STATUS OF THE CONSTRUCTION OF THE SPIRAL2 ACCELERATOR AT GANIL

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Abstract

The Driver Accelerator for the SPIRAL2 Radioactive Ion Beam facility at GANIL (Caen, France) is in the construction phase. Following the initial phase of prototyping development, the series production of major components was recently launched. Important decisions have also been recently taken concerning buildings, RIB operational aspects and related safety requirements.

INTRODUCTION

The GANIL laboratory (CNRS-CEA) in Caen (France) is one of the major radioactive and stable-ion facilities for nuclear physics, astrophysics and interdisciplinary research in the world. Since the first beams delivered in 1983 the performances of the GANIL accelerator complex, was constantly improved with respect to the beam intensity, energy and available detection systems. A major improvement was the construction of a new Cyclotron dedicated to the production and acceleration of Radioactive Ion Beams (RIB), the Spiral 1 project, which entered into operation in 2002.

Following the recommendations of international committees, the French Minister of Research took the decision in May 2005 to construct a new facility (Spiral 2) in order to enlarge the range of accelerated ions by production of high intensity RIB. 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 importance of the availability of Radioactive Ion Beams (RIB) has been often underlined in the last years. NuPECC (Nuclear Physics European Collaboration Committee) and ESFRI (European Strategy Forum on Research Infrastructures) established roadmaps and recommendations for the next generation of facilities in Europe. FAIR in GSI laboratory in Darmstadt (Germany) and Spiral 2 in GANIL laboratory are among the selected projects. Both projects are complementary and are based on two different RIB production methods: FAIR is based on In-Flight Fragmentation techniques, while Spiral 2 uses the Isotope Separation on Line (ISOL) techniques.

THE SPIRAL 2 PROJECT

The radioactive neutron rich beams will be mainly produced via the fission process induced by fast neutrons in a depleted Uranium Carbide (UCx) target (11g/cm3 density), with the aim of 5.10^{13}-10^{14} fissions/s [1]. For this purpose a high intensity CW driver accelerator will deliver 40 MeV (5 mA) to a thick Carbon target (Converter), and produce a very high neutron flux on the UCx target. The fission process will release radioactive atoms which are ionized and extracted from a target/ion-source system. The produced RIB are finally sent to either a low energy experimental hall, or driven towards a charge breeder and post-accelerated by the existing CIME cyclotron (Spiral 1).

The possibilities offered by the driver accelerator, with its capability to accelerate a large range of high intensity CW ion beams (Table 1 and 2), have opened new complementary opportunities to the Spiral 2 project:

- High intensity stable beams, i.e. Ar, Kr, etc
- Neutron experiments, i.e. time of flight
- Interdisciplinary researchs, i.e. solid state, biology, etc

Table 1: Driver Accelerator Beams

beam	p+	D+	ions	ions
Q/A	1	1/2	1/3	1/6
I (mA) max.	5	5	1	1
Womin(Mev/A)	2	2	2	2
Womax(Mev/A)	33	20	14.5	8.5
CW max beam power (KW)	165	200	44	48

Table 2: Driver Accelerator Characteristics

Total length: 65 m (without HE lines)
D+ : ECR ion source
Heavy Ions: ECR Ion Source
Slow and Fast Chopper
RFQ (1/1, 1/2, 1/3) & 3 re-bunchers
12 QWR beta 0.07 (12 cryomodules)
14 QWR beta 0.12 (7 cryomodules)
1 KW Helium Liquifier (4.2 K)
Room Temperature Q-poles
30 Solid State RF amplifiers (10 & 20 KW)

PROGRESS IN THE CONSTRUCTION OF THE SPIRAL 2 FACILITY

During the last two years (oct. 2006-sept 2008) the activities have evolved in two main directions:

1. Preparation and adoption of decisions around the project phases, considering the different beam users and the main project goals, the consequences on buildings and the safety aspects.
2. Construction and tests of main components of the driver accelerator, essentially the Injector and the SC Linac

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The new buildings: Driver Accelerator, RIB Production, and two new Experimental Halls, are illustrated in Fig. 1, close to the present buildings (in blue). New experimental halls will be dedicated to high intensity stable beams, neutron experiments, interdisciplinary physics, and low energy RIB experiments.

The production building, which will host the RIB production caves and the RIB transport lines, will be a nuclear class building. The safety requirements imply a double confinement in the whole building that will host the UCx production cave as well as the transport lines for the radioactive beams composed of fission products. The whole vacuum system will be connected to the gas storage system, and a public enquiry will be launched to get the authorization to release gas from the storage facility, after a suitable period of radioactivity decrease.

