STATUS AND CHALLENGES OF THE SPIRAL2 FACILITY

Robin FERDINAND*, Patrick BERTRAND, GANIL, Caen, FRANCE.

Abstract

SPIRAL2 is a new European Radioactive Ion Beams facility being constructed at the GANIL laboratory (Caen, France). It is based on a High Intensity CW multi-ion Accelerator Driver (Superconducting Linac), delivering beams to a High Power Production system (converter, target, and ion source), producing and post-accelerating Radioactive Ion Beams with intensities never reached before. The major components of the accelerator (injectors and SC Linac) have been presently ordered. The number of tested components is rapidly growing. The Superconducting Linac incorporates many innovative developments of the Quarter-Wave resonators and their associated cryogenic and RF systems. The first beam is expected during 2012. The first operation is scheduled for late 2013 with an initial experimental program prepared in the framework of a European Project, with many international collaborating partners.

INTRODUCTION

The GANIL facility [1] (Caen, France) is one of the major Rare (or Radioactive) Ion Beam (RIB) and stable-ion beam facilities for nuclear physics, astrophysics and interdisciplinary research in Europe. From the very beginning of the SPIRAL project, an upgrade – SPIRAL2 – was envisaged to increase both the range and the mass of exotic nuclei produced by SPIRAL [2]. In the recent years, RIBs have been recognized by the international scientific community as one of the important path for the development of fundamental nuclear physics and astrophysics, as well as in applications of nuclear science.

As an important step between the existing and the next-generation facilities (EURISOL), SPIRAL2 is a facility which meets the criteria of European dimension in terms of physics potential, site and size of the investment as it was recognised in the ESFRI (European Strategy Forum on Research Infrastructures) roadmap.

The French government approved the construction of SPIRAL2 facility at GANIL, in 2005. Its construction cost (200 M€) is shared by the CNRS/IN2P3 and CEA/DSM, the regional council of Basse-Normandie and international partners. The construction of the SPIRAL2 is supported by the EU FP7 through the Preparatory Phase contract since 2008.

The project has already been described in many documents [3]. The project is built in two phases. The first one includes the linac building, the linac experimental halls (AEL) and the accelerator process (orange part of Figure 1). The AEL includes the Neutron For Science (NFS) hall and the Super Separator Spectrometer (S3) hall. Phase two includes the whole RIBs production equipments and infrastructure, starting from the HEBT to the production building, the production and connexion to the existing GANIL facility and the DESIR facility (see Figure 1). The accelerator (Figure 2) is already well advanced, a large list of components being already ordered and tested. This paper describes the status of the project and its various challenges.

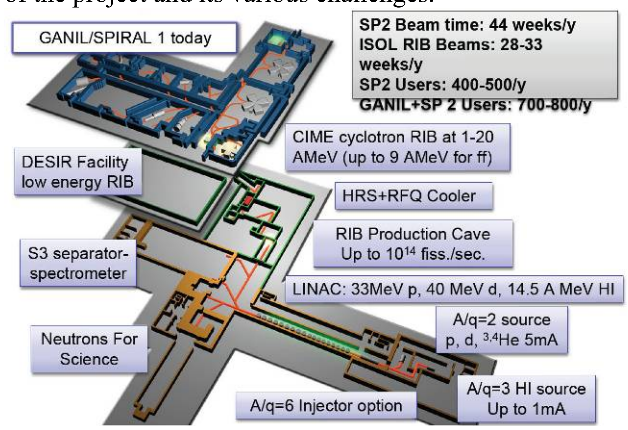

Figure 1 : SPIRAL2 project.

