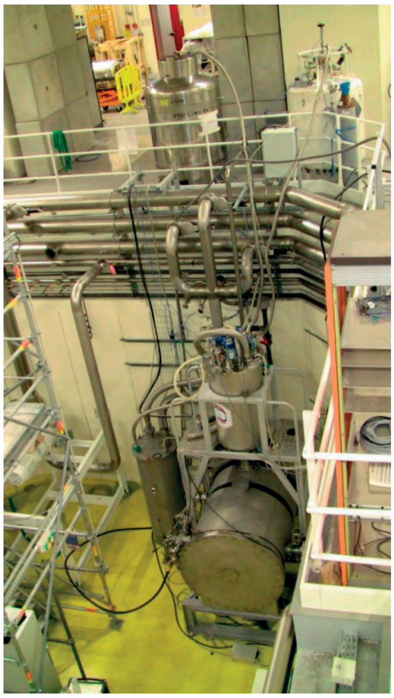

Figure 5: Experimental hall for cryomodule tests.

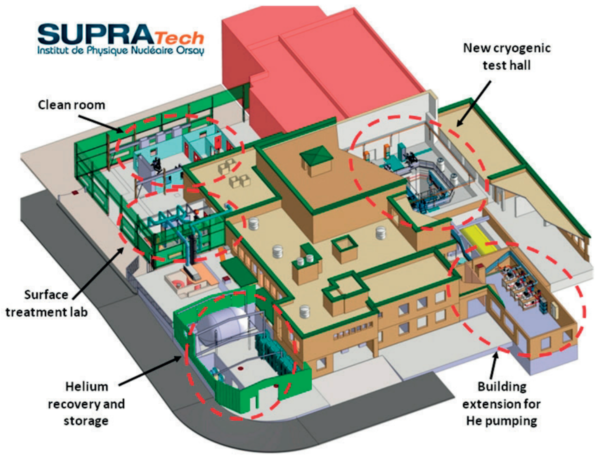

Figure 6: 3D view of the SupraTech main building

3. High power superconducting Linac activity

MYRRHA project

The MAX (MYRRHA Accelerator eXperiment, research and development program) project ensues from the recommendations of the European Union's Strategic Energy Technology Plan for the development and deployment of sustainable nuclear fission technologies in Europe. MAX participates in addressing the issue of high-level long-lived radioactive waste transmutation by pursuing the development of the high-power proton accelerator

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as specified by the MYRRHA Accelerator-Driven System (ADS) demonstrator project. MYRRHA ("Multi-purpose Hybrid Research reactor for High-tech Applications") is a new flexible fast spectrum research reactor that is planned to be operational around 2023 in SCK-CEN Mol (Belgium). Composed of a proton accelerator, a spallation target and a 100 MWth core cooled by liquid lead-bismuth, it is especially designed to demonstrate the feasibility of the ADS concept in view of high-level waste transmutation. To feed its sub-critical core with an external neutron source, the MYRRHA facility requires a powerful proton accelerator (600 MeV, 4 mA) operating in continuous mode and, above all, featuring a very limited number of unforeseen beam interruptions. The MAX team, made up of accelerator and reliability experts from several European industries, universities and research organizations, has been set up to respond to these very specific twofold specifications.

The conceptual design of the ADS-type proton accelerator was initiated during previous EURATOM Framework Programs (PDS-XADS and EUROTRANS projects). It is a linac based solution that brings excellent electric efficiency thanks to the use of superconductivity as well as a high reliability potential by the use of several redundancy schemes. The MAX team is pursuing the R&D on this ADS-type accelerator, specifically focusing on the MYRRHA case: the main goal of the MAX project is to deliver an updated consolidated reference layout of the MYRRHA LINAC with sufficient detail and an adequate level of confidence in order to initiate in 2015 its engineering design and subsequent construction phase. To reach this goal, advanced beam simulation activities are being undertaken and a detailed design of the major accelerating components is being carried out, building on several prototyping activities. A strong focus is also put on all the aspects that pertain to the reliability and availability of this accelerator, since the number of beam interruptions longer than three seconds has to be minimized. Such frequently-repeated beam interruptions could indeed induce high thermal stress and fatigue on the reactor structures, the target or the fuel elements, with possible significant damages especially to the fuel cladding.

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Beyond the activities linked to the MAX project management (IPNO is the project coordinator), the main scientific results obtained by the IPNO team during the first part of the project (2011-2012) are the following:

- Fine-tuning of the accelerator layout: participation to the definition of the new 176 MHz injector and its transfer lines (LEBT, MEBT); consolidation of the main superconducting linac and its associated high-energy final beam line; advanced beam simulations from the injector output to the target; update of the retuning schemes in case of cavity faults; beam dynamics codes benchmarking in the RFQ, CH-booster and main linac sections.

- Preliminary design of the MYRRHA Spoke cryomodule: participation to the definition of the cryogenic operating temperature (2 K); design of the MYRRHA single-spoke cavity (352 MHz, beta 0.37); conceptual mechanical & cryogenic design of the cryomodule that will host 2 cavities, including first CAD models.

