THE SPIRAL 2 PROJECT AT GANIL

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Abstract

The SPIRAL 2 facility, the GANIL extension for radioactive beam production through the fission of uranium carbide (UCx) target, was funded in May 2005. A superconducting linac with room-temperature injector, is used to accelerate a 5 mA deuteron beam up to 20 MeV/nucleon. The deuteron beam produces neutrons on a carbon converter, which are used for the fission process of the UCx target. The fission products are then accelerated by the existing CIME cyclotron. The paper presents the status of the project at the end of the 2.5 year period of the detailed design study.

BRIEF PRESENTATION OF GANIL

Ganil is a stable and RIB beam facility using a cascade of 3 cyclotrons to accelerate the primary heavy ion beam. Energies up to 100 MeV/u and intensities up to 6 kW are available with the present driver. Both the Isol and the in flight fragmentation methods are used for RIB production. Exotic beams produced with the Isol method are post accelerated via the CIME Cyclotron. With the Spiral 2 project, Ganil aims at extending the spectrum and the intensity of the rare isotope beams available to the experimental physicists.

SPIRAL 2 PRINCIPLE

The new method to produce RIBs is based on the neutrons induced fission of an Uranium Carbide target.

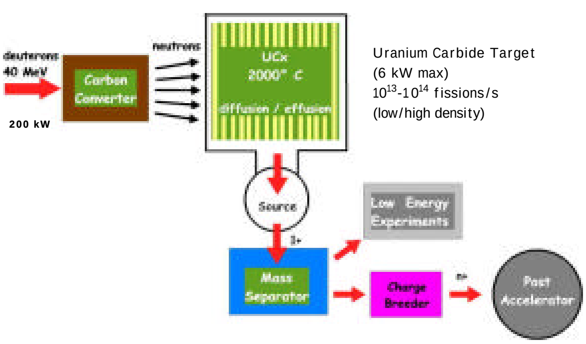

Figure 1: The Spiral 2 Priniciple

The target is heated at a temperature around 2000 °C to improve the diffusion of the radioactive elements out of the target, while the evaporation rate is still acceptable. The flux of neutrons is produced by the interaction between a high intensity, 20 kW deuterium beam and a converter where the beam power is stopped. For the converter, which has to stand 200 kW for 3 months, solid Carbon was preferred to solid Beryllium (toxic when evaporated) or liquid Lithium.

The target fission produces quite a large spectrum or RIB which are then ionised 1+ in order to be selected by a mass separator. We should be able to extract two beams simultaneously, one to be used at low energy, and the other to be post accelerated. A charge breeder enhances the RIB state of charge to the level required by the Cime cyclotron injection line.

It is also possible to use a heavy ion beam of maximum 6 kW and energy around 15 AMeV, hitting the target directly. Using different target materials it is possible to profit of fusion and evaporation reactions.

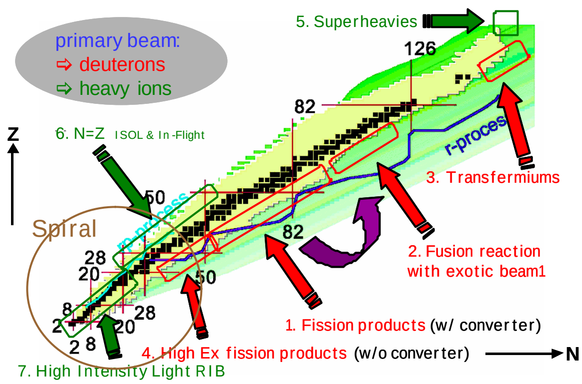

Figure 2: The Spiral 2 RIBs

HISTORICAL REVUE

First studies on the possibility of extending to medium mass nuclei the range of secondary beam produced by the present RIB facility SPIRAL, started at GANIL as early as 2000 with the LINAG project [1]. Following the recommendation of the Scientific Council of GANIL, the method relying on fission induced by light particles, either with or without an intermediate target to generate high fluxes or neutrons, was studied more in details [2] and compared to photo-fission. In 2002, the LINAG option was finally chosen after a series of reviews commissioned by a Committee comprising experts from several major laboratories. The future facility was named Spiral 2 and the use of the high neutron flux extended to other purposes like neutron tof measurements or activation and irradiation of materials whose use is envisaged in future fusion machines.

In 2003 and 2004, a detailed design study was committed and funded by the DSM and IN2P3 institutes and by the region Basse Normandie. The study involved more than 60 people, belonging to all major accelerator groups in France and focused on the:

- prototypes of the main components,
- safety aspects and preliminary safety report,

- scientific objectives within the national and international context during the assumed period of operation,
- estimations of the construction schedule and of the investment and operation costs [3].