SCIENTIFIC CASE OF SPIRAL2

A complete presentation of the scientific case of the facility can be found in the SPIRAL2 White Book, the Letters of Intent and the Technical Proposals for SPIRAL2 [4]. Hereafter are few examples of a rich and multipurpose scientific program [3]:

- Physics of Exotic Nuclei and Nuclear Astrophysics: basic nuclear science research, to establish a bridge between the nucleon-nucleon interaction inside a nucleus and the underlying quarks and gluons. This research progresses, in particular, using nuclei with unusual neutron-to-proton ratios, artificially produced in laboratories.
- Research with high intensity stable beams delivered by the Linac: A hall is dedicated to the experiments with the Super Spectrometer Separator (S3) and in-flight production of exotic nuclei using the linac heavy-ion beams. Physics topics to be addressed with this top-level equipment are nuclear haloes, N=Z nuclei, nuclear structure studied via deep-inelastic collisions, physics and chemistry of heavy and super heavy nuclei. S3 will also give access to short-lived isotopes of refractory elements which are difficult to produce using ISOL technique.
- Neutrons for Science: the production of a high neutron flux in the energy range from several hundreds of keV up to about 40 MeV offer a unique opportunity for material irradiations and cross-section measurements, both for fission-related topics (like Accelerator Driven Systems and Generation 4 fast reactors) and for nuclear fusion-related research.

More recently, the preparation of the first experiments

* robin.ferdinand@ganil.fr

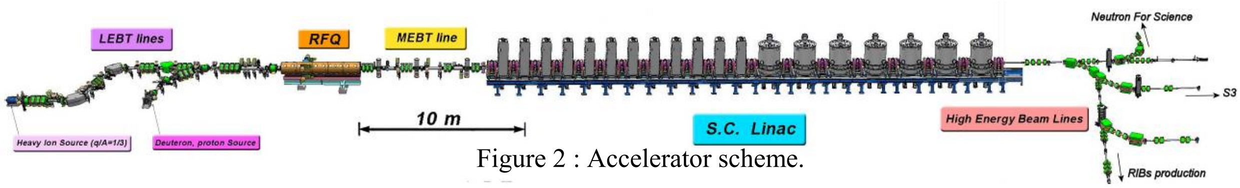

Figure 2 : Accelerator scheme.

with SPIRAL2 phase 1 has been discussed in a Scientific Advisory Committee, confirming the interest of the international community for the performances to be offered by this new facility.

SPIRAL2 CHALLENGES

The layout of the accelerator has been frozen in 2006 [5]. It takes into account the wide variety of physic demands. The intense primary beam, from proton to heavy ions, will be used at various energies and beam currents. Table 1 describes the huge variety of beam specifications.

Table 1: Beam Specifications

Particles	H^+	$^3He^{2+}$	D^+	Ions	Ions
Q/A	1	3/2	1/2	1/3	1/6
Max. I (mA)	5	5	5	1	1
Min. energy (MeV/A)	0.75	0.75	0.75	0.75	0.75
Max energy (MeV/A)	33	24	20	15	9
Max. beam power (kW)	165	180	200	45	54

Our biggest challenge is to manage this choice of beams, a quite high beam power (200kW, CW) and the deuteron beam (safety issues). This was the main reason for the multi cryostat design of the superconducting (SC) linac. The multiple possible beams, together with the different experimental rooms make also very complex the operation of the facility. It complicates the choice of diagnostics as they have to work on a wide range of dynamics, typically 1000 between low intensity of proton and high intensity of 1/3 ions. The cavities, not designed to work in pulse RF mode, have to accept pulsed beams. They must work at very low field (a few kV/m) up to their nominal field of 6.5MV/m.

The challenges on the various accelerator subcomponents are related to

- the heavy ion source performance, which has to be top level,
- the RFQ transmission specified over 97% (100% from design) since deuteron beam losses would seriously complicate the maintenance in the linac tunnel. Finally this point is not so critical, as the RFQ output energy is low (0.75MeV/u), nevertheless the design cannot be changed and lead to a very precise vanes machining (less than 40µm), while the frequency (88.05 MHz) give us a large transverse cavity (about 80 cm). All together, only a few companies have the required capability of manufacturing.
- The SC cavities have to provide 6.5MV/m in cryomodules operation, which is very demanding. The separate vacuum is a consequence of this choice, and added to the small cryostats number leads to a challenging compactness of the design, with short 300-4 K transitions, lots of pollution sources and small helium buffers reserve. The 20kW CW couplers, are not especially challenging for our community, but are not common either.
- The deuteron beam has a strong impact on the safety issues and maintenance strategies. Losses lower than 1 W/m are allowed along the tunnel, and the building design takes into account the neutron production issue. The difficulty remains in the reliability of the measurements, as we have to prove that we control the losses. As a consequence of the safety issues, the linac tunnel and the production building need a nuclear ventilation.

