ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-MOPTS005

STATUS OF THE SPIRAL2 PROJECT

P. Dolegieviez, R. Ferdinand, X. Ledoux, H. Savajols, F. Varenne, GANIL, Caen, France

Abstract

The SPIRAL2 facility at GANIL will use a high-power p, d and heavy-ion superconducting linac for a wide range of applications including RIB production using both ISOL and in-flight techniques. The SPIRAL2 phase 1 deals with the high-power superconducting linac with two experimental areas called "Neutrons for Science" (NFS) and "Super Separator Spectrometer" (S3). The low energy experimental hall DESIR, under construction, will further increase the possibility for physics experiments. All the linac is installed, the commissioning of the injector part (two sources and the A/Q = 3 RFQ) and two cool down of the entire superconducting linac have been successfully done. We are now in the linac beam commissioning phase. The project scope and parameters, the constraints linked to the safety rules, the accelerator, NFS, S3 and DESIR status and the planning will be presented.

INTRODUCTION

The SPIRAL2 project was officially launched at GANIL in May 2005. This project was carried out within the framework of a large collaboration of French (CEA, CNRS) and international laboratories.

The decision to conduct the construction in two phases was taken in 2008. The first phase concerns the accelerator and two associated experimental rooms (NFS and S3), the second phase the RIB "production facility" and the DESIR experiment hall (Fig. 1). The construction of the production part was put on hold in 2013.

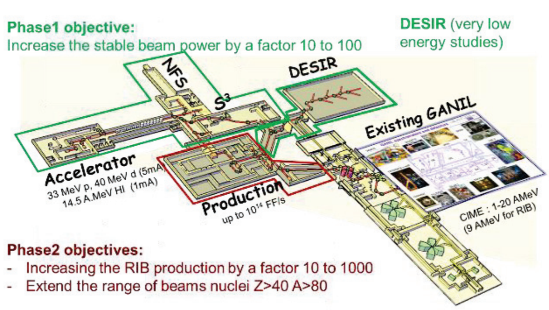

Figure 1: SPIRAL2 project and GANIL cyclotrons.

The first beam commissioning tests started in 2014 for the injector with a partial authorization by the nuclear safety authority (W < 0.75 MeV/A). In parallel the cryogenic system of the superconducting linac has been fully tested and optimized. The injection in the linac is now conditioned by the authorization of the nuclear safety authority and by the commissioning of the systems guaranteeing the installation safety functions.

INSTALLATION AND COMMISSIONING

The layout of the SPIRAL2 driver takes into account a wide variety of beams to fulfill the physics requests. The high power CW superconducting linac delivers up to 5 mA proton and deuteron beams or 1 mA A/Q < 3 ion beams (Table 1). Our major challenges are to handle the large variety of beam characteristics (particle types, beam currents from few μA to few mA, wide energy range), the high beam powers (up to 200 kW CW) and the safety issues.

Table 1: Beam Specifications

Particles	H^+	D^+	ions	option
A/Q	1	2	3	6
Max I (mA)	5	5	1	1
Max energy (MeV/A)	33	20	15	8.5
Max beam power (kW)	165	200	45	51

Project Key Dates

Nov. 2012 : start of accelerator equipment installation in the building [1]. Sept 2014 : building reception. Dec 2014 : first LEBT beam. Dec 2015 : first RFQ beam (pulsed, 4.8 mA proton beam, 100% transmission). Jan 2017 : end of linac installation. Nov 2017 : linac cool down [2, 3]. Aug 2018 : end of injector qualification (p, He, O) [4]. Nov 2018 : end of injector beam tests, MEBT installation. April 2019 : linac ready for RF commissioning.

We are now waiting the authorization of the French Nuclear Safety Authority to start the SC linac RF conditioning and to begin the beam commissioning. July 2019 is the objective date with reasonable chance.

Strategy, Planning Optimization

Most of the accelerator components were tested and validated in the partner labs ahead of their installation in the GANIL site (ion sources and LEBT, magnets and cryomodules…). Ref. [5] describes the integration of the accelerator processes, construction of the building and process connections. The accelerator installation before the end of the building construction required protection of premises against dust and a strong management of co-activities.

The commissioning of equipment and beam test before the end of the accelerator installation was researched thanks to a Nuclear Safety Authority partial authorization and a zoning of the activities.