- Experiments using the 700 MHz beta 0.5 prototypic accelerating module installed in IPNO and developed during the previous FP6 EUROTRANS programme: full qualification at low RF power and 2 K with successful results (accelerating fields up to 12 MV/m); studies on cold tuning system and associated control loops; participation to the definition of dedicated 700 MHz solid-state amplifiers and associated distribution lines; preconditioning of the RF power couplers; the next step will consist in qualifying the module at nominal RF power (50 kW) before starting a reliability-oriented experimental campaign.

http://ipnweb.in2p3.fr/MAX/

Work coordinated by CNRS/IPNO & supported by the European Atomic Energy Community's Seventh Framework Program under grant agreement nr. 269565.

European Spallation Neutron Source (ESS)

The European Spallation Source (ESS) is the future European neutron source that will be constructed in Lund (Sweden) and produce its first neutrons in 2019. The source is based on a 5 MW proton accelerator delivering a 2.85 ms long pulse of 50 mA proton beam at 2.5 GeV to the target station for neutron production. The project is presently in an active design phase to determine the final layout and technical component structure in order to be able to launch the fabrication phase in 2013. IPNO is actively participating to the ESS accelerator, especially the superconducting part, through two main tasks: the design of all components (spoke cavities, couplers, tuners and cryomodule) composing the intermediate energy section of the linac and the study of the cryomodule for the two families of elliptical cavities.

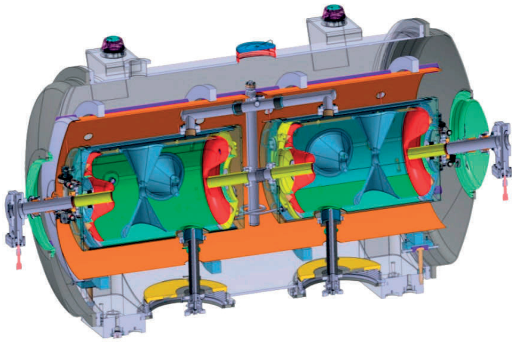

Figure 7a: Actual design of the spoke cryomodule.

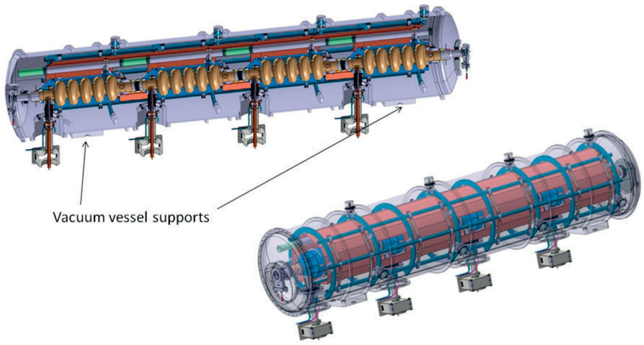

Figure 7b: Design of the elliptical cryomodule.

In ESS, the superconducting spoke section of the linac accelerates beam from the normal conducting section to the first family of the elliptical superconducting cavities. Acceleration will be performed by a single family of 0.5 bulk niobium double spoke cavities operated at 2 K, and 352.2 MHz. A total of 28 spoke cavities, grouped by 2 in 14 cryomodules, are laid along the 58.6 m of the spoke linac length. The chosen operating accelerating field is 8 MV/m and the required peak RF power to supply the cavity is about 250 kW for the 50 mA beam intensity. The design work has started in April 2011, and several important achievements have been performed over the first 18 months. The spoke cavity design has been achieved, with special attention paid to the peak field optimization and the cavity mechanical properties. In parallel, the design of the cold tuning system and the power coupler for the spoke cavities is being conducted. Both are inspired from previous developments in the framework of the Eurisol project, but integrate the specific requirements of the ESS accelerator (mainly high peak power and pulsed operation).

All cryomodules of the whole ESS accelerator – for spoke, medium and high β elliptical cavities - will be conceived and designed by IPNO. For the different linac sections, several cryostat configurations and solutions are being studied in order to optimize cryogenic performances, physical lengths, assembly easiness, alignment accuracy, mechanical stability and costs. The actual cryomodule configuration for spoke and elliptical cavities are illustrated in Figure 7a and 7b.

High power RF source SPARE

In the framework of large European programs in particle and nuclear physics, the European scientific community develops and builds large scientific instruments such as linear particle accelerators (FAIR project in Germany, LINAC4 at CERN, ESS in Scandinavia). These linear accelerators projects which are under construction or going to be built in the coming years have some common needs in terms of RF power sources. Up to 2010, there was no technology available in Europe for such RF power sources. In addition, there were not even any RF power stations to test and validate several accelerator key components at full power, including RF power couplers, superconducting cavities and the whole cryomodules. In this context, IPNO will set up an RF power test station able to deliver a peak RF power of 2.8 MW (1.5 ms, 50 Hz or 3 ms, 14 Hz) at the required frequencies of these accelerators (352 MHz and 704MH). The station will be integrated into the technical infrastructure SupraTech, see figure 8.

