THE HIGH INTENSITY SUPERCONDUCTING LINAC FOR THE SPIRAL 2 PROJECT AT GANIL

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Abstract

After a detailed design study phase (2003-2004), the Spiral 2 project at GANIL was officially approved in May 2005. The project group for the construction was launched in July 2005, with the participation of French laboratories (CEA, CNRS), the Regional Council of Basse-Normandie and international partners. The Spiral 2 Driver Accelerator is composed of an injector (protons, deuterons and heavy ions with q/A=1/3), a room temperature RFQ, and a superconducting linac with two beta families of Quarter Wave Resonators. It will deliver high intensity beams for Radioactive Ions production by the ISOL method and stable heavy ions for nuclear and interdisciplinary physics. High intensity neutrons beams will also be delivered for irradiation and time of flight experiments. In this paper we focus on the High Intensity Driver Accelerator design and the results obtained with several major components prototypes.

THE SPIRAL 2 PROJECT

The SPIRAL 2 facility will give access to a wide range of experiments on exotic nuclei, which have been impossible up to now. In particular it will provide intense beams of neutron-rich exotic nuclei (10^6–10^{11}pps) created by the ISOL production method, in the mass range from A=60 to A=140. The extracted ion beams (Radioactive Ion Beam RIB) will subsequently be accelerated to higher energies (up to 20 MeV/nucleon) by an existing cyclotron, typically 6–7 MeV/nucleon for fission fragments. High intensity stable isotope beams, especially metallic ions, will be delivered by the driver accelerator to a new experimental hall. High power fast neutrons for nuclear physics and related applications are another major goal of this facility.

SPIRAL 2 is based on a high power, superconducting driver linac, which will deliver a high intensity 40 MeV deuteron beam as well as a variety of heavy-ion beams with mass-to-charge ratio equal to 3 and energy up to 14.5 MeV/nucleon. Using a carbon converter, fast neutrons from the break up of the 5 mA deuteron primary beam, will induce up to 10^{14} fissions per second on the uranium carbide target. The fission products, ionised and extracted from a source are transported towards a charge breeder, and accelerated by an existing cyclotron or sent directly to a low energy experimental hall. The stable ion beams can be used also for the production of RIB on different target types.