This strategy paid off, mainly because it allowed us to anticipate the identification of non-compliances and to remedy them, limiting planning impacts.

REX OF INSTALL/COMMISSIONING

Several manufacturing defects were detected during the installation phase and had a big impact :

- Internal corrosion of vacuum chambers due to a non-compliance with the welding procedures (see Fig. 2)
- Non-compliance of sealing flanges difficult to detect during the receipt in the factory.
- Dimensional specifications not respected (insufficient dimensional checks, valve boxes for example).

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-MOPTS005

- Elastomer seals not compatible with ultra-vacuum (insufficient requirements, no qualification with partial pressure analysis before installation, see Fig 2).

Nearly two years were required to solve these issues.

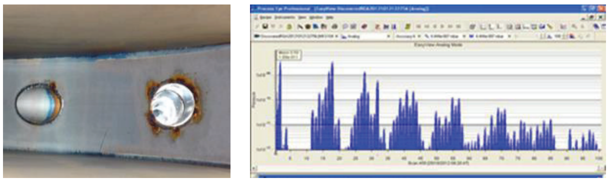

Figure 2: Internal oxidation of a vacuum chamber on welded seams and residual vacuum spectrum of an elastomer component not compatible with ultra-vacuum.

Various difficulties have arisen during the technical commissioning. The RFQ RF amplifiers and the LLRF highlighted an interface issue. They required modifications to condition the cavity at the nominal field (2 years) and the LLRF had to be upgraded to work with an external PLL. Instabilities of the helium bath pressure was observed and the instrumentation was insufficient to diagnose the origin (thermo acoustic effect and crosstalk between the different cavity systems). Control system improvements and time for development are required.

SAFETY SYSTEMS

About ten systems are required to cover the various safety functions (protection against external exposure to ionizing radiation and radioactive material confinement). These specific systems must be qualified to meet the strict nuclear safety requirements (quality insurance procedures, risk and safety analyses…). We underestimated the workload related to the installation and commissioning of these systems but they are now installed and are being tested.

NEUTRONS FOR SCIENCE

The "Neutrons For Science" (NFS) experimental area is dedicated to the study of reactions induced by neutrons, protons, deuterons and ions [6]. The wide energy range (up to 40 MeV) is of prime interest for fundamental research as well as for applications like transmutation of nuclear waste, design of future fission and fusion reactors, nuclear medicine, tests and development of new detectors... NFS is mainly composed of two underground areas separated by a thick wall in which the neutron collimator is installed.

The converter cave contains the last beam line quadrupoles, the neutron converter (thin lithium or thick beryllium targets) and the irradiation station with a pneumatic system to transfer the irradiated samples to the measurement system.

The Time-of-Flight (ToF) hall located downstream the converter cave is designed for experiments done using a well collimated neutron beam. This area is equipped with a beam pipe under vacuum to minimize neutron and photon background. This line ends with a neutron beam dump designed to minimize neutron backscattering. A second collimator, not needed for the first experiments, is under design and will be installed in 2020. Several experiments will be performed simultaneously at different distances.

The accelerator includes a bunch selector in the MEBT which allows to keep one bunch over 100 (or more) for precise time of flight measurements. The total beam power allowed in the NFS converter room is 2 kW of deuteron beam or equivalent.

The converter room is ready (Fig. 3), waiting for the linac beam. All the components and utilities are installed and tested. The converters for neutron production, the irradiation station and the pneumatic transfer system are also installed. The neutron line in the ToF room is installed.

NFS commissioning will start as soon as the proton beam will be delivered by the linac. Seven proposals of experiments were already accepted by the GANIL PAC in 2016 but not yet scheduled.

Figure 3: The NFS converter room.

SUPER SEPARATOR SPECTROMETER

The Super Separator Spectrometer (S3) is designed to perform experiments with extremely low cross sections using the very high intensity stable beams of SPIRAL2 [7].

S3 involves the participation of 28 partner laboratories gathered around a common physics ambition. The research programs is structured by 18 LoIs, signed by 170 physicists. The main focus of S3 physics is the nuclei produced by fusion-evaporation reactions, from medium nuclei at the proton drip line up to the super heavy element region, and the study of their decays, ground state or isomeric state properties. Moreover, the S3 program covers the study of reaction mechanisms, especially for low cross-section channels, in nuclear but also in atomic physics (electron exchange in beam-beam reactions).