For the construction of these buildings, and strongly related to the safety authorisation procedures, two phases have been proposed:

1. Driver Accelerator and first experimental areas
2. RIB Production building and associated experimental areas

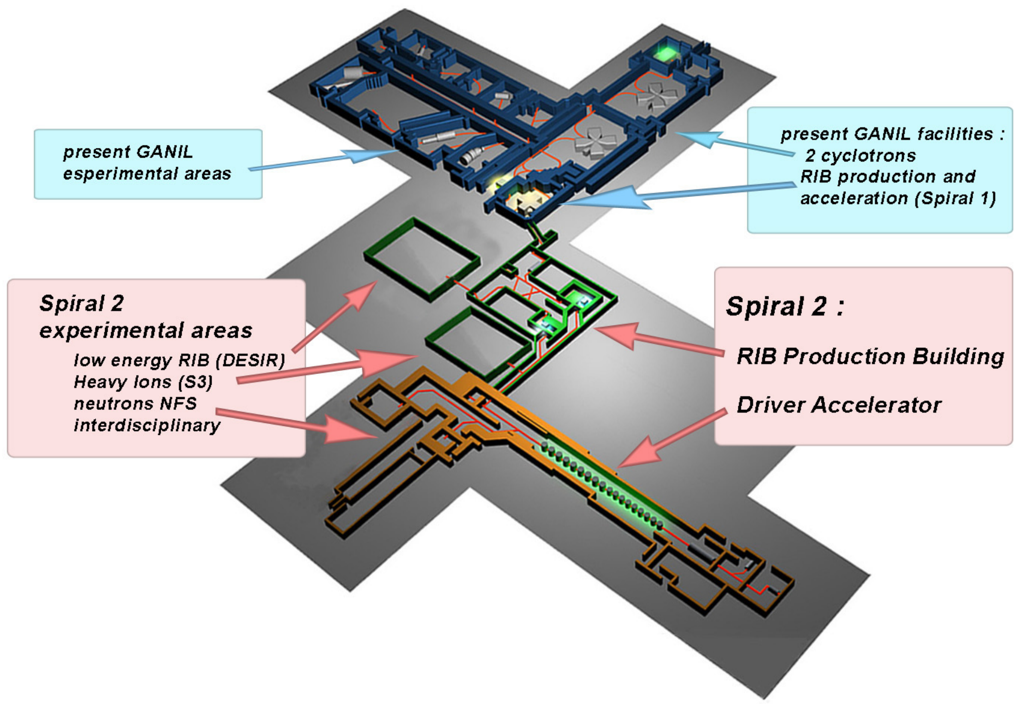

Figure 1: Present facilities at GANIL laboratory and new buildings for SPIRAL 2 Driver Accelerator and associated Experimental Areas.

GANIL is a nuclear facility and, for Spiral 2 authorizations, it is considered as an extension of the existing facility. During the last two years, together with preliminary safety studies, initial talks with the National Nuclear Safety Agency have resulted in a final agreement for the licensing procedure: A global safety report (DAM report) leading to a single Ministry Authorisation Decree with several steps.

This report must include:

- Preliminary Safety report of the two phases
- Operating ranges of the whole facility
- Study of the impact on the environment

The reports to be delivered were defined by a very recent new regulation law (2007) and Spiral 2 is the first major facility for nuclear research to be concerned by these new regulations.

Spiral 2 Schedule

The general schedule of the project is presented in Fig 2, showing the major milestones:

- October 2008: Phase 1 buildings contracts.
- Beginning of 2011 accelerator building available
- Beginning of 2012 for the first beams in the stable ion experimental hall and the neutron time of flight hall
- Mid 2013 for the first RIB and the low energy experimental hall.

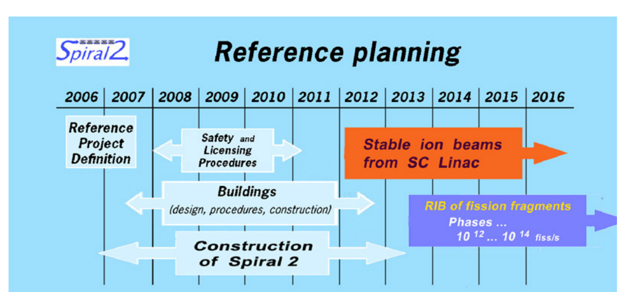

Figure 2 : Spiral 2 schedule.