The new facility was finally founded last May.

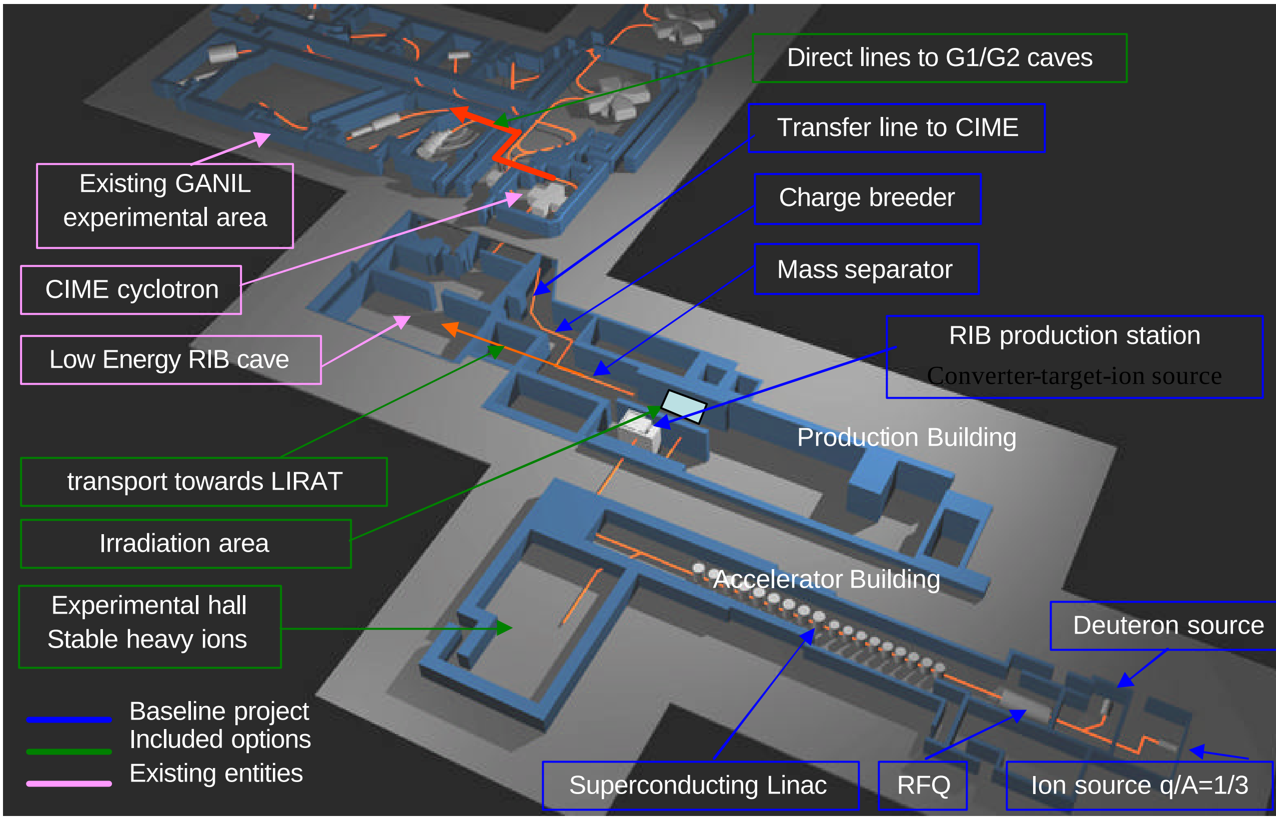

Figure 3: The SPIRAL 2 Layout

PROJECT DESCRIPTION

The project contains 3 main aspects, the accelerator, the production site and the experimental areas.

Driver and primary beams

The driver must deliver deuterons up to an energy of 40 MeV with a beam current up to 5mA and heavy ions with beam currents up to 1 mA. Two different ion sources are used.

It is optimised in energy for ions of mass-to-charge ratio A/q=3, resulting in an output energy of about 14 MeV/u. The injector is then constituted by an RFQ whose length, 5m and maximum voltage, 113 kV, are chosen for the ions.

It will also be able to accelerate ions of mass-to-charge ratio A/q=6. The room for a second RFQ is foreseen in the building as well as for the insertion dipole in the MEBT line.

Room for a fast chopper is also reserved in the MEBT line as some physics experiments require to select one bunch out of a few hundred to a few thousand.

The beam energy will be adjustable between the maximum energy and as low as the RFQ output energy 0.75 MeV/u.