On the RIBs production part, one of the biggest challenges is the production module (Figure 3). It contains the carbon wheel convertor, the UCx target and the various 1^+ sources. It accepts up to 200 kW of CW deuteron beam, and has to be extremely reliable. Among the difficulties one can quote the removable connexions (high power, RF, signals etc…) which have to work under vacuum, high voltage and under a huge neutron flux. The module is designed to be changed in 15 days, and to be reconditioned in less than 3 months. The UCx oven is also one of our main difficulties, not only because of its working temperature (2000°C) but also because of its volume (10 cm diameter, 12 cm length). The delay window, needed for the safety, will probably be based on liquid lead.

Figure 3 : Production building.

Another challenge is the transport, injection and acceleration of the high intensity radioactive beam into the existing cyclotron CIME, operational since 1998, which was constructed for rather light and very short-lived elements. The radiological impact, in terms of contamination and confinement induces important changes in the CIME hall which has to be nuclearized [6]. Also, its mass separation has to be improved in order to deliver a pure RIB to the physics experimental hall [7].

SPIRAL2 STATUS

Building

Since 2007 intensive works has been achieved in the definition of the phase 1 and phase 2 buildings.

The phase 1 detailed design was conducted with the help of specialised companies. 3D models exist including all the process, cables and wall reservations. Public enquiry was held between the 14th of June and the 15th of July 2010. It's a major step for the building permit which is expected in October this year. Ground work should start in January 2011, which means that six month delay is observed compared to previous expectation. Rooms will be available from February 2012 for process installation before the final building receptions.

The major decision on the building design was to favour external aggression resistance like truck explosion or major earthquake. As a consequence, all the tunnels and experimental halls are located under ground. The beam axis will be at -8m, the floor at -9.5m. Building is designed to resist a level 5.2 earthquake on the Richter scale at 10km, which complicates the building and process supports. The RF hall, helium liquefier, labs, linac maintenance areas will all be installed above the ground level (Figure 4). Direct connections with technical rooms generate neutron leaks. They are obviously forbidden in the linac tunnel. The resulting chicanes lead to very long electrical connexions between equipments and add difficulties.

Figure 4 : SPIRAL2 building, phase 1 and 2.

Process Installation

The process installation will start before the complete reception of the building. Interactions with the building workers have to be managed and in some places, like the alignment phases, precise planning will be shared. The objectives are to test the various equipments or assemblies as much as possible before installation in the various labs, and to start the technical tests as soon as possible in the SPIRAL2 building.

For this reason, the 1/3 and 1/2 sources are respectively installed today with their LEBT in LPSC-Grenoble and CEA-Saclay. Bunchers, power supplies, quadrupoles, cryomodules, are all tested in their respective development laboratories.

Installation in the SPIRAL2 building will be done in order to reproduce the same LEBT beams as in the laboratories. Electrical power, water, compressed air will be provided with temporary facilities to allow beam test as soon as possible.

Injectors

First beam tests have been performed in Grenoble and Saclay.

The A/Q=3 beam of Phoenix V2 [8] was first analysed in the SPIRAL2 LEBT in May 2009. Since that time, this source was improved for SPIRAL2 and it is now fully operational. Oxygen, Argon and Xenon are produced. A very good transmission (between 92 and 98%) has been achieved along the line. The milestone of 1 mA O^{6+} after the first dipole has been achieved. The source performances are reproducible and stable. Only 130 µA of Ar^{12+} has been extracted up to now as it was not yet optimized (voltage lower than the design).