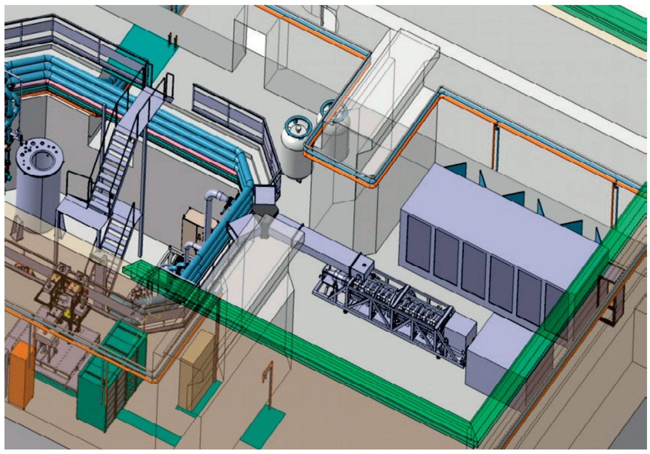

Figure 8: 3D view of the building

A collaboration agreement between Thales Electron Devices Company and the CNRS has been signed to study, implement and test a klystron. IPNO was in charge of the study and the simulation, with the FLUKA code, of the cross bar (transition waveguide - coaxial output), and also of the simulation of the radiation levels emitted by the klystron.

Once realized, the klystron was delivered to IPNO. In the meantime, IPNO has studied all power supplies required for the klystron operation. The specifications of all auxiliary power supplies (required for the feeding of the filament and three solenoids) were investigated. All power supplies were received and tested on resistive loads.

4. Radioactive Beams activity

Spiral2 project

As a major partner, IPNO is committed in the conceptual design and construction of the Spiral2 facility. The Accelerator Division has the responsibility of the following tasks:

- beam dynamics and commissioning;
- cryomodules B of the high energy part;
- cryogenic plant;
- diagnostics: overall coordination and beam position monitor (BPM);
- Febiad ion source and UCx production target;
- cryotrap.

Regarding the 'Beam Dynamic' task, studies have been performed on the high energy beam transport lines which deliver stable beams to the experimental areas (including NFS and S3), radioactive production cave and beam dump. In a second phase of the project, it is foreseen to built a heavy ion source with q/A=1/6 with its associated injector, allowing the increase of the beam energy up to 8.5 MeV/u. This option has been taken into account in the design of the HEBT lines.

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The beam optic design in the NFS converter room is now completely achieved. Precise errors calculations were made last year in order to validate completely all aspects and choice of the beam line. The magnetic primary beam rejection dipole located behind the neutrons converter (work package under the responsibility of IPNO) is now under construction.

For the production zone of the facility, the cryogenic design of the Cryotrap has been delivered. This equipment, crucial for safe operation of the facility, consists in a 'two-stages' radioactive gas trap operating at 80 K and 20 K. It will operate in a strongly radioactive zone. Due to safety constraints, the use of liquid helium has been rejected. Instead, a 10 K cryogenerator cold head will be plugged directly on the 2 trapping stages, using the recently designed CRYOCOUPLEUR.

The progress of the main tasks is described in the following sections.

Cryomodules B of the high energy part

The SPIRAL 2 superconducting linac is composed of 2 cryomodule families. In the low energy section, the first family, consists of 12 cryomodules, called cryomodules A, housing a single cavity with β=0.07. In the high energy section, the second family, is composed of 7 cryomodules housing 2 cavities with β=0.12. The frequency of these quarter wave resonators (QWR) is 88.050 MHz and the design goal for the accelerating field Eacc is 6.5 MV/m.

The mass production of the 16, β=0.12, Quarter-Wave Resonators has been finished in December 2009. From July 2008 to May 2010, 32 vertical tests have been carried out and ended up in qualifying all the 16 cavities: i.e. Eacc>6.5 MV/m with less than 10W of cryogenic losses @4.2 K, see figure 9. During this qualification test period, IPNO has developed a specific heat treatment of the cavities (baking at 120 °C for 48 hours) in clean room. Thanks to this equipment, the cryogenic losses were divided by a factor of 2 at nominal gradient.

In parallel to these RF and cryogenic qualification tests of cavities, several vertical tests were successfully performed in April 2010 to validate the performances of the pre-series dual-layer magnetic shield.

2010 was the year of delivery of most of the material and equipment and, above all, the assembly and test of the first cryomodule. The first one of the six cryomodules was delivered in Orsay in December 2009 and the last one in October 2010. All magnetic shields and superconducting plungers were received between

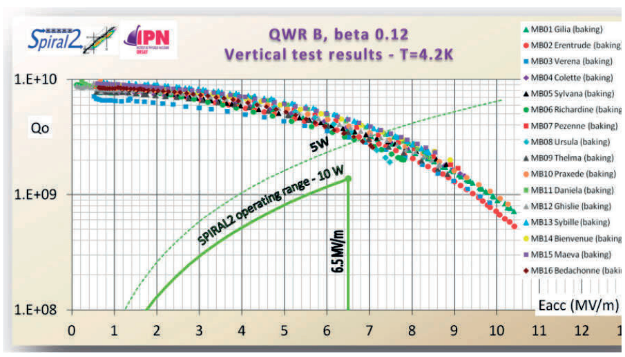

Figure 9: Vertical tests results @4.2K for the 16 beta 0.12 QWRs spiral2 cavities

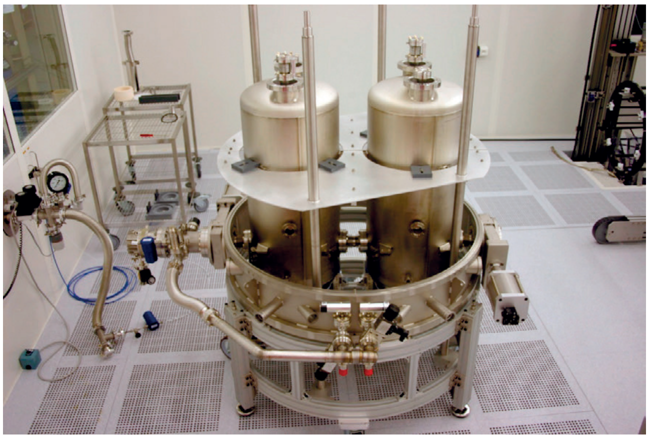

Figure 10: A couple of spiral2 cavities assembled in the clean room on the cryomodule mid-part.