The layout of the facility takes into account a possible future energy increase up to 100 MeV/u.

Production hall

The RIB production station consists of a carbon converter and a target ion source system. It is based on the plug concept already used at TRIUMF by the ISAC facility. The converter has to stand 200 kW during 3 months and ^{12}C was preferred for low cost and high thermal conductivity specifications.

The production rate of the radioactive beams produced by neutron-induced fission of an uranium target from a deuteron beam bombarding a carbon converter, must be higher than 10^{13} fissions/s. The use of high-density targets could allow us to reach an upper limit of 2.10^{14} fissions/s. However, the fission rate is limited to a maximum of 10^{14} fissions/s and this value has been used for all safety and radiation-protection-related calculations.

Without the use of a converter, the primary beam will consist of deuterons or other species (such as $^{3,4}He$, $^{12,13}C$) and the maximum power is limited by the most restricting condition, namely that the induced activity must remain below the activity induced by 10^{14} fissions/s obtained with the converter method and the maximum power that the target can withstand (presently estimated to about 6 kW for a UC_x target).

Different thick targets will replace the uranium target for fusion evaporation reactions with stable ion beams and different types of ion sources will be studied in order to get the best efficiency for the selected ion specie.

The mass separator must deliver simultaneously at least two independent beams, with a mass resolution of about 250. An identification station is essential for the control of the desired specie output.

The RIB will be bred to higher charge states by means of an ECR charge breeder prior to post-acceleration.

Use of neutrons for other applications

Room has been left for possible installation of a pulsed neutron beam facility, including an experimental hall and a ~10 m long neutron line to be used for neutron-TOF like experiments. The possibility of material irradiation studies, using the large neutron flux, especially for the study of the behaviour of materials considered for future fusion machines (ITER, DEMO), is also under investigation .

Experimental area

After post-acceleration in the existing CIME cyclotron, the secondary beams will be transported to the all the existing exp erimental area at GANIL via the ALPHA spectrometer.

A new direct beam transfer line will allow the direct delivery of SPIRAL 2 beams out of CIME to the existing caves G1/G2 and will give the possibility of using simultaneously Sissi and SPIRAL 2.

Simultaneously to the accelerated RIB, a second RIB will be transported to the very new low-energy experimental hall LIRAT.

Room for a new experimental hall is finally left in the accelerator building, to use the high-intensity stable ion beams from the linac to study fusion evaporation reactions with the in-flight method.

TECHNICAL CHOICES AND PROTOTYPE RESULTS OF THE LINAC ELEMENTS

Injector

One injector will deliver both kinds of ion beams at the required energy of 0.75 MeV/u. Two types of deuteron source have been developed: the SILHI-type source by DAPNIA/Saclay and the Micro-Phoenix source by LPSC/Grenoble. Both met the emittance and current specifications (~ 0.1 π mm mrad at 5 mA).

For the A/q=3 ions, the present state-of-the-art of ECR sources produces 1 mA for O6+ and 0.3 mA for Ar12+. The reference project will start with such a source at intermediate intensity. High confinement fields (B ~2-3 T) and high frequency (f > 28 GHz) are required to increase the ion beam currents. The A-Phoenix source (60 kV, 28 GHz), based on the combination of permanent and high temperature superconducting magnets, will permit to reach the highest intensities for noble gases.