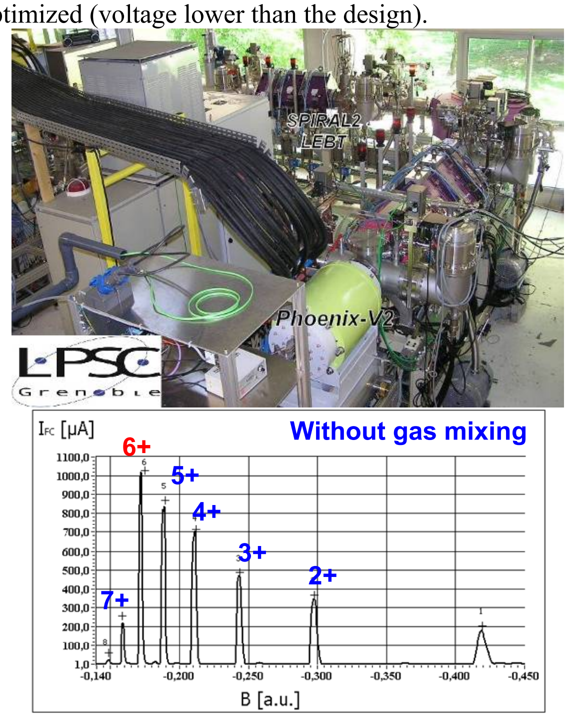

Figure 5 : Top: LEBT in Grenoble. Bottom : 1 mA of O^{6+}, $\varepsilon<0.4\ \pi\cdot$mm·mrad.

The project needs the most advanced heavy ion source. The choice between Phoenix-V2 and the more ambitious SC A-Phoenix under development in LPSC-Grenoble is obvious, and the switch was only delayed because of an air leak in one of the High Temperature Superconducting (HTS) cryostat. The final choice between A-Phoenix or other available sources will be done early next year. Metallic ion developments are ongoing, and 100µA of Ca^{11+} have been obtained to validate the good behaviour of the oven and its survey system.

Figure 6 : Source Q/A=1/2 and LEBT installation in CEA-Saclay.

The deuteron source and its LEBT are under final assembly at CEA-Saclay (Figure 6). First proton beam has been extracted in pulsed mode behind the first dipole for testing purpose, and the very first spectrums are produced.

RFQ

The 4-vanes 0.75MeV/u RFQ is under construction. It has been designed by CEA-Saclay [9]. The first meter is now in its final machining process by RI-GmbH, and we expect it to be delivered by mid November. The delivery dates for the 4 other segments are unclear at this time. Due to this delay, the 5-m long cavity will be assembled, tuned and tested in its final location in the linac tunnel instead of the CEA-Saclay test stand.

MEBT

The long transfer line between the RFQ and the linac has to allow the insertion of a future Q/A=1/6 injector, a bunch selector and its beam dump, while ensuring the beam transport and matching to the linac. All magnets have been received. The first buncher, a 3-gap RF cavity, successfully accepted the maximal RF power, but shows difficulties with the multipactor at low power. The bunch selector is comparable to a fast chopper, except that it is active all the time and let 1 bunch over 1 000 to 100 000 go through the line. This mode complicates the engineering of the design. A first prototype has been tested; a new one is under development and should be tested before mid 2011.

Superconducting Linac and Cryogenics

The SC linac is composed of cryomodules A developed by CEA-Saclay [10], and cryomodules B developed by IPN-Orsay. The A type houses a single QWR cavity optimized for β=0.07, and the B type houses two β=0.12 QWR cavities [12]. Both types of cavities are equipped with the same power coupler specified for a maximum power of 40 kW CW (in travelling wave). Couplers are developed in a third laboratory, LPSC Grenoble [11]. A first qualification cryomodule, one for each family, has been tested. These qualification cryomodules will be used in the machine. All the components of the series (cavities and cryomodules) are fabricated in industry.