March and July 2010. The first cryomodule was assembled by summer 2010 and the RF and cryogenic test took place in October 2010, followed, immediately after, in January 2011, by the test of a second cryomodule, see figure 10.

These two tests did not allow us to fully validate the performances of each cryomodule. Despite a good vacuum, a fast and reproducible RF conditioning of the couplers and static cryogenic losses of the cryomodule within the specs (i.e. <15W), 3 out of 4 cavities' gradients were limited at values smaller than 6.5 MV/m due to strong field emission. In June 2011, a new test of a third cryomodule was not successful once again. Since then, an intensive campaign of research of pollution sources has started. Very strong efforts were made to identify, track, and correct all potential and identified causes of pollution. Two new tests of a "hybrid" cryomodule, dedicated to those pollution problems, were performed in December 2011 and March 2012. By dividing the field emission rate by more than 3 orders of magnitude, the last test gives us good hope to solve this problem. The next cryomodule assembly and test will bring the final validation of the cryomodule performances.

Cryogenic plant

The AIR LIQUIDE refrigerator system that will be used to supply liquid helium to the Spiral2 linac was tested at the company stand in June 2012. Tests were satisfactory, although one could not reach the guaranteed values due to the flow limitation of the compressor used (65% of the nominal flow). The main working modes were tested, especially the nominal mode with simulation of the thermal shield dissipation with a specifically fabricated module and the helium cryomodule dissipation with a heater placed in the dewar. All the components of this installation are now ready to be installed.

Figure 11: Cryogenic distribution boxes for the Spiral2 linac.

The fluid connection between the refrigerator and the cryomodules is done through the main transfer line composed of a series of interconnected valves boxes, see figure 11. To be complete this transfer line is waiting, the manufacturing of the last components at the subcontractor's (CRYODIFFUSION) factory. They will be ready in October 2012.

Beam Position Monitors

A doublet of magnetic quadrupoles is installed between the cryomodules for the transverse horizontal and vertical focusing of the beam. The fine tuning of the LINAC requires the measurements of the position and phase of the beam which will be achieved by a set of 20 Beam Position Monitors (BPM). In order to save room, each BPM is inserted in a vacuum pipe, itself integrated in the quadrupole magnet. The BPM are mechanically indexed to the quadrupole to insure that the location of the electrical center is known with accuracy better than 0.2 mm. BPMs are made of stainless steel. Due to the location of the BPM sensors, special care has been taken for the quality insurance of the realization of this sensor. All the components of the sensors are individually tested and measured: for example the capacitance of each feedthrough is measured and their impedance profile is measured using the time domain reflectometry method. A test bench (based on a coaxial transmission line) has also been designed and built to check the time response. Other measurements with the test bench are carried out to provide data concerning the calibration and sensitivity of the BPM. Finally we have tested the mechanical assembly of the BPM prototype in the quadrupole. The electronics associated to the BPM sensors is realized in the framework of a SPIRAL2 / BARC and TIFR Institutes (India) collaboration.

Target Ion Source System

The ALTO facility has a long experience in the production of radioactive nuclear beam by ISOL technique. In recent years, developments on targets and ion sources have been achieved mainly for the future SPIRAL2 facility and the European projects EURISOL-NET and ACTILAB.

In the framework of SPIRAL2, the ALTO group has started an exhaustive R&D program on uranium carbide targets, focusing on the synthesis of porous material having high uranium concentration. This R&D program is carried out in collaboration with the radiochemistry group of IPNO and the group "Sciences Chimiques" of Rennes University. In particular, the feasibility of an experimental setup for characterizing the release of fission products from different samples has been demonstrated. This setup has been used to compare the release kinetics of different prototype materials at 1200°C and 1550°C, see figure 12. The results obtained, as well as the physicochemical properties of these materials, have been detailed in two SPIRAL2 technical reports. Recently, a paper summing up these exhaustive results has been accepted for publication in "Nuclear Instruments and Methods B Journal". The results obtained so far bring to light that many parameters of influence have to be taken into account to well control the synthesis process. To further investigate rapidly some of these parameters, systematic measurements are planned with lanthanum as a substitute of uranium.

To produce efficiently and reliably the various radioactive nuclear beams of interest, ALTO group is also responsible for a R&D program on ion sources. In the framework of SPIRAL2 and EURISOL-DS, a prototype of plasma ion source has been designed: the IRENA ion source (Ionization by Radial Electron Neat Adaptation). The concept of this type of FEBIAD source has been experimentally demonstrated and results obtained so far under unfavorable operating conditions show the possibility to work out a very competitive prototype. The results obtained have been summed up for a contribution at the international conference on ion sources ICIS'11. After finishing the optimization of the prototype, on-line tests will be carried out with a uranium carbide target to measure the production of radioactive nuclear beams. At the same time, a laser platform has been completed to run a laser ion source for resonant ionization at ALTO facility. The work on this platform has been focused on safety and reliability issues. As a result, radioactive galium beams have been selectively produced during the successful commissioning tests of ALTO facility.

