SUPERCONDUCTING DRIVER LINAC FOR THE NEW SPIRAL 2 RADIOACTIVE ION BEAM FACILITY AT GANIL

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Abstract

The new Spiral 2 facility will deliver high intensity rare isotope beams for fundamental research in nuclear physics, high intensity stable heavy ions beams, and high neutron flux for multidisciplinary applications. Based on the ISOL and in-flight isotope production methods this facility will cover broad areas of the nuclide chart. The driver accelerator must deliver CW beams of deuterons (40 MeV, 5 mA) and heavy ions (q/A=1/3, 15 MeV/A, 1 mA). The injector is composed of two ion sources (deuterons and heavy ions) and a common RFQ cavity (88 MHz). The superconducting linac is composed of two sections of quarter-wave resonators (QWR), beta 0.07 and 0.12 at the frequency of 88 MHz, with room-temperature focusing devices. After two years of preliminary study, and following the recent decision to launch the construction phase, a complete design of the driver accelerator is presently under way. Important results have been obtained during the initial R&D phase, in particular on ion sources, RFQ and superconducting resonator prototypes.

THE SPIRAL 2 PROJECT

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. 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 SPIRAL 2 facility 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.

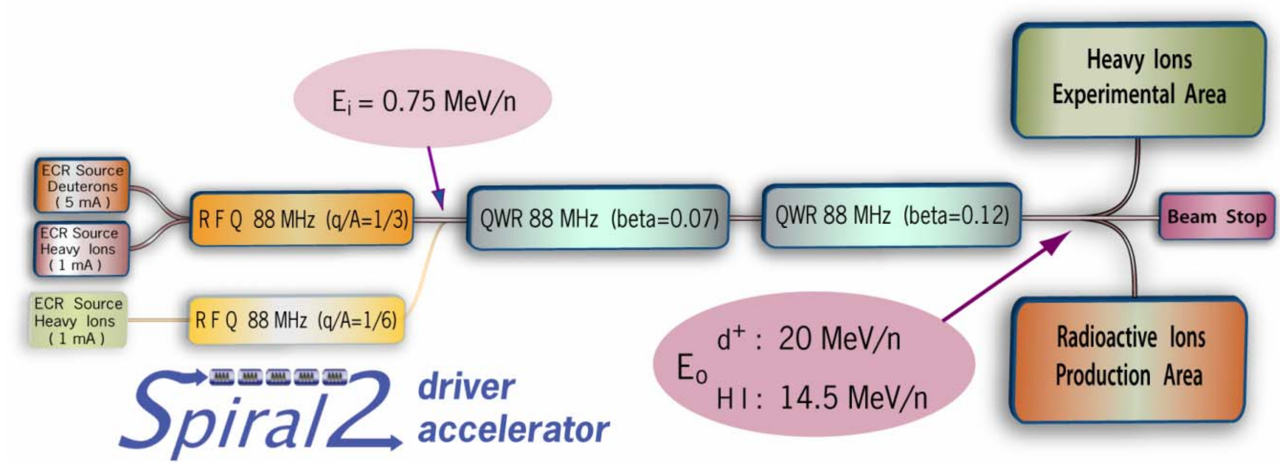
SPIRAL 2 will give access to a wide range of experiments on exotic nuclei, which have been impossible up to now. In particular it will provide intense beams of neutron-rich exotic nuclei (10^6–10^{10}pps) created by the ISOL production method. The extracted ion beams will subsequently be accelerated to higher energies (up to 20 MeV/nucleon) by the existing CIME cyclotron, typically 6–7 MeV/nucleon for fission fragments. High intensity stable isotope beams and high power fast neutrons are other major goals of the facility.

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.



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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.

A detailed study of the low energy beam lines linking the two ion sources to the RFQ [3] is presently being completed and will very soon allow the fabrication of these components.

Heavy Ion Source

A new ECR source design has recently been proposed by the LPSC Grenoble laboratory: the "A-Phoenix" source [4]. It should greatly improve on the performance of the previous Phoenix source which has already produced CW beams of 1mA O^{6+} at 60 kV with a normalized emittance of 0.2 π mm.mrad.