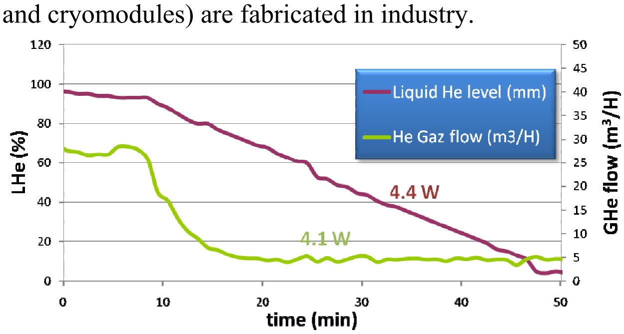

Figure 7: Static consumption of the qualification CMA.

Nine of the twelve A type cavities have been received (Figure 8). They are manufactured by Zanon and SDMS companies. Three cavities have been qualified already. The use a copper bottom cap fitted with a Helicoflex© seal allowed us to solve the Q_0 degradation problem observed on the first cavities. The prototype cryomodule has been tested, and highlighted some difficulties with cryogenic stability and cold tuning system reliability, which are both completely solved today. The static consumption of the cryomodule (w/o the valves box) is measured between 4W and 4.5W, for 3.6W calculated. Five cryostats have been delivered; the seven remaining ones are all expected before the end of the year.

Figure 8 : A (left) and B (right) type of cavities.

The production of the 16 β=0.12 cavities was achieved in November 2009 (Figure 8). They were manufactured by RI GmbH. They all comply with the requirements. The dissipated power was lowered by a factor 2 thanks to the 48h baking at 110°C. Performances were reproducible and highlight a very good mastering on both the manufacture and preparations processes (Figure 9).

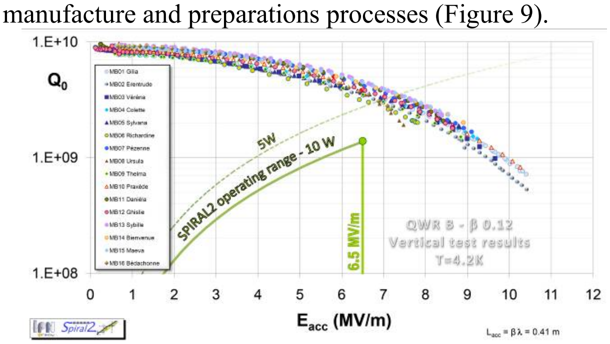

Figure 9 : The 16 vertical test results, cavities type B.

The cryomodules are all manufactured. The qualifying one has been tested with success [12]. The first series cryomodule tests will begin before the end of September. Each cryomodule will be individually tested at IPN Orsay, one every 2 months, before shipment to GANIL.

30 power couplers have been ordered at the SCT Company. 21 are already in hand, the remaining ones should be delivered this month. 8 have been conditioned.

The liquefier is under construction by Air Liquide. It will deliver 1100 W at 4.5K, 3000W at 60K and up to 10l/h of lHe @4.5K. It should be ready by October 2011, ahead of the installation schedule (April 2012).

RF Power Systems

The RFQ is driven by four 65 kW tetrode amplifiers. Long time tests of the 4 amplifiers are achieved at LNL lab (INFN Italy) since the end of 2009. The first amplifier is used for commissioning tests of other power devices. The solid state amplifiers up to 20 kW needed for the SC cavities and MEBT rebunchers are under construction by Bruker. They will work in class AB. All the circulators were designed and manufactured by AFT Company. All have already been delivered. The final design of the digital LLRF is now completed and a prototype system has been successfully tested with the cryomodule in Saclay and will be tested soon with the Orsay one. Despite high helium bath pressure fluctuations (±13 mbar) leading to strong frequency variations and vibrations, the LLRF and tuning systems managed to maintain the phase shift within ±0.1° with respect to the RF pilot (specifications: ±0.5°), and the field amplitude in the cavity within ±0.12% (specifications: 1%). The series production is expected to start after the Product Design Review by the end of 2010.

HEBT

The linac beam dump is under development at IPN-Lyon. It is design to dump 200kW of beam power, but will accept only 10 kW during 1 hour/day for activation reasons or any equivalent power/time combination (200 kW during 6 min for example). Maintenance, activation and reliability are of major concern for its design. Prototyping is ongoing (Figure 10).