In addition, a specific R&D program has been initiated to produce the best beams of rare earth nuclei using a fluorination technique. Physicochemical properties of the involved elements have been studied to synthesize suitable pellets containing rare earth. Two experimental campaigns have already been achieved successfully at the off-line isotope separator. Further tests and analysis are in progress.

DESIR

The DESIR project (Désintégration, Excitation et Stockage des Ions Radioactifs) consists in the construction of an experimental facility aiming at exploiting lowenergy radioactive ion beams at GANIL making use of Spiral1, SPIRAL2 and S3 facilities. The project is funded (9 M€) in the frame of the ANR-EQUIPEX call. Taking advantage of its experience in the construction of the ALTO facility, IPNO has decided to take in charge the development of the beam transport sections connecting different experimental areas (S3, SPIRAL2 and the existing GANIL- facility LIRAT) to the experimental hall DESIR. In addition to the beam dynamic studies, IPNO Orsay coordinates the whole integration process (mechanical,

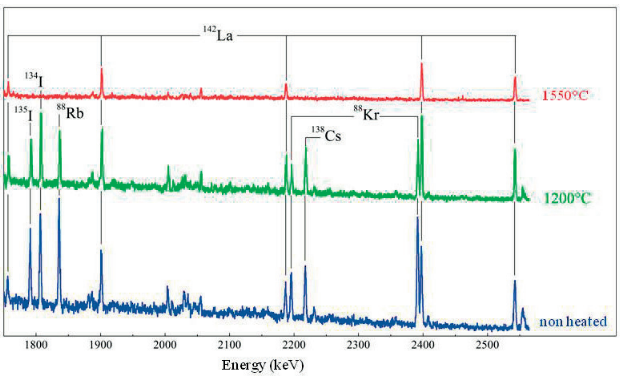

Figure 12: Partial γ-ray spectra obtained with a prototype of porous UC pellet: non-heated and heated at 1200 and 1550 °C.

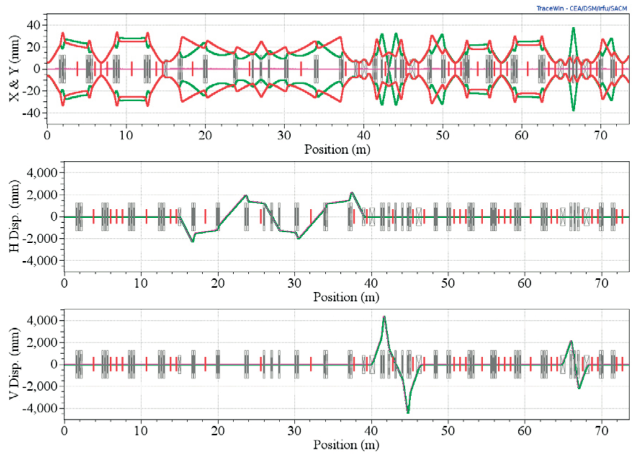

Figure 13: Optical calculation usingTraceWin code for $^{122}Sn^{1+}$ beam at 60keV having geometrical emittance of 20 π.mm.mrad.

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vacuum, diagnostic and command and control). This work is carried out in collaboration with GANIL and CENBG.

In 2011, further calculations based on the first optical studies were developed, see figure 13. In addition, a qualitative version of the transfer line based on the ALTO design has been integrated between the production hall of SPIRAL2 and the injection into the DESIR hall. Used as inputs for the civil engineering study, these first calculations have allowed taking into account the requirements of the process.

FAIR project

According to a collaboration agreement between the FAIR project and CNRS, IPNO provided the elements foreseen for the construction at GSI of the power test stand of accelerating cavities of the 70 MeV proton linac. The design of the linac is based on the use of Crossed-Bar H-cavities (CH). Unlike conventional proton linac cavities at this energy range, CH cavities do not house quadrupole lenses in each drift tube. Hence, they are shorter in length and thus generate an increased real estate gradient. Although simulations of their electromagnetic properties as well as low level measurements with scaled models are very promising, high power tests are still missing. Such tests are mandatory for several reasons.

The first reason is to test the mechanical construction of the prototype cavity, i.e. the robustness of welds to thermal stress and the exploration of locations sensitive to possible sparks at the highest electrical fields. These tests need to be performed prior to finalizing the overall linac layout based on this type of cavity.

Tests are also required during the production and delivery process of the series comprising additional six cavities. Each single cavity must be tested at high power before being transferred to and installed in the linac. Finally, after the commissioning, a fully operating high power RF-source is required at GSI for repairing failing RF devices which need maintenance during the routine operation of FAIR.

The RF-frequency is 325.224 MHz and the peak power is up to 2.5 MW pulsed at 4 Hz providing 200 µs long pulses. A 2.5 MW klystron is available on-site and a power converter should be available by the end of 2012.

The IPNO took over the supplying of all the waveguide, the circulator and the dummy load with their arc detectors, the measurement couplers, the associated instrumentation, the low level RF, and PLC, and racks. All the components have been delivered to GSI, except the circulator whose delivery is scheduled for October 2012.