BEAM LOSSES AND SAFETY ASPECTS

A complete beam dynamics study of the Linac Driver Accelerator has been completed. It includes the two injectors, the SC Linac and a preliminary version of the High Energy Beam Lines (Fig 3).

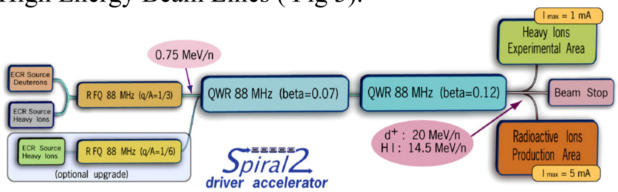

Figure 3: Driver accelerator layout.

Very extensive calculations of mutiple-ion-type beam transport using 3D maps have been performed with various conditions of space charge, and various hypothesis of space charge compensation (including solenoids 3D map) [2]. A dedicated poster covering all the beam dynamic studies is presented in this conference [3].

Two codes were used for this computing: Toutatis for the RFQ and TraceWin/Partran for the Linac . Distributed computing was performed using 40 PC in a client/server network. Errors were introduced in a statistical way for 1400 different Linac configurations and 1 million macro-particles trajectories were analyzed for each configuration. The matching and correction schemes were applied for each Linac.

The main goal of these calculations was to limit the beam losses for safety and machine protection. One important result was to define the precise position of slits in the low energy sections (Fig. 4)

- 3 slit systems to control input emittance in the RFQ and remove beam halo coming from LEBT line.About 40 W beam losses on slits (for 5 mA deuteron beam)
- 6 slit systems to remove beam halo coming from the RFQ before the entrance of the SC linac. About 6x125 W beam losses on slits (for 5 mA deuteron beam).

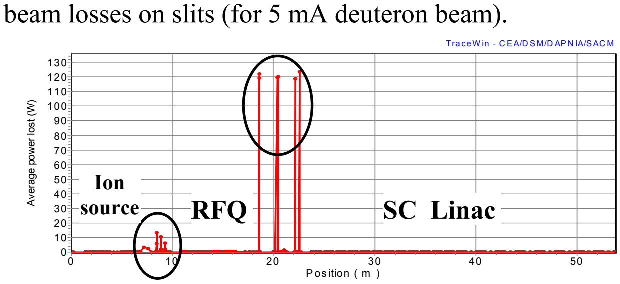

Figure 4: Beam losses on the slits.

The errors introduced in these calculations are of two types:

- Corrected (alignment, QWR steering effects, etc)
- Uncorrected (vibrations, stability of magnet currents, RF voltage, phase, etc)

The uncorrected errors are responsible for a very low level of losses: 0.20 W for the SC linac (average value of 1400 computed linacs), this corresponds to 0.2W for a length of 30m, ~6 mW/m.

Most of these losses are located in the firsts QWR of both low and high energy sections (Fig. 5)

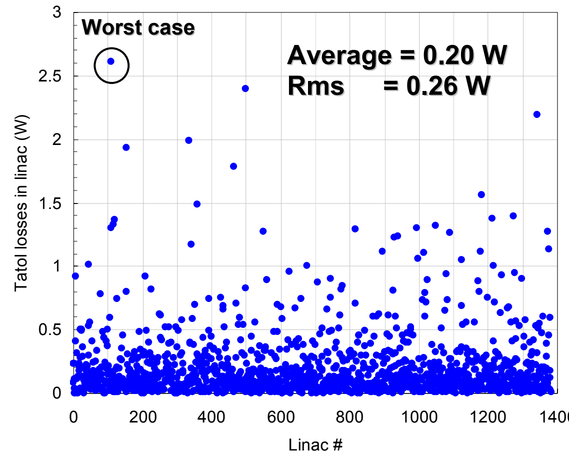

Figure 5: Statistical study of Linac losses.

Based on preliminary experience in other high intensity accelerator projects and performed calculations, a reasonable level of losses goal of ~1 W/m could be adopted. In order to stay well inside this level of losses in the Spiral 2 project, the decision was taken to install a big number of beam diagnostic systems, special mechanical adjustments systems for all the components and magnetic correcting devices all along the Linac.