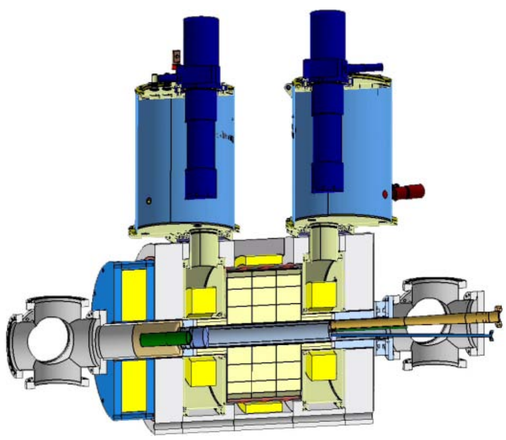

Figure 1: The A-Phoenix source.

"A-Phoenix" is a compact hybrid ECRIS (Fig. 1) that uses high-temperature superconducting (HTS) coils to generate an axial magnetic field (max. 3T) and a special permanent magnet design to create a very high hexapolar field (max. 2T). These high fields should allow

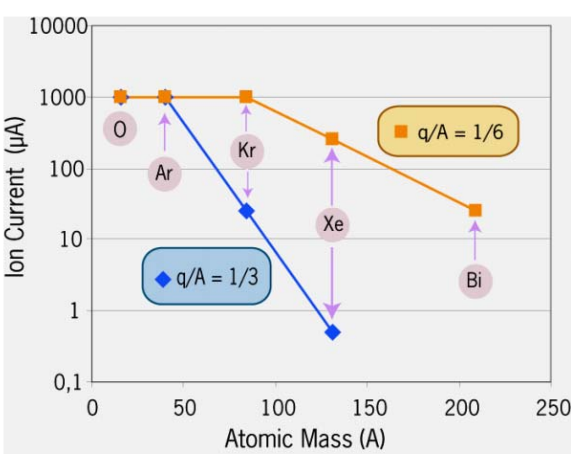

Figure 2: Comparison of expected heavy ion beam intensities with the A-Phoenix source.

the use of the 28 GHz frequency. The goal is to approach 1 mA intensity for an Ar^{12+} ion beam. This source must supply the injector with beams of q/A=1/3.

As shown in Fig. 2, the high intensity yields expected for lower charge states (q/A=1/6) could result on a major upgrade of this facility. The superconducting linac is designed to accept this charge-to-mass ratio, but a separate injector line with a new RFQ will be needed.

RFQ

The SPIRAL 2 RFQ [5] operates at 88 MHz and is designed to accelerate particles of different kinds charge-to-mass ratio, q/A. The proposed injector 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 1 m long prototype of this 4-vane RFQ (Fig. 3) has been built and tested in order to verify the mechanical assembly concept (i.e. an RFQ without any brazing). Under nominal RF power (40 kW), the operation with RF joints between the vanes and the external tube was verified, and good vacuum was obtained for heavy ion acceleration. The vane displacement under operation was below the requirements (±0.1mm), in good agreement with the simulation codes.

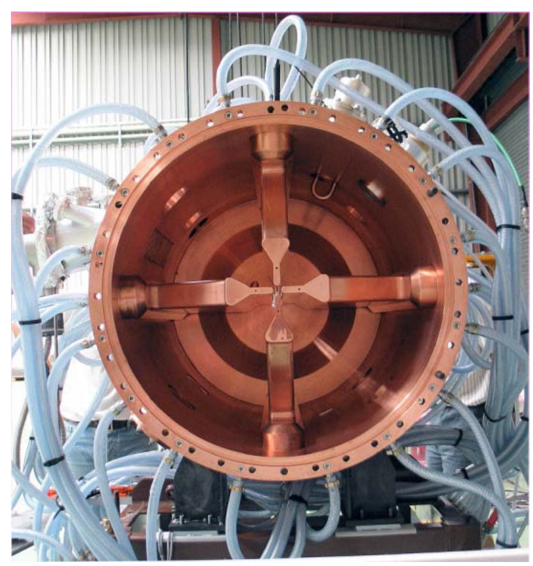

Figure 3: RFQ prototype.