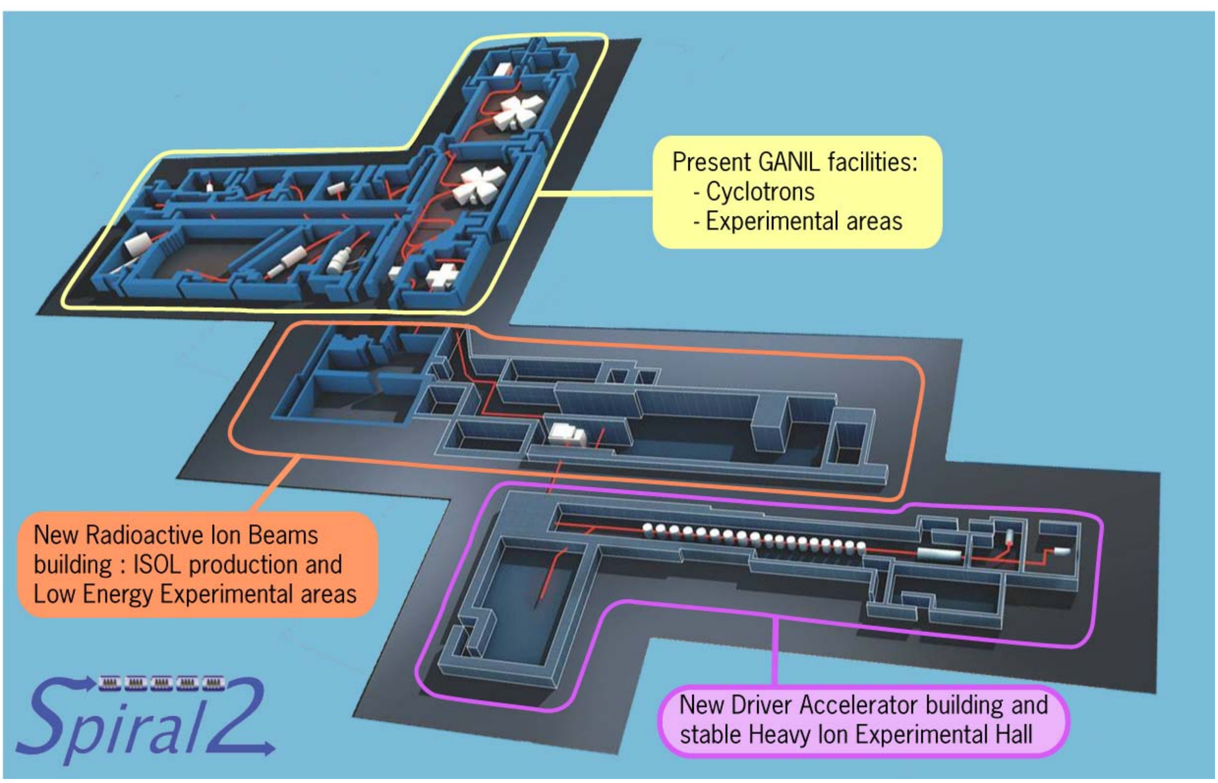

Figure 1: The Spiral 2 facility at the GANIL laboratory

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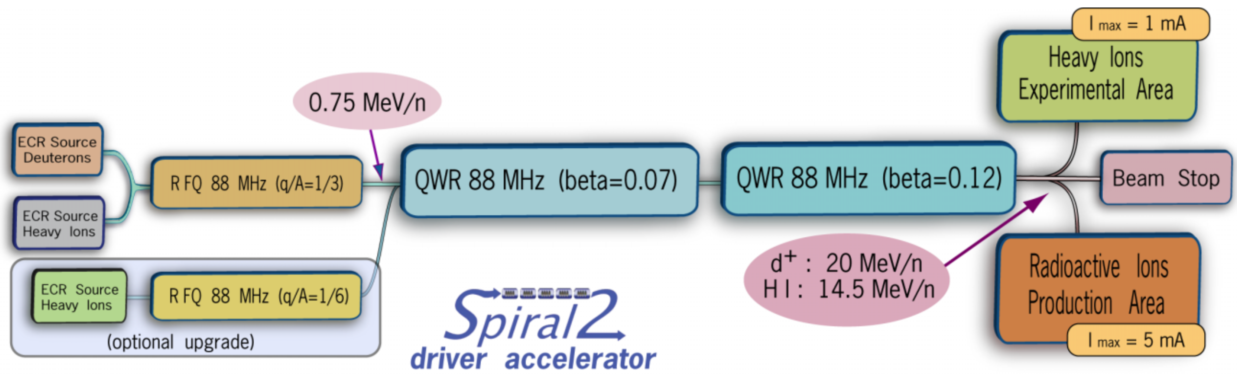

Figure 2: The Spiral 2 Driver Accelerator

After a detailed design study phase (Nov. 2002 - Jan. 2005) [1] and following the recommendations of international committees, the French Minister of Research took the decision in May 2005 to construct Spiral 2 at the GANIL site. Its construction cost was estimated at 130 M€ (including personnel and contingency). On the 1st of July 2005, the construction phase of SPIRAL2 was launched within a consortium formed by CNRS, CEA and the region of Basse-Normandie in collaboration with French, European and international institutions.

THE DRIVER ACCELERATOR

The study and construction of the Spiral 2 driver accelerator are being carried out as a partnership among several CEA and CNRS laboratories: GANIL (Caen), CEA/DAPNIA (Saclay), IPN (Orsay), LPSC (Grenoble), IRES (Strasbourg) and IPN(Lyon).

The reference design of the driver accelerator was decided at the end of the preliminary study phase [1]. A detailed error analysis was launched in order to study the effects of such errors on beam losses [2], and to specify the tolerances on components and their assembly.

The case of a 5 mA deuteron beam was studied as it was assumed to be the more critical for both space charge and radioprotection issues. The error amplitudes were typically 0.1 mm for displacements, 1 degree for the RF phase and 1% for the electromagnetic fields.

With the help of beam diagnostics (emittance meter, profile and beam position monitors) and steering coils associated with the room temperature quadrupoles, beam losses can be kept under the 0.1 W/m level for the whole linac. Two beam scrapers, one before the RFQ and the second between the RFQ and the linac, are needed to obtain this low-loss performance.

The injector is composed of two ion sources (deuteron ion source and heavy ion source, both of the ECR type). Each source is connected to a common RFQ by separate beam lines equipped with diagnostics devices.

The SPIRAL 2 RFQ operates at 88 MHz and is designed to accelerate particles of different kinds charge-to-mass ratio, q/A. The proposed RFQ can accelerate a 5 mA deuteron beam (q/A=1/2), protons (q/A=1) or a 1 mA heavy ion beam with q/A=1/3, up to 0.75 MeV/A. It is a CW machine which must operate with high stability, provide the requested availability, have minimum losses in order to minimize the activation constraints, and show a good quality/cost ratio.

A second injector (a second HI source and a new RFQ), optimized for beams with q/A=1/6, is also considered as an optional upgrade. Connecting beam lines and room in the driver building are reserved for this option.

The superconducting linac is optimized for a charge-to-mass ratio, q/A =1/3 but it can accept a large range of beams, i.e. protons, deuterons and heavy ions with q/A =1/6. It is composed of two families of quarter-wave resonators (QWRs) at 88 MHz (12 resonators with β=0.07 and 18 resonators with β=0.12). Output energy is 20 MeV/n for deuterons and 14.5 MeV/n for heavy ions.

Beam focusing is performed by means of room-temperature quadrupoles, instead of superconducting solenoids, resulting in one cryostat per focusing lattice: one β=0.07 resonator in the low energy section cryomodule and two β=0.12 resonators in the high energy section. This arrangement offers many advantages: low residual magnetic field close to superconducting resonators, much simpler cryostats, much easier cavity and magnet alignment, larger space available for diagnostics and simpler linac tuning.