The safety goals, in terms of dose rates for the Spiral 2 project are shown in the following table:

Table 3: Safety Goals in Terms of Dose Rates

	Technical Staff	People/Environment
Normal operation	< 2 mSv/year	< 10 μSv/year
Incidental situation	< 10 mSv/year	< 10 μSv/incident
Major incident	< 20 mSv/incident	< 100 μSv/incident
Major accident	Variable according to situation and potential impact	< 1 mSv/accident

The limit dose for offices, labs and workshops where permanent activity is foreseen, is 7.5 μSv/h, the limit for a zone where maintenance operations are possible is 100 μSv/h and zones where dose rates are greater than 10 mSv/h are not accessible.

Activation and dose rates calculation are based on two codes: MCNPX 2.5 for deuteron and neutron transport and Fispack 2007 for activation inventory. All the Linac components were modelled with high degree of geometric detail and material composition.

Two major contributions were studied for the more critical beam: 5 mA deuteron beam at 40 MeV:

1) interaction between deuterons and materials
2) interaction between the generated neutron yield and materials.

Both mechanisms originate high material activation, and the main contributing isotopes were identified: Co56, Fe55, Co57, Mn54, CO58 and Cr51 (for stainless steel material). Hands on maintenance operation conditions are presently under study, taking into account different levels of beam losses along the Linac and considering reasonable decay times after beam shutdown.

BUILDINGS STUDIES AND CONSTRUCTION

During the last year an intensive work has been developed for the definition of the buildings technical specifications, followed by a call for tenders and the analysis of proposals. At the present time we are very close to final contract agreement for the phase 1 (driver accelerator and stable ions experimental areas). The major decision was to install all these facilities underground. The level of Linac tunnel floor will be -9 m with a beam line at -7.5 m and an available tunnel height of 6 m. A technical tunnel running parallel to the Linac tunnel will allow installing cables, water cooling and some RF and electronics components that must be located in the linac proximity.

All the technical activities (labs and workshops, including the SC cavities preparation area, clean room and cryogenics tests) will be installed at the ground level. The RF amplifiers and the Helium liquefier will be also installed on top of the Linac minimising the distances to the cryostats and RF couplers. Total surfaces of the two levels, including the wall thickness are 8300 m2. Figure 6 shows a preliminary sketch of the underground tunnel. The height of the tunnel is 6 m and the width is 4.5 m, a crane covers all the tunnel length for manipulation of heavy components like cryomodules and Q-poles. The access to the Linac tunnel for components installation is made through special pits and elevators.

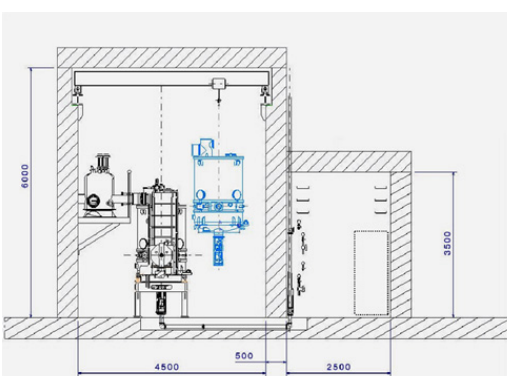

Figure 6: Underground Linac tunnel sketch.

PROGRESS IN THE CONSTRUCTION OF ACCELERATOR COMPONENTS

Injector

Complete tests of the two ion sources and the RFQ cavity are planned before the buildings completion and final installation of the components in the Linac tunnel. The Heavy Ions source with its mass analyzer and beam diagnostics will be tested in the CNRS/LPSC laboratory in Grenoble. The assembly has presently started and the first Ion Source measurements will start in January 2009.

The light ion source (proton and deuteron) with its beam transfer line and diagnostics will be tested in the CEA/Saclay laboratory, starting in mid-2009.

The construction of the RFQ cavity has started this year and after a final assembly and preliminary RF tests at the end of 2010, the cavity will be installed on the low energy deuteron line for beam tests in 2011.

SC Linac

All (12+14) SC QWR contracts are presently placed in two different companies. The first series QWR for the high energy sections (β=0.12) have been delivered. The performances reached for the first cavity in a recent test in July 2008 are shown in Fig. 7. After some conditioning needed to overcome multipacting barriers, a very high gradient was reached (9 MV/m, for a max. nominal operating gradient in the accelerator of 6.5 MV/m) and the losses at 4 K were well inside the expected range. The low energy (β=0.07) QWR prototypes exhibit also very good performances, gradients higher than 10 MV/m. The contract for the manufacturing of the series QWR is already agreed and the first cavities will be delivered starting in March 2009.