5. CERN activity

In 2008, an agreement was signed between CEA/IRFU, CNRS/IN2P3 and CERN for the extra contribution of France to CERN. This contract (11 M€) covered, different contributions such as LINAC4, SPL, CLIC and magnet developments. It was reviewed in 2009 to include other equipments in the framework of the French economics stimulus plan. The involved IN2P3 laboratories are LAL, LPSC, LAPP and IPNO. IPNO was in charge of the development of a cryostat for a large aperture quadrupole (later dropped due to the 2008 LHC incident), the Superconducting Proton Linac cryomodule studies, the design consolidation of a LHC connection cryostat and the supply of LHC vacuum tanks. The cryostat studies have been delivered, the tanks ordered from CMI Company (Angers, France) and successfully delivered to CERN.

The Superconducting Proton Linac (SPL) is an R&D effort aiming at developing key technologies for the construction, at CERN, of a multi-megawatt proton linac, based on state-of-the-art SRF technologies. It would serve as a driver for new physics facilities such as neutrino and radioactive ion beam facilities. One of the main short term objectives is the testing, by 2014, of a string of four 704 MHz β=1 elliptical cavities, made of bulk niobium and operating at 2 K in a machine-type cryomodule to provide an accelerating field of 25 MV/m. Conducted by CERN and in partnership with CEA/Saclay, IPNO is in charge of the design and construction of the 2K cryomodule and the assembly (cryostating) tooling, see figure 14.

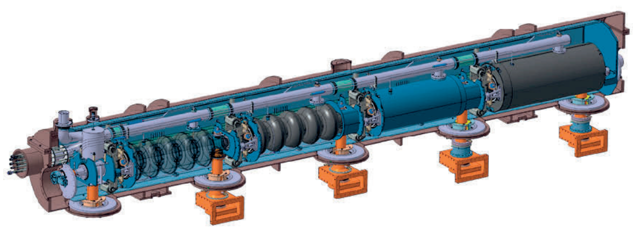

Figure 14: Superconducting Proton Linac of CERN: 704MHz elliptical cavities within their test cryomodule. From left to right, cavities are successively viewed with their helium tank and cold magnetic shield.

The originality of the design comes from the concept of supporting each cavity by its RF coupler, for thermal and mechanical benefits. Space limitations imposed on the cryomodule dimensions induce to equip the vacuum vessel with a longitudinal top aperture in order to insert the string of cavities from above vertically into the cryostat. It allows getting a better diagnostic of the string alignment prior to the cryostat closure and simplifies the assembly tooling. After a conceptual design review completed at CERN at the end of 2011, the detailed study is now in progress. The cryostat and related equipment should be delivered to CERN by the end of 2013.

6. Generic R&D and European Networks

ACTILAB/ENSAR

In ISOL facilities, the performance of UC targets mainly impacts the production of neutron-rich-nuclei beams. In order to develop efficient UC targets, a European program has been submitted in the framework of FP7-ENSAR. This R&D program involves CERN, IPNO, INFNLNL (Italy), PSI (Switzerland) and GANIL (France). The project was officially agreed in March 2010 and the kick-off meeting was organized at IPNO in January 2011. The program of the project has been broken down into four tasks: "Synthesis of new actinide targets", "Characterization of actinide targets", "Actinide targets properties after irradiation" and "Online tests of actinide targets". Having already developed various prototypes of UC materials, IPNO is in charge of coordinating the first task. So far, different new targets have been developed at IPNO. The laboratory also took part in an on-line experiment with a dense UC target. The results were presented at ARIS conference 2011 (Advance in Radioactive Isotope Science). The next on-line experiment with the currently most promising target material has been scheduled for November 2012.

EUCARD

Within the FP7-EuCARD program (https://eucard.web.cern.ch/EuCARD/), IPNO will develop an optimized beta=0.65, 704 MHz, 5-cell elliptical cavity equipped with a Titanium helium tank for the SPL (Superconducting Proton Linac) accelerator. The linac is based on two families of SC cavities (beta=0.65 and beta=1.0) operating at 704.4 MHz with accelerating gradients of 19 MV/m and 25 MV/m respectively.

IPNO has performed all RF and mechanical calculations and has worked in close collaboration with CEA/Saclay for the design of the RF coupler port and Cold Tuning System interfaces, see figure 15.

Starting in November 2011, the cavity fabrication is in progress. Delivery is planned for February 2013 and will be followed by a vertical test at 2 K.

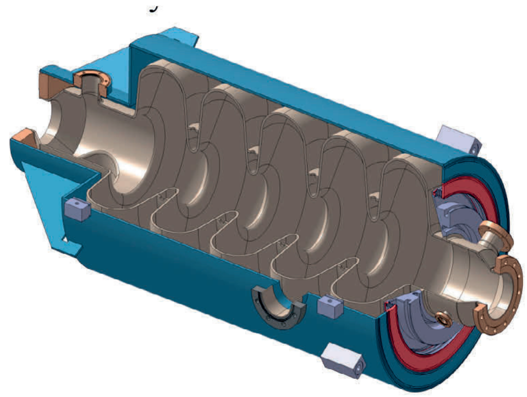

Figure 15: Beta 0.65, 5-cell elliptical cavity with its helium tank.