Figure 10 : Beam Dump and parts before assembling.

SPIRAL2 SAFETY ASPECTS

SPIRAL2 is considered as an extension of the existing nuclear GANIL facility. But it is also a major nuclear research facility concerned by the recent regulation (2006-2007) regarding the nuclear facilities in France. During the last three years preliminary safety studies and initial discussions with the French Nuclear Safety Authority have resulted in a final agreement for the licensing procedure: a global report for SPIRAL2 project has been presented in April 2009 and will lead to a single Ministry Authorisation Decree.

This important report fixed the operating ranges of the facility, the safety analyses and the environment impact (radioactive and chemical releases) of the two phases of the project. This report was considered acceptable by the authorities who allowed the public enquiry to take place.

A more detailed safety report of Phase 2 (RIB production and associated experimental areas) will be sent to the safety authorities at the end of 2011.

The Radiation Dose Rates goal adopted by the SPIRAL2 project for operator in normal operation is fixed at 2 mSv per year. This has important consequences on the design of the Linac accelerator, associated buildings and maintenance schemes.

Extensive beam dynamics calculations [13], taking into account both the corrected and uncorrected errors were performed using a statistical approach of 1400 different Linac configurations. A total integrated loss of 0.02 W for the whole linac, and maximum localised peak losses of 0.64 W in one configuration were obtained. The radioprotection calculations were performed with distributed losses of 0.6 W/m for the cryomodules and 0.2 W/m in the quadrupoles. Results are in good agreement with the objective of 2 mSv.

CONCLUSION

Almost 70% of the accelerator components have been ordered and/or tested with success. Their installation in the linac tunnel is expected to start in February 2012 and the first technical LEBT beams in late 2012.

AKNOWLEDGEMENT

The authors address their thanks to the whole SPIRAL2 project team, which is based on a very wide collaboration with French nuclear physics laboratories, as well as with European and international organisations.

REFERENCES

[1] http://www.ganil-spiral2.eu/?set_language=en and http://pro.ganil-spiral2.eu/spiral2/what-is-spiral2.
[2] MG Saint-Laurent, "Future opportunities with Spiral2 at GANIL", AccApp07, Pocatello, Idaho, July 30-August 2nd, 2007.
[3] M.Lewitowicz "The SPIRAL2 Project: Physics and Challenges", Zakopane Conference on Nuclear Physics, September 2008.
[4] http://pro.ganil-spiral2.eu/spiral2/what-is-spiral2/physics-case/at_download/file.
[5] T. Junquera "Status of the construction of the Driver Accelerator at GANIL", Linac 08.
[6] P. Bertrand, A. Savalle, "Post acceleration of High Intensity RIB trhough the CIME cyclotron in the frame of the SPIRAL2 project at GANIL" CYCLOTRON 2010 Lanzhou, China, Sept. 2010.
[7] P.Bertrand, et al., "improvement of the mass separation power of a cyclotron by using the vertical selection method", Cyclotron 2004, Tokyo.
[8] C. Peaucelle et al., ECRIS'10, Grenoble, France, 23-26 August 2010.
[9] R. Ferdinand et al, "Spiral2 RFQ design", EPAC 2004, Luzern, Switzerland, July 2004.
[10] P.E. Bernaudin et al., "Status of the SPIRAL2 superconducting linac", IPAC 2010, Kyoto, Japan.
[11] Y. Gómez-Martínez et al, "theorical study and experimental result of the RF coupler prototypes of Spiral2", EPAC 06, Edinburgh, June 2006.
[12] G. Olry et al., "SPIRAL2 cryomodules: status and first results", SRF09, Berlin, September 2009.
[13] R. Duperrier, D. Uriot, "Application of the extreme value theory to beam loss estimates in the SPIRAL2 linac based on large scale Monte Carlo computations" , Phys. Rev. ST Accel. Beams 9, 044202 (2006).