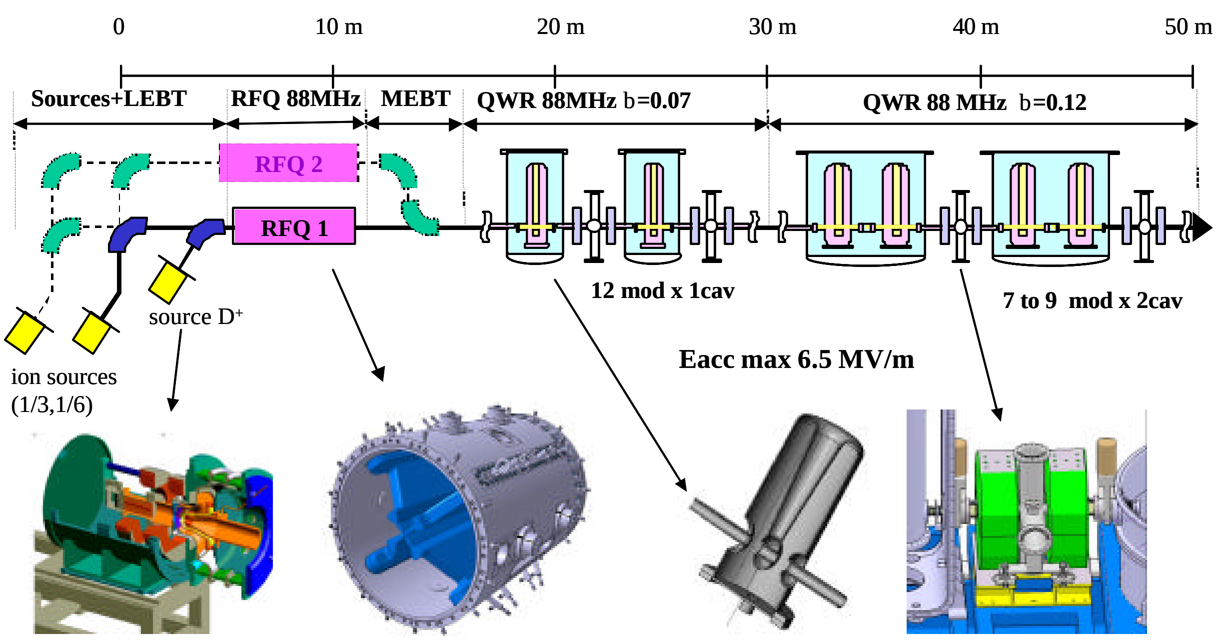

Figure 4: The driver Linac

This source is under development at LPSC and should reach the expected performance before 2008. For the production of metallic ions (Ni, Cr, etc), the required

R&D has to start very soon and can be carried out at GANIL or at LPSC.

The RFQ cavity must bunch and accelerate the beam to the required energy with a high transmission to allow for hands-on maintenance. Different technologies at 88 MHz were studied and the four-vane structure was finally chosen because of the lowest RF power consumption and of the experience on this type of structure of the team involved. A 1-m long prototype [4] was built to verify the feasibility of the mechanical assembly concept (RFQ without any brazing step) and check the construction cost. Measurements on the assembled structure gave vane tip positions globally within ±25 µm of their theoretical values with few points up to ±50 µm (measured before the final vacuum test). The Q factor: 12800, was a little bit less than expected from Microwave Studio, HFSS and Soprano simulations: ~14500. For the plungers, a tuning slope of +8.65 kHz/mm was observed. The power tests were successful and proved safe operation of the RF joints between the vanes and the external tube (45 A/cm maximum current density). A second test is foreseen next September. The final objectives are to verify that the vanes displacement under operation is below the requirements (±0.1mm), crosscheck the 3D codes used for the design with online measurement (temperature elevation, deformation, water cooling etc…), and check under power the bead-pull tuning, based on the method [5]developed for the IPHI RFQ.

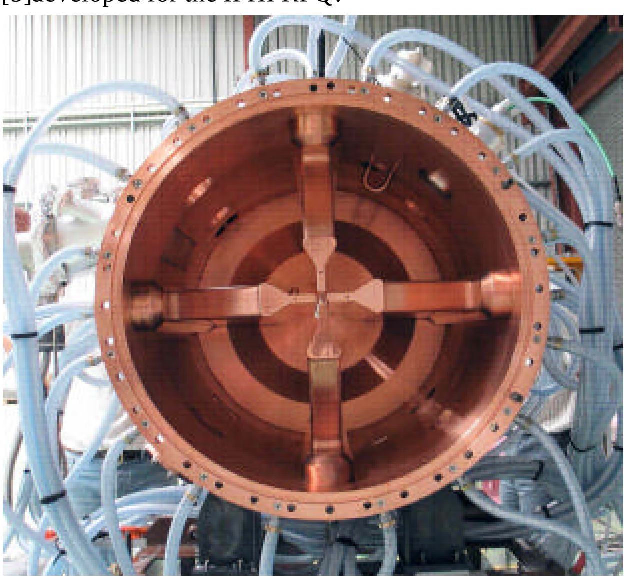

Figure 5: RFQ picture

Superconducting linac

The choice of short superconducting cavities, exhibiting very wide velocity acceptance in comparison with long multi-cell structures, allows the optimisation of the output energy for each ion specie by re-adjusting the individual RF phases. Two types of superconducting cavities were considered - Quarter-Wave Resonators (QWR) and Half-Wave Resonators (HWR) - and several different frequency scenarios have been studied. The use of 2 families of QWR resonators at 88 MHz (β=0.07 and β=0.12) was finally adopted for the following reasons:

- lower total number of cavities
- no frequency jump which would require longitudinal matching
- larger cavity aperture
- identical frequency for all RF power sources
- moderate cost

In addition, the focusing by means of room-temperature quadrupoles, instead of superconducting solenoids, resulting in one cryostat per focusing lattice, has been chosen. Despite a slight cost increase, this arrangement offers many advantages: residual magnetic field of solenoids close to superconducting resonators too high, much simpler cryostats, much easier cavity and magnet alignment and simpler linac tuning.