ECOMI

Superconducting radiofrequency resonators made of high purity bulk niobium are increasingly used in linear particle accelerators (CEBAF, SNS, XFELR, ESS, etc.). In order to push further on accelerating gradients, a major R&D effort is carried out to increase the performances of superconducting materials used in accelerator physics. New materials and new processes must be investigated to replace bulk niobium for which theoretical limits are almost reached (53 MV/m @ Bc=200 mT for a single cell cavity ILC-shape). For this purpose, a TE011 test cavity resonating at 3.87 GHz and made of bulk niobium has been developed with a dedicated instrumentation, see figure 16. It is devoted to the tests of superconducting sample for RF applications.

The system was successfully commissioned in 2010 with bulk niobium samples. An additional development has been achieved for the incident RF coupling system to tune the RF power to the coupling factor of the cavity. A movable coupler has been built and successfully used for surface resistance measurements of niobium samples. First results show that the expected sensitivity of the thermometric method is achieved. This method, associated with the new TWT RF power amplifier (2.5-7.5 GHz, 300 W) and the low level RF controller under development will allow measurements at higher power and

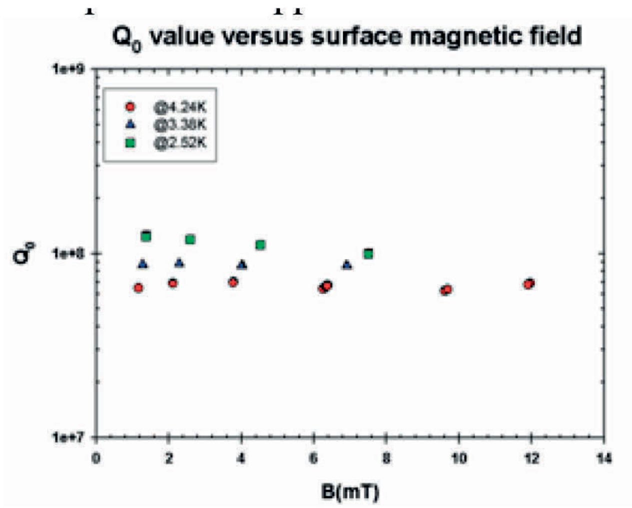

Figure 16: Q0 versus peak magnetic field on a Nb sample.

also in TE012 mode (5.19 GHz). In 2012, a first sample with a multi-layer architecture has been tested in collaboration with CEA/Saclay (IRFU and INAC). Promising results have been obtained but require to be confirmed by complementary measurements. The surface resistance measurements do not exhibit extra losses compared to bulk niobium. The screening effect predicted by Gurevich's theoretical works have been observed on magnetometry measurements (collaboration with IRFU), increasing significantly the critical field. These results will be submitted for publication at Applied Physical Letter.

TIARA

The main objective of the TIARA project (Test Infrastructure and Accelerator Research Area) project is to arrive at an organizational structure that will provide coordination for R&D efforts and associated infrastructures in the field of particle accelerators in Europe. Besides being a world-level state-of-the-art distributed R&D facility, TIARA will develop means for establishing and supporting joint accelerator R&D programming, joint education and training programmes, and will strengthened collaboration with industry. TIARA is today in a preparatory phase (PP), supported by the European Commission under its Seventh Framework Programme (FP7).

TIARA-PP is divided into nine work packages (WP): five of them are dedicated to administrative and organizational tasks (management, governance, management of R&D infrastructure, education and training, and collaboration with industry), and the four others cover the technical side of the project, addressing the upgrade or creation of R&D infrastructure.

IPNO participates in all the organizational work packages (especially the one dedicated to collaboration with industry). It also coordinates the WP9, a technical WP dedicated to the study of two specific test infrastructures relevant to EURISOL and other high power accelerators: a low beta superconducting (SC) versatile horizontal test cryostat (IPNO main activity) and a test infrastructure for high power targets (CERN is the main contributor). Since the project started in January 2011, the main activity of WP9 was dedicated to study the European user's needs and requirements for testing low beta SC cavities in order to define specifications for the cryostat. Based on this analysis, a conceptual design of the cryostat is now under progress. The challenge is to achieve a single instrument which fits to a large variety of SC cavities (quarter-wave, spoke, half-wave etc.).

Thermoacoustic activities

Thermoacoustic devices use an intense sound to produce cooling or, in a reverse way, a heat source to produce a sound, working efficiently as motors, heat pumps, refrigerators or trithermal machines. Without involving any moving part within the entire machine or nearby the cold source (as only the working fluid moves), they achieve great reliability and low maintenance cost reaching a wide range of temperature: from ambient to cryogenic levels.

At IPNO, thermoacoustic activities are foreseen as an interesting way of cooling at cryogenic temperature without using cryofluids.

THATEA-THermoAcoustic Technology for Energy Applications

Supported by the EU within the FP7, the THATEA project (Jan 2009 - Dec 2011) brought together five public partners (Energy research Center of the Netherlands, IPNO, University of Manchester, Nuclear Research and consultancy Group, Universita Degli Studi di Messina) and two companies (Hekyom and ASTER Thermoakoestische Systemen). The project aimed at developing and coupling thermoacoustic coolers with thermoacoustic wave generators (motors), achieving thermodynamic efficiencies of more than 40% of the Carnot's efficiency.