The main areas of research fit into three categories:

1) Super-Heavy Elements (SHE) synthesis, Z>104 and very heavy elements (VHE) produced by fusion-evaporation reactions.

2) Production and spectroscopy of neutron deficient nuclei close to the proton drip-line. Nuclei will be produced by fusion-evaporation reactions.

3) Ion-ion atomic interactions to study electronic exchange cross sections for plasma physics (FISIC project: Fats Ion – Slow Ion Collision).

The development of S3 required the solution of three major technological challenges: the need for very intense heavy ion-beams to access very low cross section reactions (pico-barn), the need for a powerful recoil separator with high mass resolution to ensure the selection of the ions of interest, large transmission capabilities, and the need for

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-MOPTS005

high efficiency detection systems to select and study the nuclei of interest.

A high-power rotating target system to sustain up to 10 pμA (i.e. 6.10^{13} part/s) was designed. In order to reach a transmission higher than 50% the specifications include a large angular acceptance of ±50 mrad. The need for a mass resolution M/dM > 350 implies significant higher-order multipole fields to correct optical aberrations.

The final design is a two-stage system with a momentum achromat followed by a mass spectrometer (Fig. 4) combining very high transmission with high mass resolving power. Two main optical modes are foreseen, a high acceptance mode (high transmission but low mass resolving power) or a high resolution mode (very high mass resolution with reduced transmission).

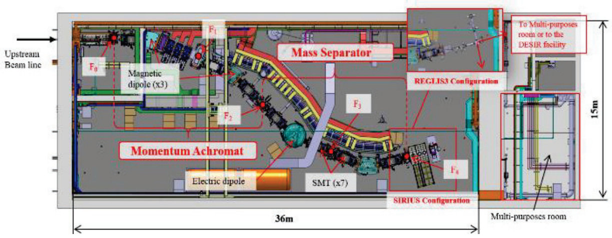

Figure 4: S3 experimental hall with the two-stage optical structure including the main elements - dipoles, Superconducting Multipole Triplet (SMT), detection systems - and the different focal planes (Fi with i = 0-4): target point F0, momentum dispersive plane F1, achromatic focal plane F2, energy dispersive plane F3, final focal plane F4.

The S3 project was launched October 2011 and most of the equipment are now constructed. The project is in an intensive and critical phase of installation and tests. Two of the superconducting multipole magnets are received, cold tests are ongoing. The installation of all the spectrometer components are planned within 2021. The Low Energy Branch is mounted at the Laboratoire de Physique Corpusculaire de Caen (LPCC) and off-line commissioning is ongoing.

THE DESIR PLATFORM

The DESIR installation is an experimental platform that will make available to researchers a variety of unique radioactive ion beams as well as high efficiency and high precision instruments [8,9]. The research program that will be conducted with DESIR focuses on the evolution of nuclear structure and shapes of the atomic nucleus as a function of its number of protons and neutrons, fundamental interactions acting in the atomic nucleus, rare modes of radioactivity, and processes of synthesis of the elements in stars.

The DESIR facility will use low energy radioactive ion beams (up to 60 keV/A) from three production sites: SPIRAL1 from GANIL cyclotrons beams (radioactive ions produced by fragmentation by ISOL method); S3 installation; and, on a longer time scale, SPIRAL2 Phase-2 which will produce fission fragments.

All the isotopes of interest delivered to the DESIR installation can be effectively separated from contaminants by means of a high-intensity cooler and buncher and a high-resolution mass separator.

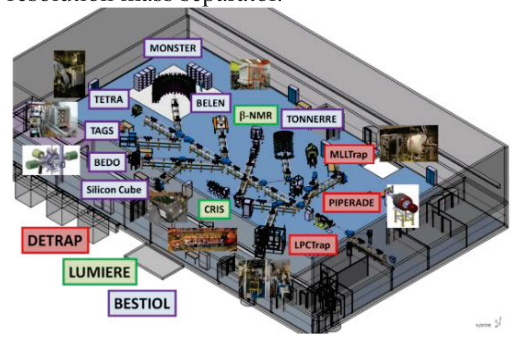

Figure 5: Overview of the DESIR experimental platform. A central beam line delivers the radioactive ions to experimental devices grouped into three subsets: DETRAP (in red), LUMIERE (in green) and BESTIOL (in purple).