A realistic accelerating field of 6.5 MV/m (normalised to the beta-lambda length) was chosen because the resulting maximum peak fields (Epk < 40 MV/m, Bpk < 80 mT) can be achieved without too much effort by using well-tried methods developed in the last ten years, such as high-pressure rinsing, high-purity niobium and clean conditions. Furthermore, free room has been left at the end of the linac to allow for the insertion of two additional high-β cryomodules, should the field gradient in operation be lower than expected.

The prototypes, built by Accel (beta 0.07) and Zanon (beta 0.12), have both reached fields at least 30% higher than required in the *vertical* tests at Saclay and Orsay. The two cryostats are now being designed and should be ordered next year.

Figure 6: Low (up) and high (down) beta cavities

Cavities and cryostats characteristics are described in detailed in references [6] and [7]. Here, we want to underline that an innovative tuning system (in SC applications), based on SC plungers placed in the high H field region, was successfully tested on the high beta resonator. Figure 7 shows the results of some tests performed up to now with or without the static tuner, and with plungers of different dimensions.

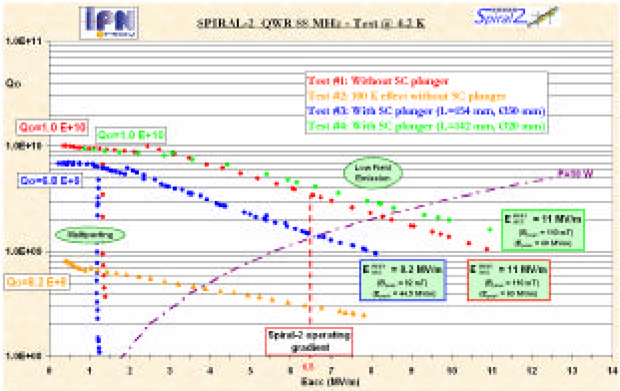

Figure 7: Performances of the high beta prototype during different tests .

Results on the use of a static element to compensate a given amount of detuning after manufacturing and polishing being very promising, a solution for a variable slow tuner in being studied now.

Two prototypes of the power couplers, with cylindrical (figure 8a) and disk (b) ceramic windows were also built A test bench, equipped with a 40 kW amplifier is being prepared at LPSC Grenoble and high power tests will begun in August.

a) b)

Figure 8: Power couplers for QWRs

A preliminary test was nevertheless performed with the 1 kW prototype of the solid state amplifiers. This module is based on a standard 1 kW amplifier for FM broadcasting, which has been equipped with isolators. The air dissipation capability limits the reflected power to 500 W but this limit can be over passed by water-cooling.

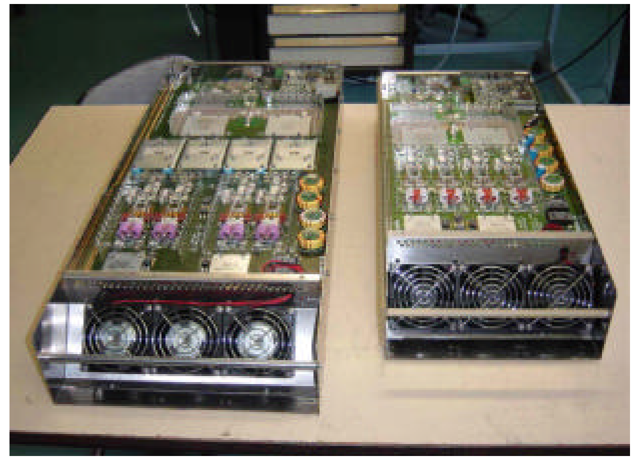

Figure 9: 1 kW prototype amplifiers

CONCLUSIONS

At the end of the 2.5 year period of detailed design study, the accelerator is the part of the project which has been studied more in detail. The design of most of single devices is going to be completed and the construction phase could begin soon.

The production building and the maintenance equipments are at the end of the conceptual design phase, and the design study has been subcontracted to the nuclear engineering branch of Thales.

The radioactive ion beam separator and transport lines are still in the conceptual design phase.

Nevertheless we expect to fill the design gap between the different parts during the time required for the procedures to obtain the authorisation for the buildings whose construction should begin in 2008.

With the Spiral 2 project, Ganil aims to make an intermediate step between existing RIB facilities and future projects like EURISOL or RIA.

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