Involved in four of the seven work-packages and leading two of them, IPNO and its partners have designed, constructed and tested a refrigerator producing 600W of cooling power at a temperature of -25°C with a maximum efficiency of 33%, see figure 17. The laboratory has also designed a thermoacoustic wave generator providing an intense sound to study non linear

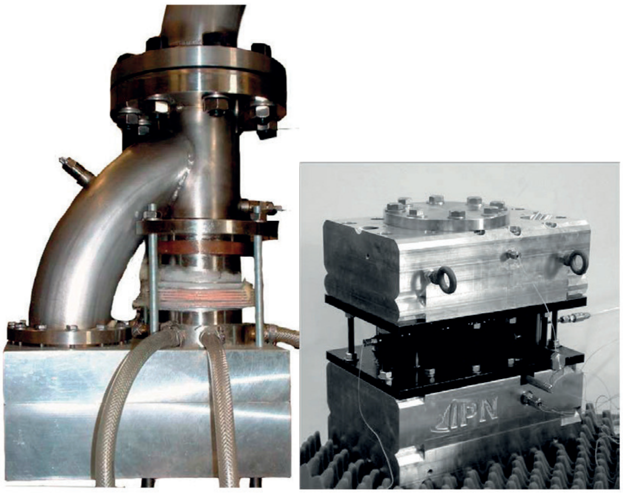

Figure 17: Thermo-acoustic refrigerators (THATEA – TACSOL).

acoustic flows and carried out a technological survey on the design and construction of thermoacoustic compact heat exchangers giving guidelines for such specific components.

TACSOL - Solar powered thermoacoustics for cold production

TACSOL is a project supported by the National Agency for Research (ANR) in the framework of its PRECODD-2008 program (PRogramme ECOtechnologies et développement Durable). Led by IPNO, this project is carried out by three public laboratories (IPNO, PROMES and LaTEP) and one company (Hekyom) to build up a solar thermoacoustic cooler.

Solar radiation is collected by a parabolic dish and focused onto a receiver placed in a cavity. This receiver requires an appropriate thermal design to collect at 700 °C the varying incident solar energy efficiently and to transmit heat to the working fluid of a tri-thermal thermoacoustic machine: helium gas being at a pressure of 42 bars. A PhD program is co-directed by IPNO and supported by the Graduate School of Paris XI for this study. The thermoacoustic device then produces 1 kW to cool a cold (-25 °C) energetic storage (latent and sensitive processes).

The direct conversion between solar and mechanical energies without any moving component and using helium gas as the working fluid makes the process simple and reliable.

High Frequency Thermoacoustic Pulse Tube

Taking advantage of the different thermoacoustic studies carried out within its different collaborations and from its historical knowledge in cryogenics, the IPNO team is developing a thermoacoustic cryogenerator devoted to producing a cooling power of 15W at 80K. Based on the pulse-tube principle, this reliable machine has no mechanical component moving at the cold tip. Its high working frequency (60 Hz) provides better stability of the cold temperature. During preliminary tests, a temperature of 135 K was already achieved.

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- *Amélie KALININE*
- *François LAUNAY*
- *Luc PERROT*
- *André TKATCHENKO*

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- *Sophie Cordillet (2009-2012)*
- *Thibault HAMELIN (2011-2014)*

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Master students

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- *Anamul Haq MIR (2011)*
- *Ouerdia SAIDOUN (2011)*
- *Julien GUILLOT (2012)*
- *Alexandre LASHEEN (2012)*
- *Melissa VIEILLE GROSJEAN (2012)*

8. Collaboration with other laboratories

- **ACTILAB :** *CERN Geneva, GANIL Caen, INFN-LNL, PSI Villigen, http://www.ensarfp7.eu*
- **SLHC PP :** *http://slhcpp.web.cern.ch*
- **Spiral2 :** *Sciences Chimiques de Rennes, Université de Rennes 1, GANIL SPIRAL2 Caen , SACM CEA Saclay, DSM/CEA Saclay, LPSC Grenoble, http://www.ganil-spiral2.eu*
- **DLLRF:** *LPNHE Paris*
- **IPHI:** *SACM CEA Saclay, LPSC Grenoble*
- **FAIR:** *GSI Darmstadt*
- **SPL:** *CERN Geneva, SACM CEA Saclay*
- **EUCARD:** *SACM CEA Saclay, IPJ and CERN Geneva*, *http://eucard.web.cern.ch/eucard*
- **ECOMI:** *SACM CEA Saclay and CSNSM Orsay*
- **Kapitza :** *LIMSI University Paris-Sud*
- **Max-Myrrha :** *SACM CEA Saclay, IAP Frankfurt, INFN Milano, SCK CEN Mol, Univ. Frankfurt, Univ. Leuven, Univ. Catol. Portugesa; and Industries: ACS, ADEX, EA, Thalès TED, http://myrrha.sckcen.be and http://ipnweb.in2p3.fr/MAX*
- **ESS:** *http://www.esss.se*
- **Collaboration with Uppsala :** *http://www.physics.uu.se/en/freia*
- **TIARA :** *CERN Geneva, http://www.eu-tiara.eu*
- **Thermoacoustic :** *ANR-TACSOL, THATEA http://www.thatea.eu*
- **Industrial collaborations:** *ACS, Thalès, Hekyom.*