The different experimental systems for DESIR are under construction in different French and European laboratories or already operated at other facilities before being transferred to DESIR. The setups are divided into three complementary groups, highlighted by different colors on Fig. 5. The DETRAP group concerns ion trapping devices dedicated to purification, to mass measurements of radioactive nuclei as well as to the study of fundamental interactions. The LUMIERE installation will be constituted of a collinear laser spectroscopy line and a nuclear polarization device using laser polarization. Finally, the BESTIOL setups consist of several detection systems with beta, gamma, neutron and charged-particle detectors to study in detail the decay of exotic nuclei.

The scientific program of DESIR is carried by a strong collaboration of more than one hundred researchers from French and other European laboratories. The ion beams and experimental devices will also be made available to other scientific communities in the multidisciplinary research framework. The construction of the beam transfer tunnels allowing to send the ion beams from SPIRAL1 and S3 to the DESIR hall will start at the end of 2020. First beams should be available for the scientific community three years later. The construction of the infrastructure and some of the experimental devices is financed by a French-German agreement, by the National Research Agency (programs EQUIPEX and ANR), and with supports from universities and different regional programs.

CONCLUSION

The SPIRAL2 accelerator is now ready to take an important step in its commissioning with the RF qualification of all superconducting cavities. This will remove doubt about a potential risk of pollution leading to a loss of performance of some cavities. Next to this step the first beams will be injected in the linac and the cavities will be tuned increasing progressively the beam power. The first NFS experiments are scheduled in 2020. The S3 spectrometer and DESIR experimental platform will extend the capability of the GANIL/SPIRAL2 facility, for the best of RIB and multidisciplinary researches.

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-MOPTS005

REFERENCES

[1] P. Bertrand and R. Ferdinand, “SPIRAL2 Accelerator Construction Progress”, in *Proc.* 26th *Linear Accelerator Conf. (LINAC'12)*, Tel Aviv, Israel, Sep. 2012, paper TH2A02, pp. 773-777.

[2] A. V. Vassal, P.-E. Bernaudin, A. Ghribi, P. Bonnay, F. Bonne, and F. Millet, “SPIRAL2 Cryogenic System Thermodynamic Behavior Prediction Through Dynamic Modeling”, in *Proc. 29th Linear Accelerator Conf. (LINAC'18)*, Beijing, China, Sep. 2018, pp. 366-369. doi:10.18429/JACoW-LINAC2018-TUPO019

[3] A. Ghribi, P.-E. Bernaudin, R. Ferdinand, and A. V. Vassal, “Cryogenic Tests of the SPIRAL2 LINAC Systems”, presented at the 10th Int. Particle Accelerator Conf. (IPAC'19), Melbourne, Australia, May 2019, paper TUPMP006, this conference.

[4] R. Ferdinand *et al.,* “Final Results of the Spiral2 Injector Commissioning”, presented at the 10th Int. Particle Accelerator Conf. (IPAC'19), Melbourne, Australia, May 2019, paper MOPTS006, this conference.

[5] P. Anger *et al.,* “SPIRAL2 Project: Integration of the Accelerator Processes, Construction of the Buildings and Process Connections”, in Proc. 28th Linear Accelerator Conf. (LINAC'16), East Lansing, MI, USA, Sep. 2016, pp. 894-897. doi:10.18429/JACoW-LINAC2016-THPLR024

[6] X. Ledoux *et al.,* “The Neutrons For Science Facility at SPIRAL-2”, Nuclear Data Sheets, Vol 119, p353-356, May 2014, https://doi.org/10.1016/j.nds.2014.08.097

[7] Dechery et al., “The Super Separator Spectrometer S3 and the associated detection systems : SIRIUS & LEB-REGLIS3”, F. Nucl. Instruments and Methods in Physics Research B 376 (2016) 125, https://doi.org/10.1016/j.nimb.2016.02.036

[8] L. Perrot, M. Kemel and S. Rousselot, “Benchmark Analyses of Electrostatic Devices for SPIRAL2-DESIR Beam Lines”, in *Proc. 9th Int. Particle Accelerator Conf. (IPAC'18)*, Vancouver, Canada, Apr.-May 2018, pp. 3225-3227. doi:10.18429/JACoW-IPAC2018-THPAK009

[9] B. Blank, “The DESIR facility at SPIRAL2” Pramana – J.Phys 75 (2010) 343-353. https://doi.org/10.1007/s12043-010-0121-9