Superconducting Linac

Independently phased superconducting resonators exhibit very wide velocity acceptance, and allow output energy optimisation for each ion specie by re-adjusting the individual RF phases. The superconducting linac 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).

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 (Fig. 4) in the low energy section cryomodule and two β=0.12 resonators (Fig. 5) 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.

The design maximum accelerating gradient of the QWR is E_{acc}= 6.5 MV/m, (defined as $E_{acc}=V_{acc}/\beta\lambda$). Two resonator prototypes were constructed during the initial R&D phase. Both resonators reached very high gradients, close to 11 MV/m with low losses ($Q_0 > 10^9$ at low field) [6,7]. Both the fabrication techniques and surface preparation procedures were verified, confirming a substantial margin for the final series production of all resonators.

Two power coupler prototypes (using disk and cylinder ceramic window geometry) were also constructed. Recent tests have confirmed good performance and the conditioning process. Both have reached CW power levels of greater than 30 kW which also give a good margin for the nominal operation power levels (10–15 kW) [8]

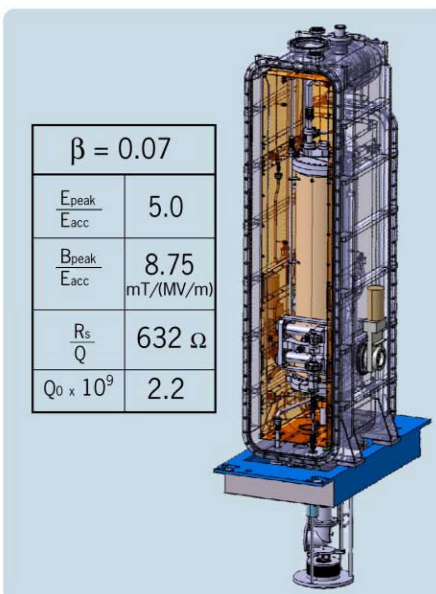

Figure 4: A β=0.07 cryomodule.

Presently, two cryomodules, one of each β-value are in construction. Complete test of these cryomodules at nominal power level are planned for the 1st quarter of 2007.

The cryogenics system has been designed with a liquefier of 900 W power at 4K (calculated required power at 4K: 570 W), 2000 W power at 60–80K (calculated power: 1600 W), and which must supply 10 l/h for other uses (e.g. superconducting resonator tests and physics experiments).

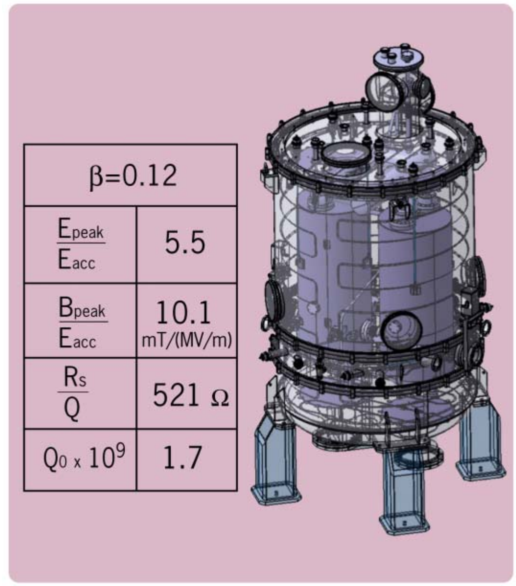

Figure 5: A β=0.12 cryomodule.

The RF amplifiers will use solid-state technology, on the basis of one amplifier per resonator, with power ranging between 10 and 20 kW. A low level RF system based on a digital solution is presently under development and must fit the requirements of all the RF cavity types: RFQ, SC linac resonators, and normal-conducting bunchers in the medium energy beam transfer line.

SPIRAL 2 CONSTRUCTION PLAN

Two major activities are foreseen in the short term:

1) construction of all the cryomodules (2007–2010)
2) construction and initial test of the whole injector system in 2009 (off site).

After the licensing procedures of the nuclear safety regulation authorities are concluded, the construction of SPIRAL 2 buildings (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.

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