PRESENT STATUS

Linac Design

Beam dynamics studies have been developed since the beginning of the construction phase in 2005, which have mainly consisted of freezing the layout of the injector low-energy beam transport lines [3]. This study is presently being completed and will very soon allow the fabrication of the beam lines components.

The capability of the SPIRAL-2 linac to fulfil some new requirements (proton acceleration, low-energy beams transport in the HEBT) have also been studied.

R&D work and prototyping

An important R&D program was started during the preliminary study phase. Prototypes of some major components were constructed and tested during this phase.

Two ion sources are under development: a) An ECR deuteron ion source based on the IPHI design has been successfully tested [3], b) an ECR heavy ion source of new design, the "A-Phoenix" source [4] is presently under construction. It should greatly improve the performance of the previous Phoenix type source, in particular increasing the intensity of heavy ion beams, i.e. 1mA CW Ar^{12+} beam at 60 kV.

A prototype of the 4-vane RFQ has been constructed and tested [6]. This 1-m long prototype (RFQ total length is 5 m) was designed to verify the feasibility and control the construction costs. Critical performances where successfully checked: vacuum quality, frequency tuning, water cooling, RF field measurements by X-ray, and vane displacement under nominal RF power. A sophisticated optical device (accuracy better than 1 µm) allow to measure vane displacements below 60 µm at nominal RF power (40 KW).

Two superconducting QWR prototypes were constructed and tested [7], [8]. Both prototypes reached very high accelerating gradients (11 MV/m, compared to the nominal design goal of 6.5 MV/). This gradient correspond to an electric surface field of 60 MV/m and a magnetic surface field of 110 mT.

Several RF couplers prototypes have been constructed and tested at a RF power of 30 KW, the operational RF power level must be in the range of 10 -15 KW [9].

An intensive R&D program on specialized beam diagnostics devices has been started. It concerns beam profile monitors, emittance meter devices, beam losses monitors and beam position monitors. The expected low beam losses in this accelerator greatly relies on the performances of these devices.

Driver Accelerator Construction

In the short term several major construction activities are foreseen: Following the good results with the prototype, the complete RFQ structure will be launched at the end of this year. Two cryomodules, one of each β-value have been also ordered (Fig. 3). Complete test of these cryomodules at nominal power level are planned for the 1st quarter of 2007. Two solid state RF amplifiers (10 and 20 KW) and a new digital low level RF are also close to be ordered. Two major operations will follow very rapidly: the construction of all the cryomodules (2007–2010) and the construction and initial test (off site) of the whole injector system in 2009.

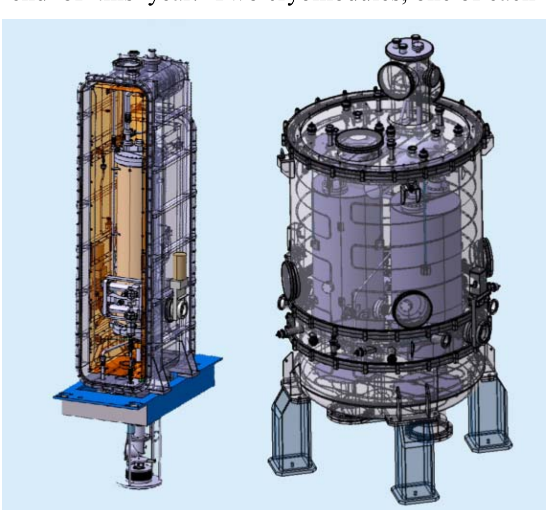

Figure 3: QWR cryomodules (left β: 0.07, right β: 0.12)

SPIRAL 2 CONSTRUCTION PLAN

The definition of the reference project by October/November 2006, in particular the RIB production building characteristics and the phases for the beam availability, will be a turning point. Following the licensing procedures of the nuclear safety regulation authorities, the construction of the SPIRAL 2 buildings (driver accelerator and production areas) at the GANIL site will start in 2009. First tests of accelerated beams at full power should take place in 2011 (Fig. 4)

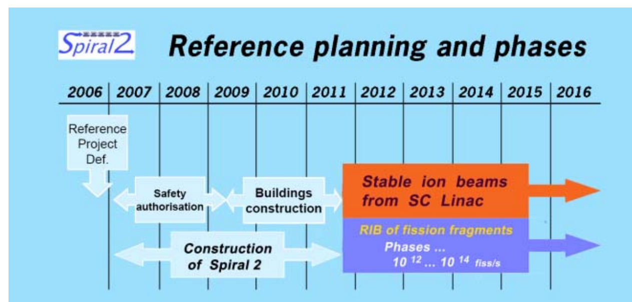

Figure 4: Reference Planning of Spiral 2

Full intensity stable beams should be available at this time. Availability of radioactive beams is presently being considered with several phases, corresponding to a progressive increase of the power on the production target.

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