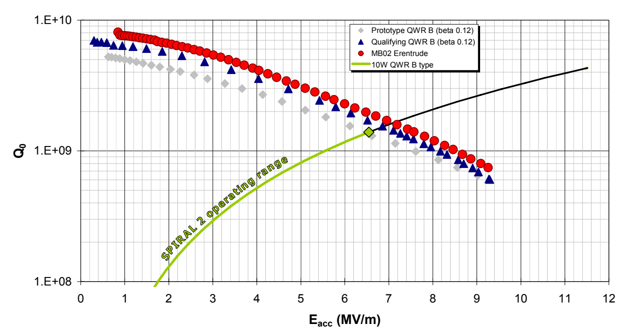

Figure 7: Accelerating gradient performances of β=0.12 QWR (2 prototypes and first of serial production).

Concerning the RF power couplers, the CNRS/LPSC laboratory in Grenoble developed a two years long prototyping program. Several prototypes models were tested at high power (40 KW) and a careful study of the multipacting and conditioning aspects was completed. These couplers have a fixed coupling position on the cavities, so the Qext adjustment must be done for the maximum current to be accelerated (5mA). The nominal CW RF operating power ranges between 5 KW and 15 KW.

First Cryomodules Tests in Orsay and Saclay Laboratories

The two first crymodules, low and high energy, have been assembled and tested at 4 K integrating all RF (power couplers, amplifiers, tuners) and cryogenic interfaces (valve boxes and He transfer lines). The results obtained (CNRS/IPN Orsay laboratory, Fig. 8) with the high energy cryomodule (including two β=0.12 cavities) are completely satisfactory, a gradient of 8 MV/m was obtained with the power coupler, all the cryogenic measurements have confirmed a low level of static losses (13 W at 4 K), a new tuner system using a movable piston was also successfully operated. All the cryogenic interfaces operates very satisfactorily allowing the launch of all the series components contracts.

The low energy cryomodule, which integrates only one cavity is presently in the final test period at the CEA/Saclay laboratory Fig. 9. The initial cryogenic tests have confirmed a good performance for the static cryogenic losses, 7 W at 4K, and a very satisfactorily operation of all cryogenic interfaces. The complete test with power coupler, amplifier and tuning system will be performed next month.

A poster covering all the technical aspects and tests performed is presented in this conference [4].

Figure 8: High Energy cryomodule tested at CNRS/IPN Orsay laboratory.

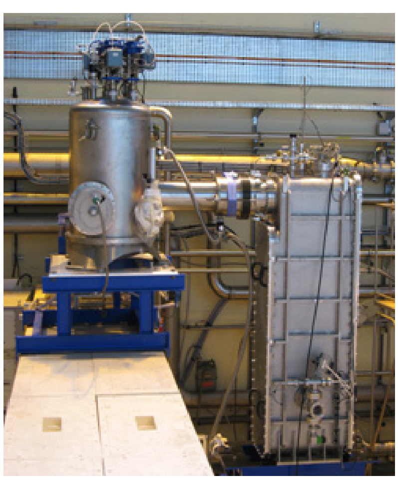

Figure 9: Low Energy cryomodule tested at CEA/Saclay laboratory.

RF Systems

Two types of RF amplifiers have been studied :

- RFQ amplifiers: 4 x 60 KW tube amplifiers
- QWR amplifiers : 12 x 10 KW and 14 x 20 KW solid state amplifiers.

One model of each amplifier type was constructed for prototyping purpose. All the prototypes were successfully tested, reaching the nominal power and exhibiting stable operation behaviour during long term tests. A dedicated poster is presented in this conference [5] giving all the results of tests and technical specifications

Between the RFQ and the first QWR of the superconducting Linac, a long Medium Energy Beam Transfer line imposes the installation of 3 re-bunchers to to optimize the beam longitudinal phase length.

An original 3-gap cavity has been designed with very large beam holes (diameter 60mm) providing up to 120 kV of effective voltage. A poster describing this design is presented in this conference [6].

The control of all RF cavities of the Driver Accelerator will be performed by a new Digital Low Level RF system which is presently under development and will cover all the particular needs in terms of independent amplitude and phase of each cavity, as well as the accurate control of its associated tuning system.

ACKNOWLEDGEMENTS

This work is the result of a large Project Team composed of people from GANIL and associated CEA and CNRS laboratories. It is also the result of an exceptional international collaborative effort of many accelerator experts in the world. Peer reviews, technical meetings, workshops, etc. have largely contributed to assess and establish the grounds for the design and construction of this new facility.

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